Bioeconomic modeling to support management and breeding of dairy cows in Costa Rica

Bernardo Vargas Leitón

Promotor: **Dr. Johan van Arendonk**
Persoonlijk hoogleraar bij de leerstoelgroep Fokkerij en Genetica
Wageningen Universiteit

Co-promotoren **Dr. Mario Herrero**
Research Fellow
Institute of Ecology and Resource Management
The University of Edinburgh

Dr. Enrique Pérez
Profesor investigador
Escuela de Medicina Veterinaria
Universidad Nacional de Costa Rica

Bioeconomic modeling to support management and breeding of dairy cows in Costa Rica

Bernardo Vargas Leitón

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
Dr. Ir. L. Speelman,
in het openbaar te verdedigen
op woensdag 13 december 2000
des namidddags te twee uur in de Aula.

Bioeconomic modeling to support management and breeding of dairy cows in Costa Rica.

Vargas Leitón, Bernardo.

Ph.D. thesis, Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences, Wageningen University, P.O. Box 338, 6700 AH Wageningen, The Netherlands.

ISBN: 90-5808-329-2

Printed by Universal Press, Veenendal, The Netherlands.
Cover design: Wim Valen and Bernardo Vargas Leitón.

The financial support for this dissertation was provided by Stichting Samenwerkings Verband IO-instellingen en Wagenigen Univesiteit (SAIL), The Netherlands.

Abstract

Vargas Leitón, B., 2000. Bioeconomic modeling to support management and breeding of dairy cows in Costa Rica.

During the past decades, genetic improvement of dairy cattle in Costa Rica has depended upon massive importation of germplasm from temperate countries. This may not be an optimal alternative if genetic × environment interactions are significant or production goals differ among countries. The purpose of this dissertation was to develop a bioeconomic model to describe performance of dairy cows under production circumstances found in Costa Rica. Several studies were undertaken to quantify the effect of genetic and environmental factors on milk yield and reproduction performance of the local cattle population. The final model was used to optimize replacement and inseminations policies for herds with different feeding strategies and to determine the economic values of production and functional traits to be included in a breeding goal. Finally, a study was conducted to compare several breeding strategies on the basis of the genetic response achieved after twenty-five years of selection. When significant genotype × environment interactions were assumed strategies based on selection within the local population performed better than strategies based on importation of semen.

Stellingen

1. Dairy farms of Costa Rica need to optimize management and breeding to survive in an open market.

   This thesis

2. Breeding cows that are efficient grazers is particularly important in Costa Rica, in order to use the abundant grass resource more efficiently.

   This thesis

3. For Costa Rica, the choice between local- and externally-based breeding programmes depends mostly on the level of Genotype × Environment interaction.

   This thesis

4. "It is not the strongest of the species that survive, nor the most intelligent, but the one most responsive to change".

   Charles Darwin

5. Sustainable animal production systems can be pursued, but never attained.

6. Science for the sake of science is a luxury that developing countries cannot afford.

7. Sustainable animal production systems require a vertical integration of research at the animal, farm and regional levels.

8. The creativity of the Dutch people can be appreciated easily by the infinite number of systems to flush the toilet.

Stellingen belonging to the thesis:
"Bioeconomic modeling to support management and breeding of dairy cows in Costa Rica"
Bernardo Vargas Leitón
Wageningen, December 13th, 2000

Table of Contents

The important thing is never to stop questioning.
A. Einstein

General Introduction

FRAMEWORK

During the last decades population growth, urbanisation, and income growth in developing countries are fuelling a massive global increase in demand for food of animal origin (7). In the period between 1971 and 1995, meat consumption in developing countries increased three times faster than in developed countries, while milk consumption increased twice as fast. During this period there has been a simultaneous growth in production of animal products in developing countries. This growth, however, has relied mainly on increasing the size of animal populations, rather than increased productivity (7).

Despite the fast growth in production, the consumption per capita of animal products in developing countries is still far from the nutritional optimum (7). The current levels of productivity do not reach the degree of efficiency required to satisfy the needs of the increasing population. A large combination of crop-based nutrients could also provide the necessary aminoacids and trace nutrients to meet nutritional needs, however, this may not be an option for low productive areas in developing countries.

Therefore, it is compelling to increase productivity of milk and meat production systems in developing countries, and this involves important developments in breeding, herd management and animal nutrition and health. This increase in productivity must also take into account important issues concerning protection of the environment and sustainable development. An optimum level of intensification for animal production systems in developing countries has to be found making optimum use of the land available (17, 22).

MILK PRODUCTION IN DEVELOPING COUNTRIES

In developing countries, environmental and social circumstances are commonly less favourable for milk production. Development of breeding programmes in these areas presents serious difficulties because of major physical and social constraints, low degree of recording (performance and pedigree), high costs of reproduction technologies, genotype × environmental interaction (G×E) and low effective population size (2, 4, 12, 28).

During the last decades, breeding strategies for dairy cattle in developing countries have relied mainly on three alternatives: breed substitution, crossbreeding and selection within local populations (2, 6, 29). Massive importation of exotic breeds and/or germplasm to developing countries has been performed as an attempt to achieve faster genetic improvement of the local cattle (14, 23). Artificial insemination has considerably spurred genetic upgrading as large-scale testing of the progeny of bulls and the subsequent use of valuable bulls has become possible (7). However, there is evidence for the existence of significant G×E interaction (20, 25, 26, 30).

Crossbreeding has been the most widely used strategy to increase productivity in dairy cattle in developing countries. Crossbreeding strategies for genetic improvement of cattle in the tropics have been extensively analyzed (4, 5, 6, 27). Economic superiority of crossbred over purebred dairy cattle has been demonstrated for some areas (9). Nevertheless, the implementation of some of the breeding strategies and mating systems that have been suggested still presents serious difficulties (29).

Some attempts have been made to implement local selection schemes similar to those found in developed countries (2). The rate of success has been generally low due to economical, social and environmental constraints. Low population size, limited registration and poor productivity of local breeds also put a limit on the rate of genetic progress that can be achieved.

GUIDELINES

Experts have formulated guidelines for a systematic establishment of a breeding programme for specialized and dual-purpose production systems in developing countries (2, 19, 28, 29). The first step in developing a breeding programme should be the choice of the most suitable breed(s) and the breeding system to exploit them. The next step would consist on further genetic improvement of the breeding stock to be used.

The choice of the breed depends on the level of nutrition and husbandry (2). For specialized dairy production systems with favourable environments, temperate breeds with high productive potential may be an option. For moderate to poor subsistence environments, use may be made of crosses of European breeds with zebu dairy breeds in a rotational crossbreeding system or composite breeds derived from European × zebu dairy crosses (4, 5, 6, 27). Other alternatives are the use of high productive potential Zebu breeds, low to moderate grades of European or exotic breeds, or local breeds and their crosses.

It is also important to set priorities on the breeds and the type of traits to be included in a breeding programme. For the tropics, the inclusion of adaptability, reproduction, milk yield and growth performance is of capital importance (19). For Latin America, traits that have been identified as priorities for inclusion in selection schemes are milk production and fertility for intensive dairies; and milk production, fertility and growth for dual-purpose systems (16, 28).

Once the breed(s) and important traits have been defined, it is important to make a reasonable choice between the different options available for maintaining genetic gain. The best way to do this is by performing a preliminary analysis on the biological and economical consequences of alternative selection schemes for a given cattle population (3, 13, 14, 15). From this analysis, it will be possible to select the alternative providing the best results according to common interests, given the present and future circumstances.

THE CASE OF COSTA RICA

Dairy breeding in Costa Rica, as for most of the developing countries, has relied mainly on the importation of germsplasm from USA, Canada, and to a lesser extent, from EU (21, 30). This strategy may not be the best if the effect of G×E interaction is substantial or production goals differ from those applied in the importing countries. There is already some evidence of significant G×E interaction in dairy cattle of Costa Rica (30).

It has been stated that countries relying on semen importation will have to switch at some point in time to more local breeding schemes (14, 23). It might be that this is already the case for Costa Rica, regarding specialized dairies. Biological and economical evaluation of alternative breeding schemes is compelling at this point. A comparison has to be made between strategies relying on continuous importation vs. strategies using local-plus-imported genetic germplasm. The aim is to find an optimal situation for the local dairy population. Such evaluation must take into account resource availability with regard to infrastructure, organisational capacity, feed sources, sustainability constraints and market trends.

Previous attempts to establish a local breeding scheme have failed, probably because they relied upon external financial support, which is no longer available (1). Local breeders associations seem unable to cope with the high financial costs associated with starting and maintaining a selection scheme.

THE ROLE OF MANAGEMENT INFORMATION SYSTEMS (MIS)

Management can be described as the decision-making process in which limited resources are allocated to a number of production alternatives (11). Management Information Systems (MIS) have already been implemented with success in dairy farms of Costa Rica (18), providing valuable information to assist the farmer in the decision-making process.

There is still a need, however, for further integration of simulation models into MIS. A model is defined as a simplified representation of a system, which can be used to predict the effects of changes in the system (8, 24). The development of simulation models as an extension of available MIS offers the possibility of providing the farmer beforehand with insight into the technical and economic consequences of various management decisions (10). In order to achieve this purpose, simulation models need to consider important interactions between factors affecting farm productivity (economics, health, breeding and nutrition) aiming at a sustainable animal production.

OUTLINE OF THIS THESIS

This dissertation has been developed with the general goal of supporting breeding and management in dairy herds of Costa Rica. In order to achieve this goal, the following objectives were defined:

1. to determine important factors contributing to the variation in animal performance;
2. to quantify genetic differences in level and shape of lactation curve and reproduction;
3. to develop a model describing performance and merit during lifetime of a dairy cow;
4. to determine the breeding objective taking into account sustainability constraints;
5. to determine an optimum breeding strategy for Costa Rican dairy cattle;
6. to determine an optimum recording scheme for dairy herds of Costa Rica.

The chapters in this thesis will deal with one or more of the previous objectives. **Chapter 1** addresses objective 1 by making a general description of the milk production systems in Costa Rica including aspects related to management, nutrition, breeding, market structure and biological and economic efficiency. **Chapter 2** deals with objectives 1 and 2 by obtaining variance components for test day yields in Holstein cows and assessing the degree of genetic variance for production in the current population. **Chapter 3** deals with objective 2 by analyzing factors affecting days to first breeding and days open of Holstein, Jersey and Brown Swiss heifers; using event-time methodologies. **Chapter 4** deals with objective 2 by analyzing data on lactations of Holstein cows, with emphasis on the use of models describing extended lactations. **Chapter 5** deals entirely with objective 3 by using parameters derived in the previous chapters to develop a bio-economic model that permits the analysis of interaction between management and breeding aspects in dairy herds. **Chapter 6** deals mainly with objectives 4 and 5, by using the previous model to analyze possible traits to be included in the breeding goal for dairy cattle in Costa Rica. Finally,

chapter 7 deals with objectives 5 and 6 by integrating all previous results into general considerations for breeding of dairy cattle in Costa Rica.

REFERENCES

1 Aragón, A., Soto, H., and E. Beck. 1992. Genetic impact by systematic breeding of livestock in Costa Rica. In: Potentials and limitations of biotechnology in livestock production in developing countries. Part 1: Animal Reproduction and Breeding. Proceedings of a Symposium held at the Institut fur Tierzucht und Tierverhalten (FAL), Mariensee, Germany in cooperation with the Council for Tropical and Subtropical Agricultural Research (ATSAF). Ed. by H. Niemann , H. Franzen and D. Smidt; pp. 23-35.

2 Bondoc, O.L., Smith, C., and J.P. Gibson. 1989. A review of strategies for genetic improvement of dairy cattle in developing countries. Anim. Breed. Abs. 57: 819-829.

3 Bondoc, O.L., and C. Smith. 1993. Deterministic genetic analysis of open nucleus breeding schemes for dairy cattle in developing countries. J. Anim. Breed. Gen. 110:194-208.

4 Cunningham, E.P. 1980. Selection and crossbreeding strategies in adverse environments. FAO Anim. Prod. and Health Pap. 24:279-283.

5 Cunningham, E.P., and O. Syrstad 1987. Crossbreeding *Bos indicus* and *Bos taurus* for milk production in the tropics. FAO Anim. Prod. and Health Pap. 68.

6 Cunningham, E.P. 1989. The genetic improvement of cattle in developing countries. Theriogenology 31: 17-28.

7 Delgado, C., Rosegrant, M., Steinfeld, H., Simeon, E., and C. Courbois. 1999. Livestock to 2020. The next food revolution. Food, Agriculture and the Environment Discussion Paper 28. (FAO, IFPRI,ILRI). 73 p.

8 Dent, J.B., and M.J. Blackie. 1979. Systems simulation in agriculture. Applied science publishers Ltd., London.

9 Holmann, F., Blake, R.W., Hahn, M. V., Barker, R., Oltenacu, P.A., and T.L. Stanton. 1990. Comparative profitability of purebred and crossbred Holstein herds in Venezuela. J. Dairy Sci. 73:2190-2205.

10 Jalvingh, A. W. 1992. The possible role of existing models in on-farm decision support in dairy cattle and swine production. Livest. Prod. Sci., 31:351-365.

11 Kay, R.D. 1986. Farm management. Planning, control, and implementation. McGraw-Hill, New York.

12 Künzi, N., and W. Kropf. 1986. Genetics improvement for milk and meat production in the tropics. In: Third Wrld. Cong. Gen. App. Livest. Prod. (Lincoln, Nebraska) pp. 165-176.

13 Lobo, C.H., and F. R. Allaire. 1999. A genetic and economic analysis of nucleus breeding plans designed to improve dairy breeds in Brazil. Anim. Sci. 68:87-96.

14 Mpofu, N., Smith, C., Van Vuuren, W., and E. B. Burnside. 1993a. Breeding strategies for genetic improvement of dairy cattle in Zimbabwe 1. Genetic evaluation. J. Dairy Sci. 76:1163-1172.

15 Mpofu, N., Smith, C., Van Vuuren, W., and E. B. Burnside, 1993b. Breeding strategies for genetic improvement of dairy cattle in Zimbabwe 2. Economic evaluation, J. Dairy Sci. 76:1173-1181.

16 Mujica, F., and A. Tewolde. 1990. Traits of economic importance, especially in dual-purpose cattle. In Memories of International Conference on breeding systems and strategies for genetic improvement in the tropics, Guatemala (Guatemala), September 1988, pp. 63-80.

17 Nicholson, C.F., Blake, R.W., and D. R. Lee. 1995. Livestock, deforestation, and policy making: intensification of cattle production systems in Central America revisited. Journal of Dairy Science 78:719-734.

18 Pérez, E., Baaijen, M. T., Cappella, E., and H. Barkema. 1989. Development of a livestock information system for Costa Rica. In *Livestock Production and Diseases in the Tropics.* Proceedings of the VIth International Conference of Institutes for Tropical Veterinary Medicine. (Editores: Kuil,H.; Paling, R.W. and Huhn, J.E.). Utrecht, Holanda, pp. 221-224.

19 Peters, K. J. 1993. Selection and breeding strategies for sustainable livestock production in developing countries, with particular reference to dairy cattle production. British Society of Animal Production, occasional publication 16:120-128.

20 Powell, R. L., Wiggans, G.R., and R. D. Plowman. 1990. Evaluations of Holstein bulls and cows in Ecuador. J. Dairy Sci. 73:3330-3335.

21 Robert Luján, E. 1989. Historia de la ganadería en Costa Rica. San José, Costa Rica. 138 p.

22 Simpson, J.R., and J. R. Conrad. 1993. Intensification of cattle production systems in Central America: why and when. J. Dairy Sci. 76:1744-1752.

23 Smith, C. 1988. Genetic improvement of livestock using nucleus breeding units. World Animal Review 65:2-9.

24 Spedding, C.R.W. 1988. An introduction to agricultural systems. Elsevier, London.

25 Stanton, T.L., Blake, R.W., Quaas, R.L., and L. D. Van Vleck. 1991. Response to selection of United States Holstein sires in Latin America. J. Dairy Sci. 74:651-664.

26 Syrstad, O. 1990. Dairy cattle crossbreeding in the tropics: the importance of Genotype × Environment interaction. Livest. Prod. Sci. 24:109-118.

27 Syrstad, O. 1996. Dairy cattle crossbreeding in the tropics: choice of crossbreeding strategy. Trop. Anim. Health Prod. 28:223-229.

28 Vaccaro, L., and R. Vaccaro. 1989. Guidelines for the genetic evaluation of dairy and dual-purpose cattle in the Latin American tropics. Rev. Bras. Gen. 12:27-35.

29 Vaccaro, L., and D. E. Steane. 1990. Practical technologies and options for the genetic improvement of livestock in developing countries. FAO Anim. Prod. and Health Pap. 107:85-98.

30 Vargas, B., and C. Solano. 1995. Genetic and environmental trends in milk production of dairy cattle in Costa Rica. Arch. Latinoam. Prod. Anim. 3:165-176.

To be absolutely certain about something, one must know everything or nothing about it.
Olin Miller

Chapter 1

Milk production in Costa Rica

ABSTRACT

A general description is given of the milk production systems in Costa Rica including aspects of management, nutrition, breeding, market structure and biological and economic efficiency. Due to the high diversity of climatic conditions, geography, and availability of feed resources, different production systems have evolved according to the specific production conditions of each region. Three main production systems are identified: specialized dairy farms, lowland dairies and dual-purpose farms. Specialized dairy production systems have the highest productivity per cow and per land unit, but production costs are higher. Lowland dairies and dual-purpose systems are less efficient but production costs are substantially lower. Historical developments in the field of breeding of the local dairy cattle population are described. Past research in the area of dairy cattle breeding indicated that the increase in productivity levels found in Costa Rican farms have been caused mainly by improvement of management conditions and to a lesser extent by breeding. It seems also that Genotype × Environment interactions have a significant impact in these dairies. The important economic and social role of milk production systems in Costa Rica is emphasized, because they provide milk in the quantity and quality needed to satisfy the local demand, with some scope for an increased participation in markets within the region. Perspectives in the area of milk production are briefly analyzed according to global trends in milk production and market structures. It is concluded that specialized production systems will need to be transformed into systems that are less dependent on costly external inputs.

(**Key words**: dairy cattle, milk production systems, Costa Rica).

1.1 INTRODUCTION

The dairy sector in Costa Rica has evolved very rapidly during the last decades (24). Current total production of milk is twice as high as it was twenty years ago. The country is self sufficient in milk production. This rapid evolution has resulted from governmental policies promoting milk production, which stimulated an increase of the dairy cattle population together with higher productivity (16). Improvements in the dairy industry and massive importation of germplasm have also played an important role.

Despite its rapid growth, the dairy sector is currently going through a transitional period. Globalisation of agricultural trading endangers local production and the future of milk production systems seems uncertain at this point (17). A point of controversy is what kind of production systems should be promoted given the actual and expected production circumstances. Some experts suggest that systems producing cheap milk should be promoted instead of more intensive systems depending on external feed resources (25).

The objective of the present study is to describe the main production systems found in the dairy sector of Costa Rica, with emphasis in the field of breeding. Current production circumstances and perspectives for the dairy sector are also briefly discussed.

1.2 GENERAL INFORMATION

Costa Rica is located in Central America between 10° to 11° north- latitude and 83° to 86° west-longitude. The country has an extension of 51,000 km^2 and a population of approximately 3.8 millions inhabitants. Despite the relatively small area, twelve different ecozones have been identified (10), all located between 0 and 3800 m. Temperatures vary from 3° to 30° Celsius. The country is characterized by its high biodiversity, i.e. more than 10,000 different species of plants and 1553 different kinds of vertebrates have been characterized.

Costa Rica has been traditionally an agricultural country. In the period from 1960 to 1994 the area covered by forest and woods was drastically reduced from 3.24 millions ha to only 1.57 millions ha (Figure 1). Simultaneously, the area covered by pastures increased from 0.92 to 2.34 millions ha, comprising at the moment almost 50% of the total area. At the same time, human population almost doubled during the last 20 yr (Figure 2), with almost 40% of the population living currently in the countryside (6).

The agricultural sector provides approximately 17% of the Gross Domestic Product (GDP) and employs 21.2% of the labour in the country (13). The production of the two main agricultural products, i.e. bananas and coffee, has increased steadily (Figure 2). Cattle population, on the opposite, has been decreasing after attaining a maximum of 2.3 millions heads around the middle eighties. This reduction, however, has occurred mainly within the beef cattle population; while the dairy population, i.e. specialized and dual-purpose cattle, are actually increasing due to governmental policies that supported the dairy sector.

The transformation of the national cattle population from beef to dairy, together with an increase in the average milk production per cow, have made the country self-sufficient for milk products. Within the agricultural sector, the dairy subsector contributes currently approximately 12% of the GDP. A total of 600,000 TM of milk is produced annually by approximately 34,469 dairy and dual purpose farms (6).

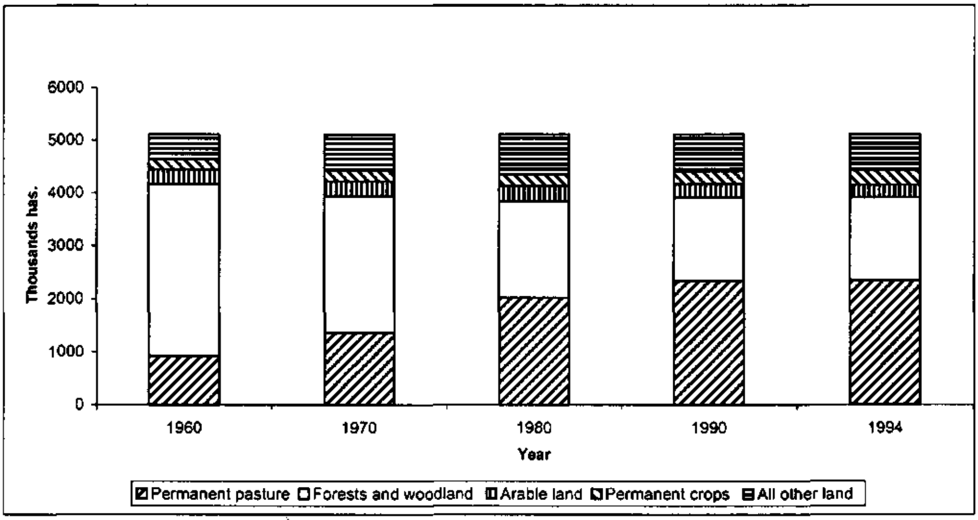


FIGURE 1. Land use trends in Costa Rica during the years 1960 to 1994. Source: FAO (6).

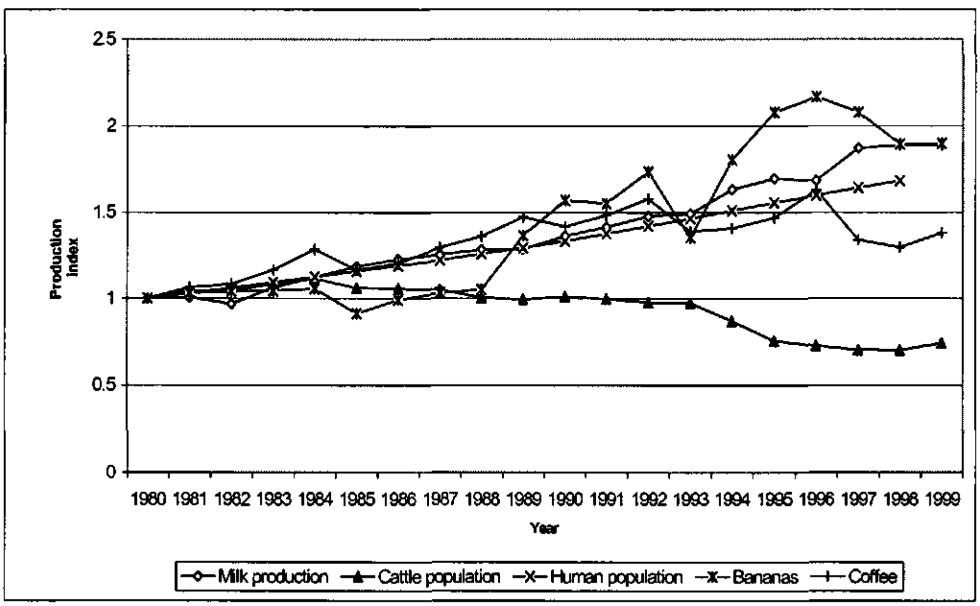


FIGURE 2. Trends in agricultural production in Costa Rica in relation to human population (Production for the base-year 1980 is set to 1 and corresponds to 317,819 TM milk, 2,181,385 heads cattle, 2,840,000 inhabitants, 1,107,518 TM bananas, 106,389 TM coffee. Source: FAO (6).

Although no recent statistics are available, the current number of adult dairy cows is estimated at 460,000, of which 207,000 are specialized dairy cows and 253,000 are dual-purpose cows. Milk consumption per capita is about 152 kg, providing about 20% of the average protein consumption. This is slightly more than twice the average of all countries in Central America (24).

1.3 MILK PRODUCTION SYSTEMS

The high variation in ecological conditions within the country facilitated the establishment of very diverse dairy production systems. Despite this diversity, three major production systems can be characterized (Table 1). These systems are described below:

1.3.1 Specialized Dairy Farms in the Highlands

This production system is commonly found at altitudes above 1300 mosl. Climatic conditions in these areas have permitted the introduction of exotic breeds, mainly Holstein and Jersey, as well as high quality pastures, such as Kikuyu grass (*Pennisetum clandestinum*). These systems are highly technical and productivity levels are close to those found in temperate countries. A high proportion of cows are bred by Artificial Insemination (21). Cows are milked twice a day and the feeding of female calves is artificial. Use of concentrates is relatively high, representing as much as 45% of the total costs. Industrial or agricultural by-products are frequently used. The production cost per kg of milk is the highest, but this system also has the highest productivity per animal and per unit of land.

1.3.2 Specialized Dairy Farms in the Lowlands

This production system is normally found below 900 m. Due to the higher temperatures, the use of pure European breeds is not common in these areas. Crossbred cattle with a high proportion, i.e. over 50%, of European breeds are preferred by the farmers. Cows are usually milked twice a day and feeding of females calves is mostly made artificially. Feeding of cows relies mainly on low quality pastures with restricted use of concentrates, though some other supplements, i.e. agricultural by-products, are commonly used. Production costs per kg of milk are lower than in specialized dairies, but productivity per area and per cow is consistently lower (Table 1).

1.3.3 Dual-purpose Farms

Dual-purpose is defined as a system combining beef and dairy with limited or no use of concentrates. The cows stay permanently on low quality pastures, suckle their calves, are milked once a day and are occasionally fed low quantities of concentrate. In Costa Rica, this is the most common system. Most frequent crosses are between B*os taurus* breeds such as Holstein, Brown Swiss and Jersey, with Zebu breeds such as Brahman and Gyr, or beef-type *Bos taurus* breeds such as Simental and Charolais. In general terms approximately 65% of the income of dual purpose farms comes from the selling of milk and the remaining 35% comes from the selling of calves after weaning at an age of approximately 8 mo. Economical efficiency within these production systems is highly heterogeneous, because different degrees of technification and intensification can be found. However, when compared to specialized dairy systems, higher utility margins per kg of milk and lower productivity per area and cow are found for dual-purpose systems (Table 1).

1.4 MARKET STRUCTURE

Due to the high diversity of production systems, the market structure for dairy products in Costa Rica presents some particularities.

Considering the origin (Figure 3), approximately 70% of the milk is produced by specialized dairy farms, almost in equal parts from highlands and lowlands; while the remaining 30% is produced by dual-purpose farms located in humid and wet/dry lowlands (9).

Considering the destination of milk, several uses can be identified (Figure 3). The farmers use an estimate of 10% of the fresh milk for self-consumption or feeding of calves, another 50% is industrialized by a small number of dairy cooperatives and cheese factories and the remaining 40% of the milk is commercialized as non pasteurized milk.

One major dairy cooperative process almost 80% of the total milk, while the remaining 20% is processed by 6 other factories (24). Most of these cooperatives and factories are vertically integrated, i.e. they perform the recollection of milk at the farms and also carry out the processing and commercialization of products (24). The production of the largest cooperative is regulated by means of milk quotas. The amount of milk that can be delivered to the cooperative is fixed according to the number of milk-quota shares owned by the farmer. As a reference, the cost of 1 kg of milk quota in 1998 was $US40 (16). At the moment, this cooperative is not selling milk quota, although this can be traded among farmers. The payment system used by local factories is usually established according to milk quality standards, i.e. content of solids per kg of milk and hygiene norms.

TABLE 1. Main characteristics of milk production systems in Costa Rica[1].

	Highlands	Lowlands	Dual-purpose
% of income from milk	>95	70-85	45-55
Location (m.a.s.l)	1200-3000	0-1200	0-900
Temperature (°C)	10-20	20-30	20-35
Breeds	Holstein Jersey	Holstein × Zebu Brown Swiss × Zebu	Holstein × Zebu Brown Swiss× Zebu
Milk yield per lactation (kg)	3500-6000	1900-2500	400-1200
Concentrate (kg/cow/d)	3-10	<3	0-2
Age at first calving (mo)	25-30	30-35	30-35
Lactation length (d)	328	>300	210
Calving index (%)[2]	85.3	...	63.3
Most common pastures[3]	Kikuyu Star Grass	Ratana Brachiaria Star Grass	Jaragua Natural Imperial
Stocking rate (AU/ha)	2-3.5	1.5-2	1.0-1.5
Cost/kg milk ($US)	0.23-0.25	0.20-0.22	0.18-0.20
Profitability/ kg milk (%)	<22	25-30	35-50
Kg milk/farm/yr	40,000-60,000	>20,000	33,000-125,000

[1] Information was obtained from several studies on local production systems (2, 9, 12, 14, 16, 26, 27, 28, 29, 30).

[2] Calving index: Number of calvings/Number of cows available.

[3]Ratana: *Ischaemun ciliare*; Brachiaria: *Brachiaria ruziziensis*/brizantha, *Brachiaria decumbens*; Kikuyu: *Pennisetum clandestinum*; Star Grass: *Cynodon nlemfuensis*; Natural: *Paspalum notatum*; Imperial: *Axonopus scoparius*.

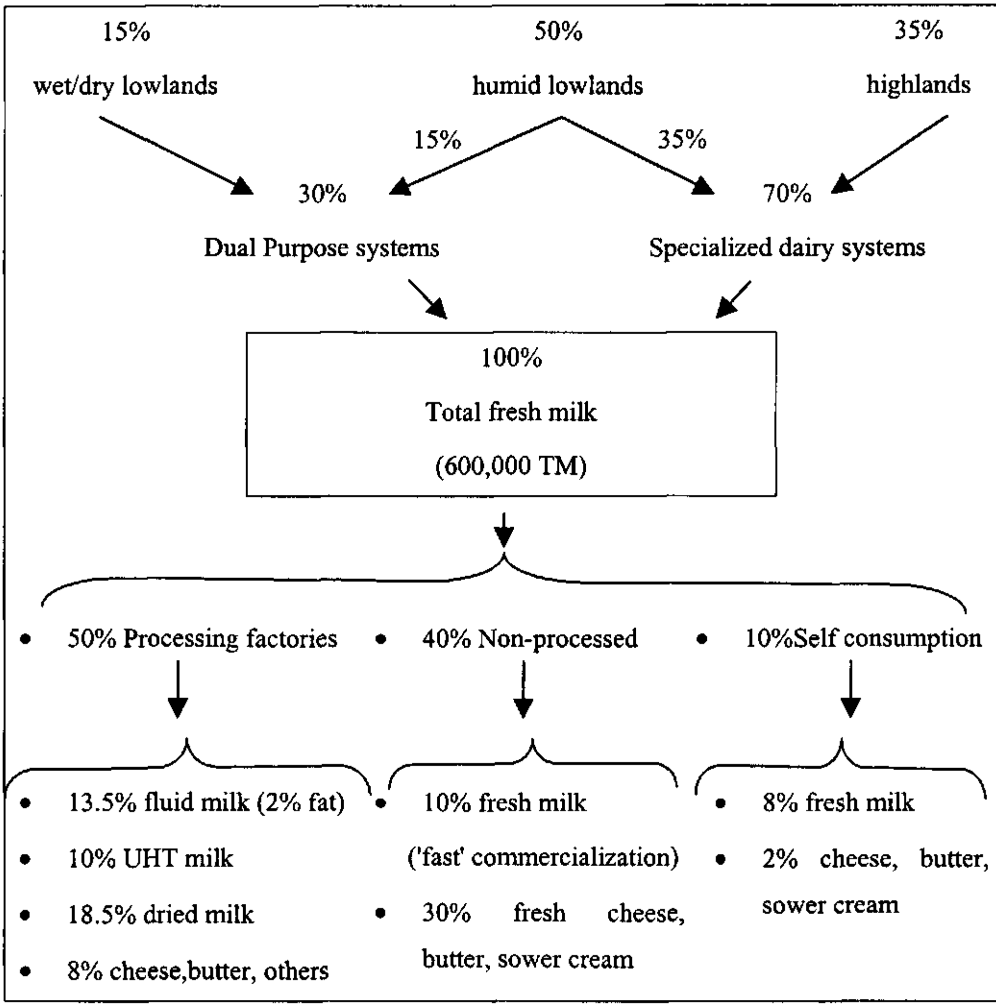


FIGURE 3. Origin and destination of milk in Costa Rica. (Sources: 6, 8, 12, 24, 27, 28)

It is important to notice that the milk that is processed in Costa Rica is produced by no more than 5000 farms, i.e. approximately 14% of the total number of dairy farms. Most of these farms are specialized dairy farms, able to cope with the high-quality standards required by the dairy industry. Another important fact is that approximately 30,800 TM of milk-equivalent products is exported (6), which is more than 10% of the industrialized milk. This is proportionally higher than the quantity exported by some of the main milk producing countries.

The non-pasteurized milk is produced by approximately 30,000 farms, i.e. approximately 86% of the total number of farmers. These are mainly low and medium size farms operating under lower quality standards. Commercialization of this non-pasteurized milk takes place in different ways, either as fresh milk or as transformed products, directly from the farm of with intermediates (24). This informal sector is by far less predictable and less stable than the formal sector, however it plays a very important role in the milk production in Costa Rica.

1.5 BREEDING

Breeding of dairy cattle in Costa Rica has followed the same patterns as for most of the developing countries in Latin America and the world (4). Before the introduction of European breeds, the local cattle population consisted mostly of Creole cattle, which probably originated of the Spanish cattle brought to America by the end of the 15th century (19). These cattle evolved in complete isolation during almost four centuries. By the end of the 19th century, the importation of European breeds, such as Friesian, Jersey and Guernsey, was initiated. After 1930, the introduction of improved pastures was also initiated, which had an important effect on dairy production. The first Cattle Breeders Association was created in 1938 and the fist herdbook was initiated in 1945. Introduction of AI occurred in the late forties, but massive semen imports began after 1960. By the end of the sixties most of dairy cattle in Costa Rica had already some exotic genes. As a result, the local dairy breeds have almost disappeared, even though their genes are still present in the population on a very low proportion. Semen imports in 1982 were 42000 doses (3). In 1983, for the first time, 100 frozen embryos were imported from USA (3). Currently, the genetic material is imported mainly from USA and Canada and to a lesser extent from Europe and other countries in the world. Semen imports from USA amounted approximately half a million US$ in 1998.

The effect of germplasm importation on local milk production has not been yet precisely assessed on a national scale. Preliminary analysis on data from specialized dairy farms indicates some trends (7, 22, 23, 30). These results are shown in Table 2.

These studies indicate a significant increase in milk yield per lactation during the past decade. The respective contribution of environmental and genetic components to this increase is not clear. Two studies indicate a low heritability of 0.10 for milk production and almost no genetic gain (7, 23). Another study based on more extensive data shows heritability estimates for milk yield in the range of 0.36 for Holstein and 0.26 for Jersey (30). For the same study the phenotypic increase in milk yield per lactation between the years 1979 to 1992 was 111.4±5.9 and 91.3±6.8 kg for Holstein and Jersey, respectively. The increase in PTA was 21.9±0.4 and 12.1±0.7 kg for Holstein and Jersey, respectively. The phenotypic and genetic trend for the Holstein breed is shown in Figure 4.

These results indicate that the increase in productivity of dairy cows in Costa Rica has been mainly due to the improvement of environmental conditions, i.e. housing, nutrition and health management; and to a lesser extent, though not negligible, to genetic improvement. According to this analysis, the genetic correlation among USA Holstein sire evaluations and the local estimations were 0.62. This correlation provides some evidence for the existence of Genotype × Environment interaction within specialized dairy cattle in the highlands of Costa Rica.

Similar studies for dual-purpose cattle in Costa Rica are not available at this moment and they are difficult to obtain, given the high diversity of breed types and the low number of cattle for each of these types. However, it seems reasonable to expect that the effect of germplasm imports on productivity is lower on dual-purpose systems and lowland dairies, where G×E interactions are expected to be larger.

TABLE 2.

Phenotypic and genetic trends for milk production in dairy cattle of Costa Rica.

Parameter	Soto and Aragón (22) [1]	Soto et al. (23)[1]	Vargas and Solano (30)[2]	Godínez and Soto (7)[1]
Breeds	Holstein	Holstein	Holstein (H) Jersey (J)	Holstein
Years	84-91	68-90	79-92	75-95
Data				
Lactations	128	2479	15648	5286
Cows	103	1055	9797	2315
Sires	29	204	1953 (689 AI)	340
Herds	-	27	199	67
h^2 (Repeatablity)	-	0.10	0.36 H (r=0.45) 0.26 J (r=0.49)	
Phenotypic gain (kg/cow/yr)	-	93.3	111.3 (H) 91. 3 (J)	59.2
Genetic gain (PTA/cow/yr)	-	1.1(*)	21.9(**) (H) 12.1(**) (J)	1.43(*)

[1] Godínez and Soto (7), Soto and Aragón (22), Soto et al. (23) used an Animal Repeatability Model with total unadjusted milk yield per lactation as dependent variable; herd, year, sire, lactation number and sire origin (USA vs. CR) as fixed effects; cow age and lactation length as covariates, and animal and permanent environmental random effects.
[2]Vargas and Solano (30) used an Animal Repeatability Model with adjusted 305-d milk yield as dependent variable, herd-year fixed effect and herd-sire, animal and permanet environmental random effects. Age/season adjustment factors were taken from Vargas and Solano (29).
* p>0.05; ** p > 0.01.

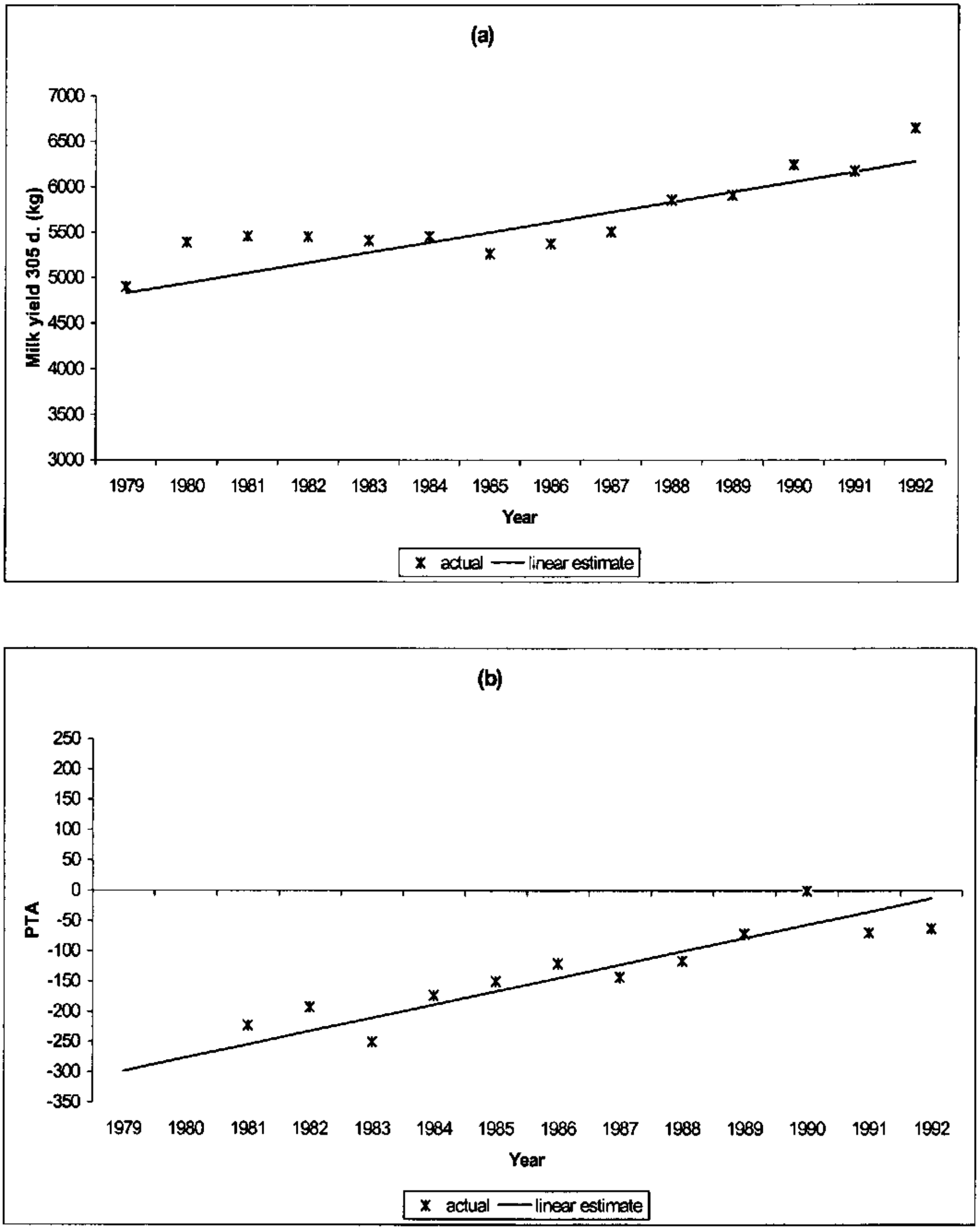


FIGURE 4. Phenotypic (a) and genetic (b) trends for milk yield of Holstein cows of Costa Rica (30).

In 1988 the Ministry of Agriculture started a local Dairy Herd Improvement Association (DHIA), in collaboration with some international organisations and the Dairy Breeders Association (1). The objective of the project was to implement an Open Nucleus Breeding Scheme (ONBS) in order to achieve a faster dissemination of superior germplasm. The programme was stopped after some years when international support ceased.

1.6 PERSPECTIVES

The future of milk production in Costa Rica has to be analyzed taking into consideration the effect of global trends in agricultural trade. In developing countries, major determinants for the scope of dairy production are dairy pricing policies, efficiency of marketing systems, processing options, access to input and services, and the land tenure system (18). As a member of WTO, Costa Rica has agreed to gradually reduce the tariff barrier imposed for imported dairy products from 96% in 1999 to 65% in 2001 (15). This measure could certainly have a major impact on the local production, especially if there is a chance for importation of milk products at a lower price (17). Currently, the price per kg of milk paid to farmers is US$0.27 and the price paid by the consumers is US$0.40. These prices have been stable during the last years and are considerably lower than prices in other countries in Central America. However, prices of milk in Central America are considerably higher than other countries in Latin America and the three major producers in the world, i.e. EU, New Zealand, and USA. This is mainly the result of distorted policies in international trade of dairy products. An earlier study utilised modelling techniques to analyze the possible impact that a reduction in tariff barriers to a 20% could have on local production (9). According to this analysis, local prices of milk would have to be reduced by 10% and substantial changes at the farm level would have to be made to be competitive with milk imports. The efficacy of WTO as an international regulator of dumping policies will play an important role to determine the effect of the reduction in the tariff barriers on milk production in Costa Rica. Besides, given the important social role and the high organisation level of the dairy sector in Costa Rica, it seems unlikely that tariff barriers will be completely eliminated.

On the other hand, if the country consolidates its condition as exporter within the region, this may have an important positive effect on local production. This exportation, however, must be oriented to products with high added value, other than fluid or dried milk, for which the possibility to compete with high volume international exporters is low. Some initial steps have been made, with the creation of new infrastructure for milk processing and the establishment of international trade agreements with some countries in Central America and the Caribbean.

If the international situation evolves positively, as previously discussed, there could be an option for a further increase in milk production in Costa Rica. The question remains, however, on the type of production systems that should be encouraged, and accordingly, the type of cows that should be bred. On this respect, there are some other considerations to be made, including aspects related to social welfare and sustainable development.

Specialized dairy production systems are usually addressed as the less sustainable alternative, because of the relatively high use of external inputs and increased pollution (25). On the other hand, this type of production systems contributes largely to the current state of self-sufficiency. The increase in human population in developing countries, and the reduction in the amount of land dedicated to agriculture, demand for increased productivity in animal production systems (5). The specialized dairy production systems can achieve the productivity levels required to satisfy the requirements of local and future international markets (20). However, the economic and environmental costs involved may be high. This apparent conflict still needs to be resolved.

Dual-purpose systems and lowland dairies also play a key role in the economy. These systems are usually seen as more sustainable alternatives for milk production, due to the relatively low production costs, the increased use of local resources and higher utility margin per kg of milk. It is the opinion of some experts that production systems providing cheap food should be given priority (25). In addition, there are some studies indicating that this system can be economically as efficient as specialized dairies (11). It is also evident the social importance of this sector, which currently embraces more than two thirds of the total number of dairy producers and provides cheap milk for a very important sector of the population in marginal areas (27). This sector has made possible the relatively high milk consumption per capita, among the top three in Latin America and similar to indexes in some developed countries.

Given the previous considerations, it is clear that all production systems play an important role in the country. It is also clear however, that producers need to achieve higher biological and economical efficiency within the constraints set by the local production circumstances.

REFERENCES

1 Aragón, A., Soto, H., Beck, E. 1992. Genetic impact by systematic breeding of livestock in Costa Rica. In Potentials and limitations of biotechnology in livestock production in developing countries. Part 1: Animal Reproduction and Breeding. Proceedings of a Symposium held at the Institut fur Tierzucht und Tierverhalten (FAL), Mariensee, Germany in cooperation with the Council for Tropical and Subtropical Agricultural Research (ATSAF). Ed. by H. Niemann , H. Franzen and D. Smidt; pp. 23-35.

2 Baars, R.M.T. 1997. Nutrition management, nitrogen efficiency and income over feed cost on dairy farms in Costa Rica. J. Dairy Sci. 81: 801-806.

3 Beck, E. 1985. Artificial insemination and veterinary services in Costa Rica. Tierarztliche-Umschau 40(2), 109-112.

4 Bondoc, O.L., Smith, C., Gibson, J.P. 1989. A review of strategies for genetic improvement of dairy cattle in developing countries. Anim. Breed. Abs. 57: 819-829.

5 Delgado, C., Rosegrant, M., Steinfeld, H., Simeon, E., and C. Courbois. 1999. Livestock to 2020. The next food revolution. Food, Agriculture and the Environment Discussion Paper 28. (FAO, IFPRI,ILRI). 73 p.

6 FAOSTAT 2000. FAO online agricultural database collections. Food and Agriculture Organisation of the United Nations. http://faostat.fao.org/default.htm.

7 Godínez, J., and H. Soto. 1996. Análisis genético de la producción láctea, los días abiertos y el intervalo entre partos en el hato Holstein nacional. X National Congress.Abstract 126, p. 397.

8 Herrero, M. 1997. Modeling dairy grazing systems: an integrated approach. Ph.D. thesis. University of Edinburgh. 283 p.

9 Herrero, M., Fawcett, R.H., and J.B. Dent. 1999. Bioeconomic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. Agric. Syst. 62:169-188.

10 Holdridge, L. R. 1982. Life zone ecology. Inter American Institute for Cooperation in Agriculture (IICA), San José, Costa Rica.

11 Holmann, F., Blake, R.W., Hahn, M.V., Barker, R., Oltenacu, P.A., and T.L. Stanton. 1990. Comparative profitability of purebred and crossbred Holstein herds in Venezuela. J. Dairy Sci. 73:2190-2205.

12 IICA, 1994. El subsector lechero en Costa Rica. Inter American Institution of Cooperation in Agriculture (IICA). 122 p. (mimeo).

13 INFOAGRO, 2000. Costa Rican- Agricultural Sector Statistics. www.infoagro.com.

14 Kropf, W., Aragón, A., Kunzi, N., and W. Hagnauer. 1983. Dairy ranching in Costa Rica. World Anim. Rev. (FAO) 45:23-27.

15 La Gaceta 1999. Decreto No. 27684. Official journal of the government. Año CXXI. Alcance 14. 45:1-4.

16 Montenegro, J., and S. Abarca. 1998. La ganadería en Costa Rica: tendencias y proyecciones 1984-2005. Ministerio de Agricultura y Ganadería (MAG). 70 p.

17 Núñez, R., and A. Galeto. 1993. Opciones de liberalización del comercio de lácteos. Regional Unit of Technical Assistance (RUTA II). 49 p.

18 Peters, K. J. 1993. Selection and breeding strategies for sustainable livestock production in developing countries, with particular reference to dairy cattle production. British Society of Animal Production, ocassional publication 16,120-128.

19 Robert Luján, E. 1989. Historia de la ganadería en Costa Rica. San José, Costa Rica. 138 p.

20 Simpson, J.R., and J. R. Conrad. 1993. Intensification of cattle production systems in Central America: why and when. J. Dairy Sci. 76:1744-1752.

21 Solano, C. 2000. Decision-making profiles, managerial capacity, management and performance: A study of Costa Rican dairy farmers, Ph. D. Thesis, University of Edinburgh, 185 pp.

22 Soto, H., and A. Aragón. 1992. Predicción del valor de cría de animales reproductores en el programa nacional de prueba y mejoramiento genético de Hatos Lecheros (PNPMHL). Horizonte Lechero 17:21-23.

23 Soto, H., Aragón, A., and E. Beck. 1994. Genetic analysis of milk yield of Holstein cattle in Costa Rica. In: Fifth Wld. Cong. Gen. App. Livest. Prod. (Guelph, Canada) pp. 352-354.

24 Umaña, V. 1998. Comercio de productos lácteos en Centroamérica. In: La ganadería e industrias afines en centroamérica. Edited by R. Guillén et al. Unidad Regional de Asistencia Técnica (RUTA). San José, Costa Rica. 227 p.

25 Vaccaro, L., and D. E. Steane. 1990. Practical technologies and options for the genetic improvement of livestock in developing countries. FAO Anim. Prod. and Health Pap. 107:85-98.

26 Van der Grinten, P., Baaijen, M.T.,Villalobos, L., Dwinger, R.H., and L. 't. Mannetje. 1993. Utilisation of kikuyu grass (pennisetum clandestinum) pastures and dairy production in a high altitude region of Costa Rica. Trop. Grass. 26:255-262.

27 Valverde, M. 1994. Información básica del sector lechero. Secretaría Ejecutiva de Planificación Sectorial Agropecuaria. 11 p. (mimeo).

28 Vega Valverde, A. 1994. Caracterización de la actividad lechera en Costa. Secretaría Ejecutiva de Planificación Sectorial Agropecuaria. 11 p. (mimeo).

29 Vargas, B., and C. Solano. 1995a. Projection and adjustment factors for lactational milk production of dairy cows in Costa Rica. Arch. Latinoam. Prod. Anim. 3:131-148.

30 Vargas, B., and C. Solano. 1995b. Genetic and environmental trends in milk production of dairy cattle in Costa Rica. Arch. Latinoam. Prod. Anim. 3:165-176.25

Chapter 2

Analysis of Test Day Yield Data of Costa Rican Dairy Cattle

B. Vargas,*[†] E. Pérez,* and J.A.M. van Arendonk[†]

*Escuela de Medicina Veterinaria, Universidad Nacional de Costa Rica,
PO Box 304-3000, Heredia, Costa Rica
[†]Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences,
Wageningen Agricultural University,
PO Box 338, 6700 AH Wageningen, The Netherlands

Published in Journal of Dairy Science 81: 255-263

ABSTRACT

Estimates of variance components for test day records in an animal model that considered multiple traits over multiple lactations were calculated using REML methodology. Test day records were classified into 11 periods within first and later lactations. Missing ancestors in the relationship matrix were classified in genetic groups. Data were collected from Costa Rican dairy farms. Estimates of components for total and additive genetic variance were clearly heterogeneous during the lactation. Heritabilities for traits in later parities were slightly higher than those for traits in first parity. Heritabilities were highest for records of midlactation. Phenotypic and genetic correlations for adjacent test days were close to one. Phenotypic correlations were lower than genetic correlations. Heterogeneity of variances during the lactation suggests the adequacy of the multiple-trait test day model to describe milk yield during the lactation. When missing ancestors were allocated to a single base population, instead of genetic groups, the estimates of residual variance were lower, and the estimates of genetic variance and genetic correlations were higher. When standardized records were used instead of actual test day records, the estimates of residual and total variance were lower, and the estimates of genetic variance were higher. Consequently, estimates of heritability and genetic correlations were also higher. Use of standardized data obtained by interpolation procedures is not advised for estimation of genetic variance components in a test day model.

(**Key words:** test day yields, genetic parameters, genetic groups).

Abbreviation key: TDM= test day model.

2.1 INTRODUCTION

The use of test day models (**TDM**) for the analysis of traits related to milk yield has received considerable attention during recent years (8, 10, 12, 17, 20, 21, 26). Test day models have been defined as a statistical procedure that considers all genetic and environmental effects directly on a test day basis (12). This methodology has several advantages compared with the traditional 305-d model. The TDM maximizes the amount of information to be gathered for each animal and avoids the use of factors to extend part lactation records (26). Another important advantage is that TDM account for factors that are specific to each test day, such as management groups within a herd on a test day (5, 15). In addition, the problem of differences in the amount of information contributing to the 305-d prediction is overcome (15).

Various statistical models have been proposed for the analysis of test day records, and the most widely used model has been the repeatability model (12). Under this model, consecutive test day samples from the same lactation are considered as repeated observations on the same trait with a permanent environmental effect accounting for environmental similarities between different test days within the same lactation. A random regression test day model (RRM) has also been proposed (17). In this model, two sets of regressions of milk production on DIM are performed, one fixed for cows in the same subclass and one random, accounting for deviations of the cows with respect to the fixed parameters in the group. A version of this model for multiple lactations has also been applied for the analysis of somatic cell score in Germany (14, 15). Recently, a model for multiple traits and multiple lactations has been suggested that integrates linear functions of test day observations into a canonical index (8, 26), and an alternative model used covariance functions (7).

Some problems of the TDM have not yet been elucidated clearly. A major disadvantage for the repeatability model is the heterogeneity of the residual variance during the lactation (12). The model for multiple traits has been proposed as a solution to this problem. However, the increase in the amount of information, which can be nearly 10 times higher than with the traditional schemes, represents a big computational burden (8, 12, 26).

Estimates of genetic parameters for test day records have been presented previously (6, 8, 11, 10, 13, 26). Estimates of heritability were sometimes similar to those reported for 305-d milk yield, especially for midlactation records, with lower estimates for records at the beginning and at the end of the lactation (6, 8, 26). In general, high phenotypic and genetic correlations have been reported, being close to 1 for consecutive records (6, 8, 11, 26). However, analysis frequently has been restricted to complete lactations with a minimum number of test days regularly distributed during the lactation (8, 10, 13). In some cases, standardized data have been calculated by the use of a test interval method (**TIM**) which allows the estimation of test yields at fixed times within the lactation (18). The effect of the use of selected and standardized data on the estimates of variance is not very clear. No estimates of heritability have been presented using an approach with multiple traits for actual instead of standardized data, without any previous selection on a minimum number of records per lactation.

Most of the research on test day models has been carried out in countries with well-established breeding programs, official milk recording schemes, and accurate pedigree information. In Costa Rica, the total number of dairy cattle is relatively small. A local breeding program has not yet been established successfully, and genetic improvement has relied mainly on the importation of semen. Use of local unproven bulls is still frequent. Official milk recording schemes are only implemented in a small proportion of the population, pedigree information is not always available, and breed variation at the farm level is high. However, a considerable increase in milk yield of 111.4 kg/yr per lactation has been reported for Holstein cattle from 1979 to 1992 (24). This increase has been achieved mainly by the improvement of nutritional and management conditions. The genetic component seems to have played a less important role (19, 24). Test day models have been suggested as the method of choice for the analysis of milk production traits in order to maximize the use of all the available information (12). This result becomes even more important in countries with few cattle without well-established milk recording schemes. In addition, the use of a genetic grouping strategy provides a powerful tool to deal with cases in which accurate pedigree information is not available (25).

The objective of this analysis is to determine genetic and environmental factors affecting daily milk yield in Costa Rican dairy cattle using an animal model for multiple traits and multiple lactations. Given the characteristics of the data file, the effects of using a genetic grouping strategy and actual instead of standardized data on the final estimates of variance components and genetic parameters are also investigated.

2.2 MATERIALS AND METHODS

2.2.1 Data Source

Analysis were performed on data provided by Universidad Nacional de Costa Rica (UNA). These data were collected from 1980 to 1996 on dairy farms from five regions in Costa Rica. These farms participate in a project that focuses on the collection and analysis of information about health, and productive and reproductive components (2). Test day milk yields were entered in the software package VAMPP (9) by staff of UNA or directly by farmers. Cows included in the analysis were of the following breed types: Holstein, Jersey, Guernsey, Brown Swiss, and combinations of *Bos taurus* × *Bos indicus* and *Bos taurus* × *Bos taurus* breeds.

2.2.2 Statistical Model

The following animal model for multiple traits and multiple lactations was used to analyze first parity test day records.

$$[y_l - y_{11}]_{ijkl} = \mu + HYS_i + b_1(age_j) + b_2(age_j^2) + b_3(day_k) + A_l + E_{ijkl} \qquad [1]$$

where:

$[y_1 - y_{11}]_{ijkl}$	=	test day records for 11 milk production traits analyzed by defining 11 periods within the lactation where trait y_1 comprised samples obtained between d 4 and 16 in the lactation, trait y_2 comprised samples obtained between d 15 and 31 in the lactation, and traits y_3 to y_{11}, represent samples obtained in subsequent periods of 30.4 d;
μ	=	population mean;
HYS_i	=	fixed effect of herd-year-season i in which the sample was taken;
b_1,b_2	=	linear and quadratic effects of age at calving (age_j) on test day yield;
b_3	=	linear effect of day of sampling k (day_k) within period;
A_l	=	random animal effect for which relationship matrix was used; and
E_{ijkl}	=	random residual.

Two seasons were defined according to the ecological region where the farms were located (4). The length of the seasons ranged from 4 to 8 mo accounting for climatic characteristics of the region.

For later parities, records in different lactation for the same period within the lactation were treated as repeated records for the same trait (i.e. y_{12} to y_{22}). To account for repeated samples on the same animal, a random permanent environmental effect was added to Model [1] for test day records in later parities.

2.2.3 Data Editing

Given the aforementioned definition of traits and effects, the following editing procedures were undertaken. All data from a cow were removed when the breed type could not be classified in one of the pre-defined groups. Data from one lactation was removed when the previous gestation length >295 d or <240 d and when age at calving was <18 mo or >42 mo for the first parity group. Lactation data was also removed when age at calving in later parities was <28 or >150 mo and when the previous dry period was <15 d. A maximum of 10 lactations per cow was considered.

A minimum of 5 lactations within each herd-year-season of calving class was required. When this number was lower, an attempt was made to join adjacent seasons of consecutive years. A maximum of three seasons, when necessary, were joined. If the final number of lactations in the newly formed herd-year-season class was still <5, then the respective lactations were removed.

The number of samples per lactation was not restricted. Test day records within a lactation were eliminated when the day of sampling was <6 or >304 and when milk production was <4 or >70 kg. When additional samples within a period within parity were available, only the first sample was used in the analysis, and the others were removed.

2.2.4 Analytical Procedures

Because of incomplete data and pedigree records, a genetic grouping procedure was used. Missing ancestors were classified in genetic groups according to selection path, breed type, and estimated birth year (25). Animals included in the relationship matrix were cows having own information (n=28,417) and sires (n=1161). Sires comprehended 656 Non-AI sires, 353 AI sires with at least 5 daughters in the data file and 152 sires of sires. Sires of sires did not have always an identified sire themselves. Four generations of AI sires were included in the relationship matrix, when available. Missing sires or sires with <5 daughters in the data file were allocated to genetic groups. Dams of cows without own information on milk production and dams of sires, although available in some cases, were also coded as genetic groups. Following this strategy a total of 208 genetic groups were formed.

The variance-covariance matrix for the 22 traits was calculated by REML using a superlinearly converging *quasi*-Newton algorithm with exact analytical derivatives as implemented in the REML-VCE software (3). Because of the high number of equations and the limited computing resources, the following steps were performed to estimate all the elements of the variance-covariance matrix:

Step 1. In order to get starting values for REML-VCE, phenotypic correlations were calculated using SAS least squares analysis (16).

Step 2. Subsequently, all traits were analyzed separately using univariate analysis and Model [1]. In this way, estimates for residual, genetic, and permanent environmental variance components were obtained for each trait separately.

Step 3. Six groups of traits within parity group were formed (Table 1), five of them with two traits and the sixth group with one trait. Thirty different REML-VCE runs were performed following a strategy combining two different groups of traits within parity level. For every run, starting values for the estimates of residual and genetic variance components were specified based on estimates of variance calculated from the phenotypic correlations and the estimates of variance components obtained from the univariate analysis. Five heritability estimates were obtained for every trait using this strategy. Similarly, five estimates of genetic correlation were obtained for traits in the same group and one estimate for traits in different groups. Standard errors of the estimates were obtained based on the approximated Hessian matrix produced by the quasi-Newton optimizer implemented in VCE-REML.

Step 4. All estimates of heritability and correlations were pooled. When more than one estimate of heritability or genetic correlation was available, as specified previously, the respective mean is reported in the final variance covariance matrix.

TABLE 1.

Groups of test day records[1] of first and later parities comprised in the analysis.

First parity		Later parities	
Group	Traits	Group	Traits
1	y_1 and y_7	7	y_{12} and y_{18}
2	y_2 and y_8	8	y_{13} and y_{19}
3	y_3 and y_9	9	y_{14} and y_{20}
4	y_4 and y_{10}	10	y_{15} and y_{21}
5	y_5 and y_{11}	11	y_{16} and y_{22}
6	y_6	12	y_{17}

[1] Traits y_1 and y_{12} are test day records between d 4 and 16 of first and later parities, respectively. Traits y_2 and y_{13} are test day records between d 15 and 31 of first and later parities, respectively. Traits y_3 to y_{11} and y_{14} to y_{22} are test day records between d 30 and 306 of first and later parities, divided into 30.4-d periods.

Two additional analyses were carried out in a subdataset including only midlactation first parity traits, y_4 to y_7. One analysis was performed in order to evaluate the effect of the use of genetic groups on the estimates of variance components. Variance components for the traits y_4 to y_7 were calculated for both cases. For first case, the genetic groups were coded following the strategy previously explained, and for the second case, unidentified ancestors were coded as missing, i.e., genetic grouping was ignored and consequently all missing ancestors were joined in a single base population, as frequently performed.

A second analysis of the same subset of data was done to evaluate effects of using standardized test day records, instead of actual records, for the calculation of variance components. Standardized records were calculated for the last day of the four different periods using simple linear interpolation between the two closest records around the fixed day. Following this strategy, a standardized test day record was calculated for all four periods. In order to be able to calculate standardized yields using linear interpolations, animals were required to have at least one test day record in or before period 4 and one in or after period 7. Variance components for standardized test day records were estimated using Model [1] excluding the covariate. A total of 9648 lactations were used, 76% of them had records for all four traits analyzed, and the other 24% lacked at least one record in one of the periods. To enable a good comparison, variance components for actual data test day record in this subset were estimated using Model [1].

2.3 RESULTS AND DISCUSSION

2.3.1 Data Description

The number of complete lactations (at least 305 d), represented 52.6% of the total number of lactations in the original data file, before editing. The number of samples was reduced considerably in the editing procedure (Table 2). The mean number of samples per lactation before editing was 14.2 ± 11.7 (SD), ranging between 1 and 90. After editing, this mean decreased to 7.31, which was similar to values recently reported for other countries (20, 26). The main causes for this reduction were additional samples in the same period, comprising 35.5% of the test day records, and samples taken before d 5 or after d 305 in the lactation, which comprised 10.1% of the samples. A total of 24.6% of the samples pertained to first lactation cows. The mean milk production per lactation, calculated from 40,318 finished and unfinished lactations with more than 250 d was 4427 ± 1685. This number is substantially lower than the data reported for Holstein cattle in the US and Germany (20, 22).

The initial number of breed types was high (Table 2). However, the number of samples per breed type was very low in some cases. For the analysis, breed types were joined in six different groups: Holstein (56.61%), Jersey (19.95%), Brown Swiss (9.20%), *Bos taurus* × *Bos indicus* crosses (8.06%), *Bos taurus* × *Bos taurus* crosses (3.83%), and Guernsey (0.99%). Most common breed crosses involved Holstein or Jersey and *Bos indicus* breeds, such as Brahman.

TABLE 2.

Structure of the data file before and after editing.

Parameter	Data file: Original	Data file: Final
Farms included	230	222
Breed types	107	6
Cows	29,702	28,417
Lactations	62,405	57,891
Individual samples	886,253	423,366

Only a small fraction of cows had both parents identified (Table 3), which is common in countries with relatively new breed registration and milk recording organizations. This fact is demonstrated by the high proportion of non-AI sires, which was approximately 56.5% of the total number of sires. However, a total of 54.2% of the cows with known sires were daughters of AI sires.

TABLE 3.

Number of individuals (cows and sires) in the relationship matrix according to the existence or nonexistence of identified parents

Class	Both		Only dam		Only sire		None		Total	
	n	%	n	%	n	%	n	%	n	%
Cows	3398	11.5	922	3.1	12,173	41.2	11,924	40.3	28,417	96.1
Sires	0	0.0	0	0.0	425	1.4	736	2.5	1161	3.9
Total	3398	11.5	922	3.1	12,598	42.6	12,660	42.8	29,578	100.0

The weighted means for daily milk yield (Table 4) were 14.0 and 16.9 kg for first and later parities, respectively. Standard deviations for daily milk yield are higher than figures given in previous research (6, 20), partly because of the high number of breed types included and the wider range in management practices.

TABLE 4.

Total number of records (n), arithmetic mean and standard deviation of test day records [1] of first and later parities.

First parity				Later parities			
Variable	n	$\bar{x}$	SD	Variable	n	$\bar{x}$	SD
y_1	6410	14.8	4.8	y_{12}	20,225	19.3	6.8
y_2	8236	16.1	5.4	y_{13}	26,104	20.7	7.5
y_3	11,561	16.0	5.8	y_{14}	36,686	20.5	7.7
y_4	11,441	15.4	5.8	y_{15}	36,067	19.4	7.5
y_5	10,917	14.6	5.7	y_{16}	34,372	18.1	7.1
y_6	10,661	13.9	5.5	y_{17}	33,420	16.9	6.7
y_7	10,123	13.3	5.3	y_{18}	31,849	15.7	6.3
y_8	9714	12.8	5.1	y_{19}	30,475	14.6	5.9
y_9	9088	12.3	4.9	y_{20}	28,737	13.4	5.5
y_{10}	8083	11.7	4.8	y_{21}	24,929	12.2	5.1
y_{11}	6174	11.2	4.6	y_{22}	18,094	11.4	4.8
Total	102,408	(14.0)			320,958	(16.9)	

[1] Traits y_1 and y_{12} are test day records between d 4 and 16 of first and later parities, respectively. Traits y_2 and y_{13} are test day records between d 15 and 31 of first and later parities, respectively. Traits y_3 to y_{11} and y_{14} to y_{22} are test day records between d 30 and 306 of first and later parities, divided into 30.4-d periods

2.3.2 Variance-Covariance Matrix and Genetic Parameters

Estimates of heritability ranged from 0.15 to 0.23 and from 0.13 to 0.24 for first and later parity traits, respectively (Table 5). The standard errors of these estimates ranged from 0.02 to 0.03 for test days in the first parity and were always lower than 0.01 for later parities. Slightly higher heritabilities were found for midlactation test day records than for those at the beginning or end of lactation. In general, heritabilities for daily milk yield are low compared to estimates reported in literature. Higher estimates of heritability for test day records in first lactation cows using a sire model have been reported (8, 11, 13). Heritability in these studies ranged between 0.17 to 0.27 (8), 0.27 to 0.39 (11), and 0.10 to 0.37 (13).

TABLE 5.

Heritabilities (diagonal) and genetic (below diagonal) and phenotypic (above diagonal) correlations of test day records in first and later parities.

	First parity										
	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	Y_{10}	y_{11}
y_1	0.23	0.82	0.78	0.73	0.70	0.68	0.66	0.65	0.62	0.60	0.58
y_2	0.81	0.15	0.89	0.85	0.82	0.79	0.77	0.75	0.73	0.70	0.65
y_3	0.85	0.96	0.20	0.89	0.87	0.83	0.82	0.80	0.78	0.74	0.70
y_4	0.75	0.77	0.88	0.21	0.90	0.87	0.85	0.83	0.81	0.77	0.72
y_5	0.71	0.72	0.83	0.92	0.17	0.90	0.87	0.85	0.82	0.78	0.74
y_6	0.60	0.54	0.82	0.89	0.90	0.15	0.90	0.87	0.85	0.81	0.76
y_7	0.63	0.54	0.79	0.87	0.97	0.99	0.20	0.90	0.88	0.83	0.78
y_8	0.72	0.75	0.89	0.86	0.94	0.96	0.96	0.23	0.90	0.85	0.80
y_9	0.49	0.76	0.78	0.85	0.98	0.96	0.97	0.97	0.19	0.89	0.84
y_{10}	0.65	0.75	0.74	0.88	0.84	0.94	0.84	0.90	0.96	0.23	0.87
y_{11}	0.62	0.77	0.77	0.71	0.78	0.87	0.77	0.60	0.81	0.97	0.16
	Later parities										
	y_{12}	y_{13}	y_{14}	y_{15}	y_{16}	y_{17}	y_{18}	y_{19}	y_{20}	y_{21}	y_{22}
y_{12}	0.13	0.85	0.83	0.79	0.77	0.75	0.72	0.70	0.66	0.62	0.56
y_{13}	0.93	0.16	0.90	0.87	0.84	0.81	0.79	0.77	0.72	0.66	0.60
y_{14}	0.96	1.00	0.21	0.90	0.87	0.85	0.82	0.80	0.75	0.70	0.63
y_{15}	0.89	0.95	0.99	0.20	0.91	0.88	0.85	0.82	0.78	0.72	0.65
y_{16}	0.85	0.93	0.96	1.00	0.22	0.91	0.88	0.84	0.80	0.74	0.66
y_{17}	0.79	0.88	0.93	0.98	1.00	0.22	0.90	0.87	0.82	0.76	0.69
y_{18}	0.75	0.82	0.90	0.94	0.98	0.99	0.24	0.90	0.85	0.79	0.71
y_{19}	0.71	0.81	0.86	0.93	0.95	0.97	1.00	0.24	0.88	0.82	0.73
y_{20}	0.68	0.78	0.82	0.87	0.90	0.94	0.97	0.99	0.23	0.87	0.78
y_{21}	0.61	0.69	0.76	0.82	0.84	0.87	0.94	0.97	0.99	0.20	0.84
y_{22}	0.55	0.62	0.67	0.75	0.79	0.80	0.89	0.91	0.94	0.98	0.18

[1] Traits y_1 and y_{12} are test day records between d 4 and 16 of first and later parities, respectively. Traits y_2 and y_{13} are test day records between d 15 and 31 of first and later parities, respectively. Traits y_3 to y_{11} and y_{14} to y_{22} are test day records between d 30 and 306 of first and later parities, divided into 30.4 d periods.

Heritability estimates for test day records using a sire model with multiple traits and a canonical transformation of the data have been reported (8). The estimates of heritability reported with this procedure ranged from 0.24 to 0.35, which were considerably higher than those found in the present analysis. A characteristic shared by these studies was that lactations were required to have a minimum number of samples, and partial lactation records were sometimes removed. These two restrictions implied the elimination of a large quantity of data.

Estimates of phenotypic correlations in the present analysis ranged from 0.58 to 0.90 and from 0.56 to 0.91 for test day records in first and later parities, respectively (Table 5). The estimates of genetic correlations ranged from 0.49 to 1.0 and 0.55 to 1.0, for test days in first and later parities, respectively. Standard errors for genetic correlations were between 0.02 and 0.07 for test days in first parity and always lower than 0.01 in later parities. The estimates of the correlations among daily milk yield from different periods were conversely related to the relative distance within the lactation (i.e., a decrease when the interval increased). However, this trend was not always consistent, especially for first parity traits (Table 5). Genetic correlations presented in the literature are in the range of 0.39 to 0.95 (8), 0.73 to 0.99 (11), and 0.43 to 0.95 (15). Differences in the range of the correlations between the results reported in literature and those found in the present analysis may be due to differences in the model used, the quantity of data available, and differences in definition of test day records.

A previous result has been reported using a similar methodology (26). Estimates of heritability were between 0.14 and 0.23 for first parity traits. Phenotypic and genetic correlations among test day records ranged from 0.20 to 0.63 and 0.50 to 1.0, respectively. These results are generally in agreement with our analysis; however, the differences between phenotypic and genetic correlations in the mentioned study (26) were much higher and the trend in genetic correlations was more consistent. In our analysis, mainly for first parity traits, the trend in the correlation was not always consistent. As an example, the genetic correlation among y_1 and y_9 was lower than the respective value among y_1 and y_{10}. A possible reason for this result is the use of unstandardized data without restrictions on the number of samples per lactation. In addition, the size of our data file was relatively small, and, consequently, the estimates of standard errors for genetic correlations of first parity traits in our analysis were sometimes close to 0.07. As to be expected from the larger number of records, the results obtained in our analysis in later parities were more consistent with estimates in literature.

Variances during the lactation were clearly heterogeneous. For test day yields in first parity (Figure 1), the estimate of total variance for y_1 and y_{11} were 11.5 kg^2 and 8.9 kg^2, respectively. Estimates of residual variance for the same traits were 8.8 kg^2 and 7.8 kg^2, respectively. For test day yields in later parities (Figure 2), the estimate of total variance for y_{12} was 19.3 kg^2, which then increased to around 20.5 kg^2 for y_{13} and y_{14}, and decreased to a value of 13.3 kg^2 for y_{22}. The residual variance decreased progressively from 14.8 kg^2 for y_{12} to 8.0 kg^2 for y_{22}. Estimates of residual variance have been reported in the range of 3.5 to 9.5 kg^2 (5) and 5.16 to 8.31 kg^2 (8). The higher values found in the present analysis were partly due to the lower estimates of heritability and to the use of samples from later lactations.

The estimates of repeatability, defined as the ratio of genetic plus permanent environmental variance, divided by the total phenotypic variance, increased from 0.23 for y_{12} to 0.42 for y_{20} and then decreased to 0.35 for y_{22}. Estimates of repeatability of 0.52, 0.71, and 0.66 for the first, second, and third trimester of lactation have been previously given (6). However, in that report the permanent environmental effect was defined for repeated observations within the same trimester in the lactation. This repeatability should be compared with the phenotypic correlation between test day yields (Table 5) and not the repeatability across lactations in the present analysis.

2.3.3 Genetic Grouping Versus a Single Base Population

Few animals in the data file had both parents identified (Table 3). In addition, the data span a relatively long period, and pedigree could not be traced for all animals. A large proportion of the sires was imported. Assigning missing ancestors to a single base population instead of to genetic groups resulted in a decrease in the residual variance and an increase in the genetic variance (Table 6). This trend was the same for all four traits studied (y_4 to y_7). As a consequence, heritabilities were also higher (Table 7).

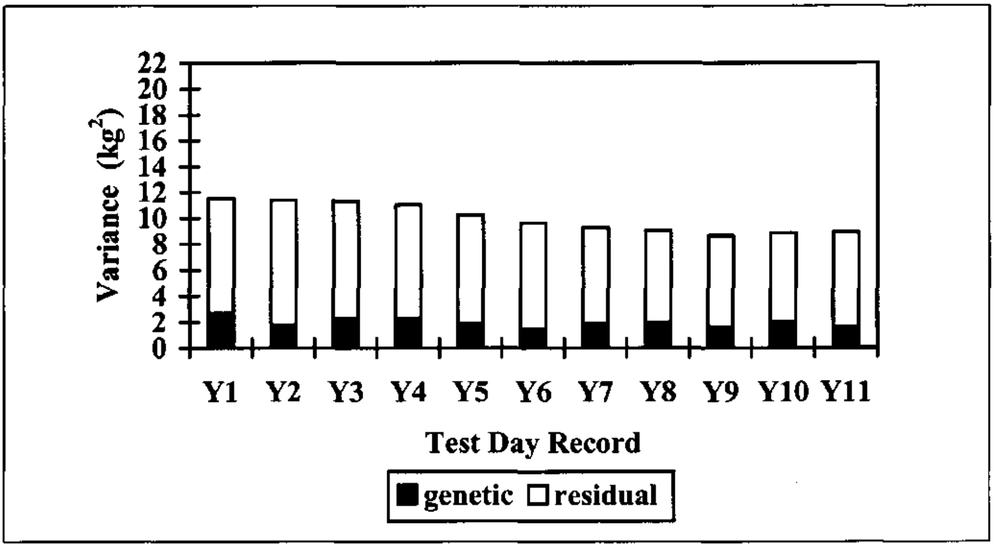


FIGURE 1. Estimates of genetic and residual variance for test day records of first parity Trait y_1 comprised test day records between d 4 and 16, trait y_2 comprised test day records between d 15 and 31, and traits y_3 to y_{11} comprised test day records between d 30 and 306, divided into 30.4-d periods.

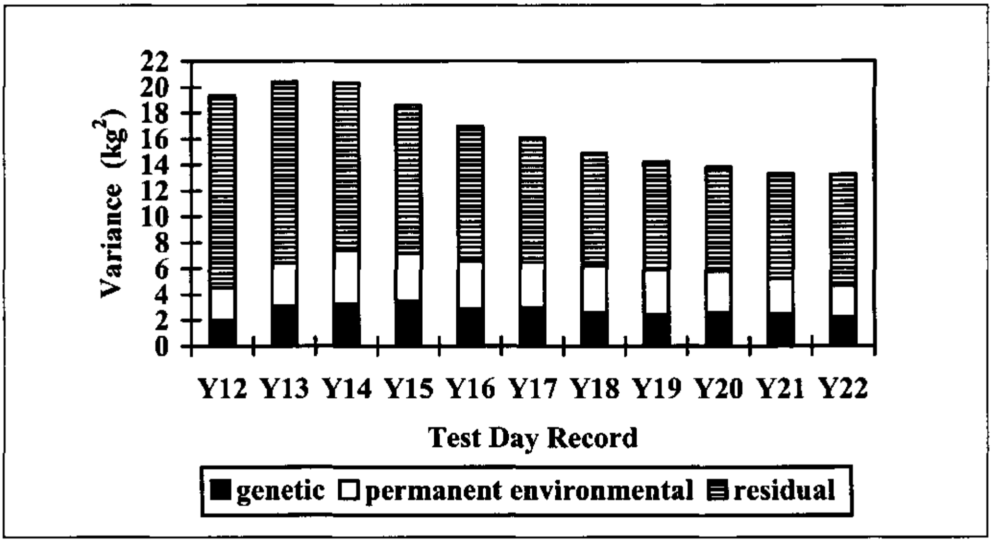


FIGURE 2. Estimates of genetic, permanent environmental, and residual variance for test day records of later parities. Trait y_{11} comprised test day records between d 4 and 16, trait y_{12} comprised test day records between d 15 and 31 and traits y_{13} to y_{22} are test day records between d 30 and 306, divided into 30.4-d periods.

TABLE 6.

Variance-covariance components estimates for residual and genetic effect in traits y_4, y_5, y_6 and y_7[1] obtained by using actual data with genetic groups vs. actual data with a base population vs. Standardized data with genetic groups.

	Actual data-genetic groups[2]				Actual data-base population				Standardized data-genetic groups			
	y_4	y_5	y_6	y_7	y_4	y_5	y_6	y_7	y_4	y_5	y_6	y_7
Residual	8.02	8.04	7.74	7.44	7.78	7.54	7.42	6.62	6.52	6.40	6.23	6.09
Genetic	1.96	1.18	1.20	1.41	2.48	1.90	1.68	2.43	2.11	1.94	1.87	1.84
Total	9.98	9.22	8.94	8.85	10.26	9.44	9.10	9.05	8.63	8.34	8.18	7.93

[1] Traits y_4, y_5, y_6 and y_7 comprised test days records taken in the periods between d 30 to 61, 60 to 91, 90 to 121 and 120 to 151 in the lactation, respectively.
[2] Genetic groups (n = 208) were defined according to estimated birth year, selection path, and breed type.

The effect of the use of a conditional model accounting for selected base animals has been previously addressed (23). Genetic grouping to account for effects of selection is more likely to have a major effect on the estimates of variance components when the number of animals lacking pedigree information is high (25), as is the case in our analysis. When genetic groups are assigned, missing ancestors are allocated to different groups. This grouping resulted in a decrease in the additive variance, which is a reflection of genetic differences between breeds and genetic trend within breeds.

2.3.4 Standardized Versus Actual data

Some discrepancies have been found among studies in heritability estimates for test day records. These differences may be due to the use of actual data in some studies instead of standardized records. Standardized records are obtained by the test interval method (TIM) which uses interpolation or extrapolation on observed test day records to obtain yields at fixed points in time.

The consequences of using standardized test day records for the calculation of variance components in a test day model have been quantified (Table 6). Standardization of milk yield to fixed days in lactation resulted in a decrease in the residual variance and an increase in the genetic variance, compared with the results that were obtained when actual data were used. Standardization also reduced the total variance, and, consequently, the estimates of heritability increased (Table 7). Standardization of test day records can be compared with averaging actual records flanking the time for which the yield is to be calculated. Residual correlations between subsequent yields are substantially lower than 1. Consequently, error variance on average is lower than that on a single observation. The effect on the genetic variance is small when the genetic correlation is high, as is the case here (Table 5). The results in Table 6 and 7 are in agreement with these expectations.

The reasons are less obvious for the increase in additive genetic variance because of standardization. The high correlations between yields might have played a role. The correlations for the standardized data were clearly higher than those for actual data. In calculating the standardized yields in subsequent months, one actual record contributes to two standardized records, i.e. the preceding and the following, which introduces an extra source of covariance. When the interval between actual test records increases, the size of the additional covariance increases.

TABLE 7.

Heritabilities and genetic correlations for traits y_4, y_5, y_6 and y_7[1] obtained by using actual data with genetic groups vs. actual data with a base population vs. Standardized data with genetic groups.

	Actual data-genetic groups[2]				Actual data-base population				Standardized data-genetic groups			
	y_4	y_5	y_6	y_7	y_4	y_5	y_6	y_7	y_4	y_5	y_6	y_7
y_4	0.20	0.89	0.81	0.78	0.24	0.95	0.93	0.88	0.24	0.99	0.88	0.87
SE	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.00)	(0.01)	(0.01)
y_5		0.13	0.91	0.89		0.20	0.94	0.95		0.23	0.94	0.90
SE		(0.01)	(0.01)	(0.01)		(0.01)	(0.01)	(0.01)		(0.01)	(0.01)	(0.01)
y_6			0.13	0.94			0.18	0.98			0.23	0.94
SE			(0.01)	(0.01)			(0.01)	(0.01)			(0.00)	(0.00)
y_7				0.16				0.27				0.23
SE				(0.01)				(0.01)				(0.00)

[1] Traits y_4, y_5, y_6 and y_7 comprised test days records taken in the periods between days 30 to 61, 60 to 91, 90 to 121 and 120 to 151 in the lactation, respectively.
[2] Genetic groups (n = 208) were defined according to estimated birth year, selection path, and breed type.

2.3.5 Computational Aspects

Available computer resources were not sufficient to solve the model when all traits were included simultaneously, as previously stated, and, for this reason, grouping of traits was performed. A model with multiple traits including four first parity test days and using the Model [1] required in average 19.6 h of CPU time on a HP-9000/735 workstation. This time comprised 2.78 h (14.2%) setting the mixed model equations, 0.23 h (1.2%) inverting the equations, and 16.6 h (84.6%) iterating and finding the final solutions. The model allowed for missing observations, which complicated the application of canonical transformations that could have been used to reduce the computing time. A technique has been suggested to circumvent this problem (1) based on the substitution of the missing values by their expectations. However, although such a technique would have reduced the computing time, it is not expected to affect the results.

2.4 CONCLUSIONS

One of the frequently mentioned advantages of the test day model is its ability to account for the heterogeneity of genetic and environmental variances during the lactation (8, 21, 22). In our analysis, heterogeneity of variance is clearly demonstrated (Figures 1 and 2). Previous research (27) has shown that the highest response to selection could be obtained by using only milk yield during the second trimester of the lactation because the consequences of lower genetic correlations are compensated by a shorter generation interval and higher heritability. However, those estimates of heritability were obtained using standardized milk yield records. Results shown in Tables 6 and 7 indicate that the use of standardized milk yield may inflate the actual value of these genetic parameters.

There is still a further question to be answered about the adequacy of a model for multiple traits (8, 26) or a repeatability model (12, 17). The increased computational burden for estimating breeding values using a model for multiple traits may be reason to use a repeatability model instead. However, the heterogeneity of variances during the lactation and the patterns in genetic and phenotypic correlations suggest that multiple-trait approach is more accurate than the repeatability model. A relatively new methodology based on the use of covariance functions (7) has been suggested that could increase the flexibility of a model for multiple traits and could allow the inclusion of all observations. Rather than applying models with many traits, the variance covariance structure of repeatedly measured traits over time is modeled using a covariate function.

Conditions in Costa Rica are ideal for the application of the test day model. Genetic and phenotypic parameters obtained in this paper can be used to develop management tools to be implemented in on-farm management programs and in the design of a breeding scheme for local dairy cattle.

ACKNOWLEDGMENTS

The authors thank the farmers and staff at UNA for collecting the data. B. Vargas gratefully acknowledges the financial support from Netherlands Organization for International Cooperation in Higher Education (NUFFIC) and the Wageningen Agricultural University, Wageningen, The Netherlands.

REFERENCES

1 Ducrocq, V. and B. Babes. 1993. Solution of multiple trait animal models with missing data on some traits. J. of Anim. Breed. Genet. 110:81-92.

2 Dwinger, R.H., E. Cappella, E. Pérez, M. Baaijen, and E. Muller. 1994. Application of a computerized herd management and production control program in Costa Rica. Trop. Agric. (Trinidad) 71:74-76.

3 Groeneveld, E. 1996. REML-VCE User's Guide. Version 3.2. Inst. of Anim. Husb. and Anim. Ethologie. Mariansee, Germany. Sci. 52 pp.

4 Holdridge, L. R. 1967. Life zone ecology. Inter American Inst. for Agric. Sci. (IICA), San José, Costa Rica.

5 Jamrozik, J., L. R. Schaeffer, and J.C.M. Dekkers. 1996. Random regression models for production traits in Canadian Holsteins. Page 124-134 *in* Bulletin no. 14 Interbull Annual Meeting, INTERBULL, Veldhoven, The Netherlands.

6 Kettunen, A., and E. A. Mäntysaari. 1996. Estimation of genetic parameters for test day milk production at different stages of lactation in first parity dairy cows. Page 51 *in* Book of Abst. 47th Annual meeting of the European Association for Animal Production. Wageningen Pers, Wageningen, The Netherlands.

7 Kirpatrick, M., W. G. Hill, and R. Thompson. 1994. Estimating the covariance structure of traits during growth and ageing, illustrated with lactation in dairy cattle. Genet. Res. 64:57-69.

8 Meyer, K., H. U. Graser, and K. Hammond. 1989. Estimates of genetic parameters for first lactation test day production of Australian Black and White cows. Livest. Prod. Sci. 21:177-199.

9 Noordhuizen, J.P.T.M, and J. Buurman. 1984. Veterinary automated management and production control program for dairy farms (VAMPP). The application of MUMPS for data processing. Vet. Q. 6:62-77.

10 Pander, B. L., and W. G. Hill. 1993. Genetic evaluation of lactation yield from test day records on incomplete lactation. Livest. Prod. Sci. 37:23-36.

11 Pander, B. L., W. G. Hill, and R. Thompson. 1992. Genetic parameters of test day records of British Holstein Friesian heifers. Livest. Prod. Sci. 55:11-21.

12 Ptak, E., and L. R. Schaeffer. 1993. Use of test day yields for genetic evaluation of dairy sires and cows. Livest. Prod. Sci. 34:23-34.

13 Reents, R., J.C.M. Dekkers, and L. R. Schaeffer. 1994. Genetic parameters of test day somatic cell counts and production traits. Proc. 5th. World Congr. Genet. Appl. Livest. Prod., Guelph, ON XVII:120-123.

14 Reents, R., J.C.M. Dekkers, and L. R. Schaeffer. 1995. Genetic evaluation for somatic cell score with a test day for multiple lactations. J. Dairy Sci. 78:2858-2870.

15 Reents, R., J. Jamrozik, L. R. Schaeffer, and J.C.M. Dekkers. 1995. Estimation of genetic parameters for test day records of somatic cell score. J. Dairy Sci. 78:2847-2857.

16 SAS® User's Guide: Statistics, Version 6.0 Edition 1990. SAS Inst., Inc., Cary, NC.

17 Schaeffer, L. R, and J.C.M. Dekkers. 1994. Random regressions in animal models for test day production in dairy cattle. Proc. 5th. World Congr. Genet. Appl. Livest. Prod., Guelph, ON XVIII:443-446.

18 Schaeffer, L. R., and J. Jamrozik. 1996. Multiple-trait prediction of lactation yields for dairy cows. J. Dairy Sci. 79:2044-2055.

19 Soto, H., and A. Aragón. 1994. Genetic analysis of milk yield of Holstein cattle in Costa Rica. Proc. 5th. World Congr. Genet. Appl. Livest. Prod., Guelph, ON XX:352-354.

20 Stanton, T. L., L. R. Jones, R. W. Everett, and S. D. Kachman 1992. Estimating milk, fat and protein lactation curves with a test day model. J. Dairy Sci. 75:1691-1700.

21 Swalve, H. H. 1995. Test day models in the analysis of dairy production data - a review. Arch. Tierz. Dummerstorf 38:591-612.

22 Swalve, H. H. 1995. The effect of test day models on the estimation of genetic parameters and breeding values for dairy yield traits. J. Dairy Sci. 78:929-938.

23 Van der Werf, J.H.J. 1990. A note on the use of conditional models to estimate additive genetic variance in selected populations. Proc. 4th. World Congr. Genet. Appl. Livest. Prod., Edinburgh, Scotland XIII:476-479.

24 Vargas, B., and C. Solano. 1995. Tendencias genéticas y ambientales en producción de leche en ganado lechero de Costa Rica. Arch. Latinoam. Prod. Anim. 3:165-176.

25 Westell, R. A., L. R. Quaas, and L. D. Van Vleck. 1988. Genetic groups in an animal model. J. Dairy Sci. 71:1310-1318.

26 Wiggans, G. R., and M. E. Goddard. 1996. A computationally feasible test day model with separate first and later lactation genetic effects. Pages 19-21 *in* Proc. 56th New Zealand Soc. Anim. Prod. Annu. Mtg. Hamilton, New Zealand.

27 Wilmink, J.B.M. 1988. Effects of incomplete records on genetic parameters among cumulative yields in first lactation and on extension of part lactations. Livest. Prod. Sci. 18:19-34.

Making the simple complicated is commonplace; making the complicated simple, awesomely simple, that is creativity.
C. Mingus

Chapter 3

Event-Time Analysis of Reproductive Traits of Dairy Heifers

B. Vargas,*,† T. Van Der Lende,† M. Baaijen* and J.A.M. Van Arendonk,†

*Escuela de Medicina Veterinaria, Universidad Nacional de Costa Rica,
PO Box 304-3000, Heredia, Costa Rica

†Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences,
Wageningen Agricultural University,
PO Box 338, 6700 AH Wageningen, The Netherlands

Published in Journal of Dairy Science 81:2881-2889

ABSTRACT

Data on the reproductive traits of dairy heifers were analyzed using event-time techniques. Traits analyzed were age at first calving (n = 4631), days to first breeding and days open (n = 1992) during the first lactation. A proportional hazard model was used that included fixed effects of herd-year, year-season, breed type, herd weight and heifer weight. Body weights were recorded at 390 d of age, on average. The model for days open and days to first breeding included two additional fixed effects of herd and heifer milk yield at 100 d. A significant effect of heifer weight category on age at first calving was found. The chance of calving was consistently higher for herds and heifers with higher body weight at 390 d, and decreased linearly from the top to the lowest quartiles. The effect of herd weight category on days to first breeding and days open were significant. Heifers in herds with a higher average body weight were less likely to be bred, and heifers in herds with lower average body weight were less likely to get pregnant. Effect of heifer weight category on days to first breeding or days open was not significant. The effect of herd milk yield on days to first breeding was significant. Heifers in herds with lower yield were more likely to be bred. The effect of heifer milk yield category on days to first breeding and days open was significant, but no linear trend was found for the estimates of the hazard ratios. The chance of a heifer being bred and becoming pregnant was similar among the first three quartiles and was lower for heifers in the lowest quartile. The probability of a heifer reaching a first calving can be improved by increasing the body weight at 390 d. Body weight at 390 d did not appear to have a large effect on reproductive performance after first calving. High milk yield appears not to have a large negative effect on days open, at least for the milk yield levels analyzed in this study.

(**Key words:** event-time analysis, dairy heifers, age at first calving, days open).

3.1 INTRODUCTION

Reproductive performance has a large impact on the economy of dairy farms (3, 14, 18), and factors that affect reproductive performance of dairy cattle have been extensively documented (5, 11, 12, 13, 15). Several, mainly linear, regression techniques have been applied to the analysis of reproductive traits. A disadvantage of these techniques is that they are not able to account for heifers that lack information on the trait under analysis [i.e., heifers that do not have a calving or conception date (1, 8, 11, 15)].

Several techniques allow a nonlinear analysis, such as logistic analysis, discriminant analysis, and event-time regression, and are more suitable for the analysis of reproductive traits. Event-time regression, also known as survival analysis or failure data analysis, enables the use of data on the reproductive traits of cows that have only partial records for a specific trait [i.e., cows that did not calve or become pregnant by the time at which data for the study were collected (1, 8, 11, 15)]. This methodology has been employed for the analysis of data when the outcome variable corresponds to the measure of the time elapsed from some starting point until the occurrence of an awaited event (11). The length of this interval may not be known because, prior to the event time, competing events may intervene and preclude further observation, as occurs, for example, when cows are culled or sold. Additionally, the results obtained from event-time analysis are given in the form of time-specific probabilities, which can be included in bioeconomic models (15). Time-dependent covariates can also be added to the analysis (10) to enable measurement of the effect of a given risk factor on a response variable as well as the ability to model this effect along the time during which the individual is exposed to the factor.

An analysis of the effect of body weight on age at first calving using event-time regression has not been documented. Previous results, using mainly linear regression techniques, seem to agree that the onset of puberty and the chance to get pregnant are more related to growth parameters (i.e., body weight and size), than to chronological age (2, 9, 16, 17, 21). Conversely, the relationship between weight at first calving and subsequent reproductive performance does not appear to be strong (17). However, little is known about the strength of this relationship at the herd level.

The use of an event-time approach to analyze days open for dairy cattle has received considerable attention in recent years. Research has mainly focused on the effect of risk factors such as disease incidence, time-dependent covariates, milk yield category on days open, or days to first breeding (1, 11, 12, 13). Two studies (11, 12) indicate that 60-d milk yield has a minimal effect on pregnancy rate, and only cows with a very high milk yield category had a lower rate of conception than that of their herdmates. A third study (8) has found that cows in the highest category for cumulative individual 60-d milk yield show an increase of median days open and a 29% higher number of services per conception than do cows in the lowest category. Differences in the available results could be related to the way in which herd management practices are accounted for in the analysis. Herds with higher mean milk yields are associated with higher chances of conception (11, 12).

In this study, event-time regression is used to quantify the effect of breed type, herd weight level, and individual weight on the age at first calving. In addition, an analysis is performed of days to first breeding and days open postpartum to quantify the effect of herd as well as individual body weight and milk yield.

3.2 MATERIALS AND METHODS

3.2.1 Data Source

The analysis was performed on data provided by Universidad Nacional de Costa Rica (UNA). These data were collected from 1987 to 1994 on dairy farms in Costa Rica. Farms participated in a project that focused on the collection and analysis of data about health, milk yield, and reproduction performance (7) in order to provide advice to farmers and to identify adequate management practices. Body weight records, reproductive events, daily milk yield, and herd characteristics were entered in a modified version of the VAMPP software package (19) by the staff of UNA or directly by farmers.

Records of body weight were collected at fixed dates every 2 mo by a research team using either an electronic scale or heart girth measurements. Consequently, age at sampling was not uniform for all heifers. Data on milk yield and reproductive performance were collected either by the farmer using farm-owned equipment or by the research team. The frequency of milk sampling varied between daily to monthly recording schemes. The integrity and accuracy of this information were assessed by internal controls available within the software based on biological feasibility, population parameters, and previous history of the individual heifer.

3.2.2 Trait Definition and Data Editing

For the analysis of age at first calving heifers were used that had a record for body weight at 390 d of age. Heifers without records for body weight or heifers that were culled before 390 d were not included in the analysis. As a consequence, to fulfil the requirements of event-time regression analysis, the starting point of the measurement period is considered to be 390 d and not the date of birth.

Days to first breeding postpartum was defined as the period between first calving and the first recorded service. Days open was defined as the period between first calving and the day of subsequent pregnancy. Pregnancy was confirmed by a calving date. Body weight at 390 d of age and milk yield at 100 d of lactation were obtained by linear interpolation procedures from the individual observations. Heifers were required to have at least two records for body weight for the period from 9 to 17 mo of age. For the calculation milk yield at 100 d of lactation, heifers were required to have at least 1 test day record in the periods 5 to 50, 50 to 100, and 100 to 150 d after calving (i.e., a minimum of three records before 150 d after calving).

Following the conventions of event-time analysis, all heifers that had a date of first calving, date of first service, or a date of pregnancy were considered to have a failure date; therefore, this record was considered as uncensored. Heifers that did not have a failure date were considered as having censored records, and the date of censoring had to be available. As performed in earlier research (*11*), for the present analysis the record was considered to have been censored at the last date for which any herd record existed for that heifer. According to the information available in the data file, this date could have corresponded to a date of sampling (i.e., body weight or milk yield), a reproductive event or a culling date.

3.2.3 Model

A semiparametric Cox proportional hazards model (4) was fitted to the data using the Survival Kit package (6). The model is represented as follows:

$$\lambda(t;\mathbf{x}) = \lambda_0(t)\, e^{(\mathbf{x}'\beta)} \quad [1]$$

where:

$\lambda(t;\mathbf{x})$ = hazard of event for a heifer at time t with covariates **x**,

$\lambda_0(t)$ = baseline hazard function describing the hazard of event for an hypothetical situation when all covariate values are set to zero, and

$e^{(\mathbf{x}'\beta)}$ = Term specific to individuals with covariates **x** that is always positive and acts multiplicatively on the baseline hazard function.

The model is a semiparametric model because it does not require specification of a distribution for the baseline hazard function. The effects of the covariates on the event times are of a parametric form.

The set of covariates **x** was defined as follows:

HY_i = Fixed effect of herd-year i in which the sample was taken (i = 1 to 222),

YS_j = Fixed effect of year-season j in which the sample was taken (j = 1 to 15),

$BREED_k$ = Fixed effect of breed type k (k = 1 to 3),

H_WE_l = Fixed effect of herd weight category l (l = 1 to 3), and

C_WE_m = Fixed effect of heifer weight category m (m = 1 to 4).

For the analysis of days to first breeding and days open, two additional effects were added to those already mentioned:

H_MY_n = fixed effect of herd milk yield category n (n = 1 to 2); and

C_MY_o = fixed effect of heifer milk yield category o (o = 1 to 4).

Heifers included in the analysis were of the following breed types: Holstein, Jersey, Guernsey, Brown Swiss, and combinations of *Bos taurus* × *Bos indicus* and *Bos taurus* × *Bos taurus* breeds. Because of the low number of records for some of the breed types, only three classes were formed (Holstein, Jersey and others). Approximately 80% of the heifers included in the third breed class were Brown Swiss crosses. Two seasons were defined according to rainfall profiles for the regions where the farms were located. The length of the seasons ranged from 4 to 8 mo and accounted for climatic characteristics of the region (26).

The use of categorized variables was performed in order to look at possible nonlinear effects and to account for differences in variance within herds. Herd weight category (i.e., H_WE) was defined within every breed type by classifying the herds into three classes according to the average body weight of heifers at 390 d. Herds in class 1 (H_WE1) were those located in the top quartile, herds in H_WE3 were those located in the lower quartile, and herds in H_WE2 were those located in the second and third quartiles. This classification was intended to stratify the herds according to possible differences in genetic level for body growth, or differences in management during the rearing period.

Heifer weight categories (i.e., C_WE) were defined by classifying the heifers within herds and breeds in four classes according to body weight at 390 d of lactation. Heifers in the highest category (C_WE1) had a body weight that was at least one standard deviation higher than the corresponding mean. Heifers in the lowest category (C_WE4) were those that had a body weight that was more than one standard deviation below the corresponding mean. Heifers in categories C_WE2 and C_WE3 were above or below the population mean but deviated less than one standard deviation from the mean, respectively. Body weight at 390 d was first adjusted for the factors breed, herd-year-season, and herd weight and for significant interactions among factors. Adjustment factors were obtained from a least squares analysis (22).

Herd milk yield category (i.e., H_MY) was defined within every breed type by classifying the herds in two classes according to the median 100-d milk yield. Herds in class H_MY1 were those above the median, and herds in class H_MY2 were those located below the median. This classification was intended to stratify the herds according to differences in genetic level for milk yield, or differences in management during the lactation.

Heifer milk yield categories (i.e., C_MY) were based on milk yield adjusted for factors of breed, herd-year-season, herd milk yield, and significant interactions. Adjustment factors were obtained from least squares analysis (22). The categories were defined by classifying the heifers in four categories according to the 100-d milk yield. Heifers in class C_MY1 were those that had a 100-d milk yield that was at least one standard deviation above the population mean. Heifers in class C_MY4 were those that had a 100-d milk yield that was more than one standard deviation below the population mean. Heifers in classes C_MY2 and C_MY3 were above or below the population mean, but deviated less than one standard deviation from the mean.

3.2.4 Construction of the Final Models

In order to assess the effect of heifer weight and heifer milk yield on the response variables, initial models were fitted to the data, including all main effects and relevant two-way interactions. This model was refined by following a backward elimination procedure dropping progressively nonsignificant effects using the chi-square probability test. The final model included the effects under analysis, all other significant main effects, and two-way interactions.

In order to assess the effect of herd weight and herd milk yield on the response variables a reduced model was also fitted to the data. This reduced model included all effects in the full model, with the exception of herd-year, which due to the large number of classes, would also explain the variance due to herd weight and herd milk yield. Thus, results for test of significance and hazard ratios for herd weight and herd milk yield are given according to this reduced model.

The Survival Kit (6) pursues the maximization of the -2 log likelihood through an iterative procedure ending at a given convergence criteria, which, in the present analysis, was set to a value of 1×10^{-8}.

Coefficient estimates of the survivor function and hazard ratios were obtained for all classes within factors included in the final model. An additional analysis was performed stratifying the data file according to heifer weight and heifer milk yield categories in order to obtain Kaplan-Meier estimates of the survivor function for the different strata and to compare the pattern of the survival curves among strata.

3.3 RESULTS AND DISCUSSION

3.3.1 Age at First Calving

The mean age at first calving was 843.7 d (Table 1). A total of 23.5% of the heifers with a recorded body weight did not have a subsequent calving date. The number of censored records appears to be large; however, this situation could be due to the large variation and high mean for age at first calving. In addition, only heifers with a confirmed date of calving were considered as having a failure date. All other heifers were included within the censored population, which consisted mainly of heifers undergoing pregnancy or heifers still waiting to be bred. A few others heifers left the herd due to disease or death, or were sold for dairy purposes to other farms.

TABLE 1.

Descriptive statistics of variables under analysis.

Factor	Age at first calving	Days to first breeding	Days open
Total records, no.	4631	1992	1992
Right censored records, no.	1087	69	183
Minimum censoring time, d	391	19	19
Maximum censoring time, d	760	436	610
Average censoring time, d	456.1	155.0	183.5
Uncensored records, no.	3544	1923	1809
Minimum failure time, d	541	16	22
Maximum failure time, d	1751	220	338
Average failure time, d	843.7	76.5	109.8
Herds, no.	73	48	48
Heifers per herd, no.	63	42	42
Years under analysis, no.	8	7	7

The range of variation in body weight at 390 d for classes of breeds, herd weight and heifer weight were 60.2, 65.2 and 95.9 kg, respectively (Table 2). The range of variation in milk yield at 100-d for classes of breeds, herd milk yield and heifer milk yield were 541.0, 517.8 and 985.9 kg, respectively (Table 2). These values indicate that not only variation between herds is high, but also the variation among heifers within herds. This large variation is likely due to the great diversity in feeding regimes, climatic conditions, and genetic composition that characterizes dairy farming in Costa Rica (24, 25,26, 27).

TABLE 2.

The mean and standard deviation of body weight and milk yield of individual heifers in different categories[1].

Factor	Class	n	$\overline{x}$	SD
			Body weight	
	General	4631	252.6	51.8
Breed	Holstein	2526	271.5	50.3
	Jersey	1269	211.3	34.3
	Others[2]	836	258.3	41.8
Herd weight	H_WE1	1602	277.9	44.7
	H_WE2	2241	248.6	49.9
	H_WE3	788	212.7	41.4
Heifer weight	C_WE1	570	307.0	44.8
	C_WE2	1838	261.8	46.1
	C_WE3	1637	238.3	44.1
	C_WE4	586	211.1	41.9
			Milk yield	
	General	1992	1897.8	540.9
Breed	Holstein	1114	2127.8	542.6
	Jersey	592	1586.8	362.9
	Others[2]	286	1646.0	387.0
Herd milk yield	H_MY1	1016	2151.5	521.6
	H_MY2	976	1633.7	421.2
Heifer milk yield	C_MY1	288	2482.0	493.3
	C_MY2	727	1983.7	474.7
	C_MY3	696	1728.6	435.3
	C_MY4	281	1496.1	416.1

[1] Yields within category were adjusted for variation due to other factors.
[2] Approximately 80% of the heifers included in this class were Brown Swiss crosses.

Factors that had a significant effect on the continuous variable age at first calving (Table 3) were herd-year, year-season, and heifer weight category. Breed type was not significant. Effects of herd weight category, assessed by the reduced model, was significant. Two-way interaction effects were not significant.

TABLE 3.

Chi-square values for factors included in the final model for the continuous traits age at first calving, days to first breeding, and days open.

	Age at first calving			Days to first breeding			Days open		
Factor	df	χ^2	$P>0$	df	χ^2	$P>0$	df	χ^2	$P>0$
Herd year	221	1187.0	0.01	167	308.8	0.01	167	278.5	0.01
Year season	14	57.04	0.01	12	8.19	0.77	12	4.25	0.98
Breed	2	3.88	0.14	2	19.13	0.01	2	14.20	0.01
Herd weight[1]	2	454.4	0.01	3	13.66	0.01	3	16.77	0.01
Herd milk yield[1]	...	...	...	1	9.96	0.01	1	0.49	0.48
Heifer weight	3	79.14	0.01	3	2.45	0.48	3	3.65	0.30
Heifer milk yield	...	...	...	3	22.17	0.01	3	9.54	0.02

[1]These two effects were assessed by fitting a reduced model. The reduced model was the full model without the herd year effect.

Estimates of hazard ratios for breed type, although not significant, indicated that Jersey heifers were 1.18 times more likely to calve than were Holstein heifers (Table 4). The third breed category, mainly Brown Swiss crosses, was also 1.10 times more likely to calve than were Holstein heifers. These differences in the hazard ratios might be due to the fact that Holstein cows in the tropics are more likely to present fertility problems and therefore, a higher proportion will not achieve a first calving (20).

According to the reduced model, effect of herd weight on age to first calving was significant (Table 3), which illustrates that herd weight explains a significant proportion of the variation between herds. The hazard ratios suggest that the probability of calving is higher for heifers pertaining to herds in a higher herd weight category. For example, heifers pertaining to herds in class H_WE1 were 1.18 times more likely to calve than were heifers from herds in class H_WE2; herds in class H_WE3 were only 0.91 times as likely to calve as heifers in H_WE2 (Table 4). It is likely that heifers pertaining to herds in the top weight categories are reared more intensively, and more attention is dedicated to feeding, disease control and breeding. Substantial differences in the feeding systems within the population under analysis have been documented (24). It has been demonstrated that the effect of environmental factors on survival rate of European breeds raised in the tropics is a factor of major importance (20). Differences in genetic level and breeding policies for the herds included in this study have also been documented (27).

TABLE 4.

Estimates of hazard ratios for age at first calving for classes within factors.

Factor	Class	β[1]	SED[2]	Hazard ratio[3]	Uncensored failures
Breed	Holstein	0.00	...	1.00	1976
	Jersey	0.16	0.08	1.18	952
	Others[4]	0.10	0.16	1.10	616
Herd weight	H_WE1	0.17	0.17	1.18	1208
	H_WE2	0.00	...	1.00	1806
	H_WE3	-0.09	0.17	0.91	530
Heifer weight	C_WE1	0.22	0.06	1.25	399
	C_WE2	0.00	...	1.00	1471
	C_WE3	-0.19	0.04	0.83	1324
	C_WE4	-0.35	0.06	0.70	350

[1] Regression parameter of the survivor function.
[2] Standard error of difference between β in this class and the largest class.
[3] Hazard ratios within factor are given relative to the hazard for the largest class, which is set to 1.0.
[4] Approximately 80% of the heifers included in this class were Brown Swiss crosses.

The most important finding from this analysis was the significant difference in the chance of parturition for heifers with different heifer weight categories (Table 3). The trend suggests that the probability of calving becomes higher for heifers with a higher body weight at 390 d. For heifers in class C_WE1, the chance of calving was 1.25 times higher than for heifers in class C_WE2 (Table 4); heifers in classes C_WE3 and C_WE4 were only 0.83 and 0.70 times as likely to calve as heifers in C_WE2. Other studies (2, 9, 16, 17, 21), using different techniques, have also shown that growth parameters are inversely related to age at puberty or age at first calving. Our study shows that the body weight of heifers also had an effect on the chance of the heifer to have a subsequent parturition. It is likely that onset of puberty could be delayed and fertility reduced in underfed heifers.

The plot of the survivor function (Figure 1) within heifer weight category shows how the survival curves for heifers in the third and fourth quartiles are higher than those for heifers in first and second quartiles. For almost any age, the survival probability (i.e., the heifer does not have a record of first calving), is higher for heifers with lower body weight. In other words, the chance of a failure (i.e., the heifer reaches parturition), is lower for heifers with lower body weight. This result is in agreement with the hazard ratios.

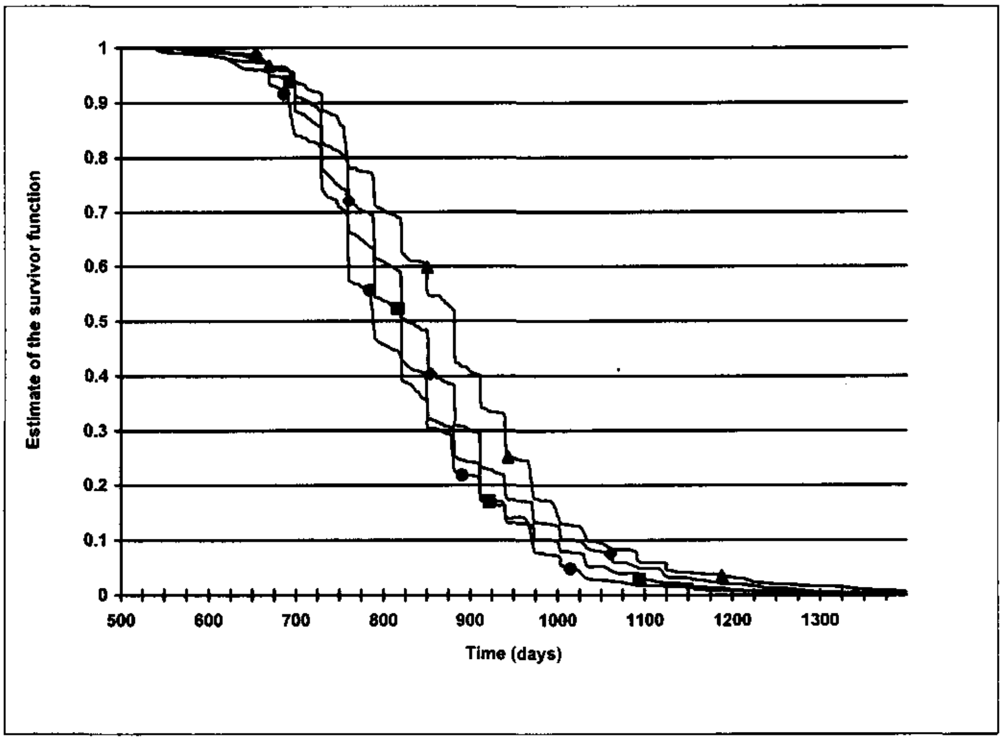


FIGURE 1. Kaplan-Meier estimates of the survivor function for trait age at first calving within heifer weight strata: C_WE1(●), C_WE2 (■), C_WE3 (▲), and C_WE4 (◆).

The irregular shape of the curves (Figure 1) is due to the tendency of censoring times to be grouped. As stated previously, censoring dates were defined on the basis of the last recorded event for the heifer. Further analysis of the data set showed that for a large proportion of the heifers, this corresponded to the measurement of the body weight, which was predicted by interpolation at 5-mo intervals, therefore, the stepwise pattern arises.

3.3.2 Days to First Breeding and Days Open

The unadjusted mean for days to first breeding and for days open was 76.5 and 109.8 d, respectively (Table 1). The number of records was low because heifers included in this analysis were required to have information on 390-d body weight and 100-d milk yield. The number of animals that did not have a first service was 45 for Holstein, 12 for Jersey and 12 for other breeds. According to the full model, factors with a significant effect on both continuous traits (Table 3) were herd-year, breed type, and heifer milk yield category. The effect of heifer weight was not significant. The effect of herd weight, assessed by fitting the reduced model, was significant. The effect of herd milk yield, also assessed by fitting the reduced model, was significant only for the variable days to first breeding. Two-way interaction effects were not significant.

Estimates of hazard ratios (Table 5) indicated that Jersey heifers and heifers in the third breed class were 1.64 and 1.73 times, respectively, more likely to have a first service than Holstein heifers. The ratios obtained for days open for the same breed types were 1.52 and 1.42, respectively. This result seems to indicate, as found with age at first calving, that Holstein heifers have a lower chance of getting pregnant and also a lower chance to be bred. The relatively low reproductive performance of European breeds in the tropics has also been documented in previous research (20).

According to the analysis of days to first breeding (Table 5), heifers from herds classified in H_WE1 had a lower chance of being bred. In contrast, results for days open indicate that heifers in H_WE3 were only 0.68 times as likely to become pregnant as heifers in H_WE2; thus, heifers from herds with higher body weight at 390 d have more chance of getting pregnant. This contradictory result could be explained by differences in breeding policies before and after first breeding. It seems necessary to confirm this result by characterizing breeding policies within herd categories, and this was not possible with the data set available.

TABLE 5.

Estimates of hazard ratios for classes within factors for the traits days to first breeding and days open.

		Days to first breeding				Days open			
Factor	Class	n[1]	β[2]	SED[3]	HR[4]	n	β	SED	HR
Breed	Holstein	1066	0.00	...	1.00	1007	0.00	...	1.00
	Jersey	581	0.49	0.11	1.64	562	0.42	0.11	1.52
	Others[5]	276	0.55	0.21	1.73	240	0.35	0.22	1.42
Herd weight	H_WE1	575	-0.42	0.21	0.66	525	-0.03	0.21	0.98
	H_WE2	1052	0.00	...	1.00	1004	0.00	...	1.00
	H_WE3	296	-0.10	0.27	0.91	280	-0.39	0.27	0.68
Heifer weight	C_WE1	990	0.07	0.08	1.07	943	0.10	0.08	1.11
	C_WE2	933	0.00	...	1.00	866	0.00	...	1.00
	C_WE3	243	-0.01	0.06	0.99	223	0.09	0.06	1.10
	C_WE4	759	-0.08	0.08	0.93	715	0.11	0.08	1.12
Herd milk yield	H_MY1	665	0.00	...	1.00	631	0.00	...	1.00
	H_MY2	256	0.27	0.37	1.31	240	0.15	0.39	1.15
Heifer milk yield	C_MY1	278	-0.13	0.08	0.88	259	-0.08	0.08	0.92
	C_MY2	717	0.00	...	1.00	678	0.00	...	1.00
	C_MY3	678	-0.09	0.06	0.92	638	-0.05	0.06	0.95
	C_MY4	250	-0.37	0.08	0.69	234	-0.25	0.08	0.78

[1] Uncensored failure.
[2] Regression parameter of the survivor function.
[3] Standard error of difference between β in this class and the largest class.
[4] Hazard ratios within factor are given relative to the hazard for the largest class, which is set to 1.0.
[5] Approximately 80% of the heifers included in this class were Brown Swiss crosses.

For heifer weight categories, the values of hazard ratios tended to be linear for days to first breeding, but not significantly (Table 5). The ratios indicate that heifers with a higher body weight at 390 d of age had a slightly higher chance of being bred after the first calving. For days open, the estimates did not follow the same linear trend and were not significant. These estimates seem to indicate that differences in body weight at 390 d do not have a large effect on reproductive performance after calving.

Estimates of hazard ratios for herd milk yield indicate that heifers in the low category were 1.31 times more likely to be bred than were heifers from herds in the high category. The respective value for days open decreased to 1.15 and was not significant (Table 3). Another study (12) showed a maximum range of 5% for heifers and 13% for heifers pertaining to herds classified in four categories of milk yield and a higher chance of conception for herds with lower milk yield. This result was similar to the estimates found in the present study and might indicate that herds with higher milk yield also have a higher incidence of reproductive problems and, therefore, longer days open.

Significant differences among heifer 100-d milk yield categories were detected (Table 3). The estimated hazard ratios (Table 5) show a nonlinear effect of milk yield on days to first breeding and days open. Heifers in the top three classes had a similar probability of being bred or becoming pregnant; the chance was much lower for heifers with the lowest milk yield (i.e., C_MY4). To confirm these results, the survivor function for days open was plotted for heifers stratified by milk yield categories (Figure 2). This plot shows that the survival curve for heifers in the fourth quartile (i.e., C_MY4) is consistently higher than survival curves for heifers in the third, second, and first quartiles, in the same order. It is important that the main differences are for heifers with the lowest milk yield, as found with the hazard ratios. The main differences appear only after 100 d from the calving date, which might reflect that these heifers were probably no longer being inseminated.

An earlier study (8) has shown that the effect of milk yield on conception rate is minimal. Another study (12) has found a lower conception rate for high yielding heifers, but not for cows. In theory, cows with a high milk yield are expected to have more days open because of the negative effect of milk yield on energy balance and reproductive performance. Our analysis does not fully support this effect because heifers in the highest milk yield category showed only a slightly lower chance to be bred and to become pregnant, and the difference among the survival curves for the three first categories are not clear. In contrast to some results of previous research (12), the chance of calving was the lowest for heifers with the lowest milk yield, which could be the result of an unidentified management practice, rather than a result of genetic factors. The effects of management strategies on days open have been previously documented (9, 23). Farmers likely do not show the same interest in breeding low yielding heifers.

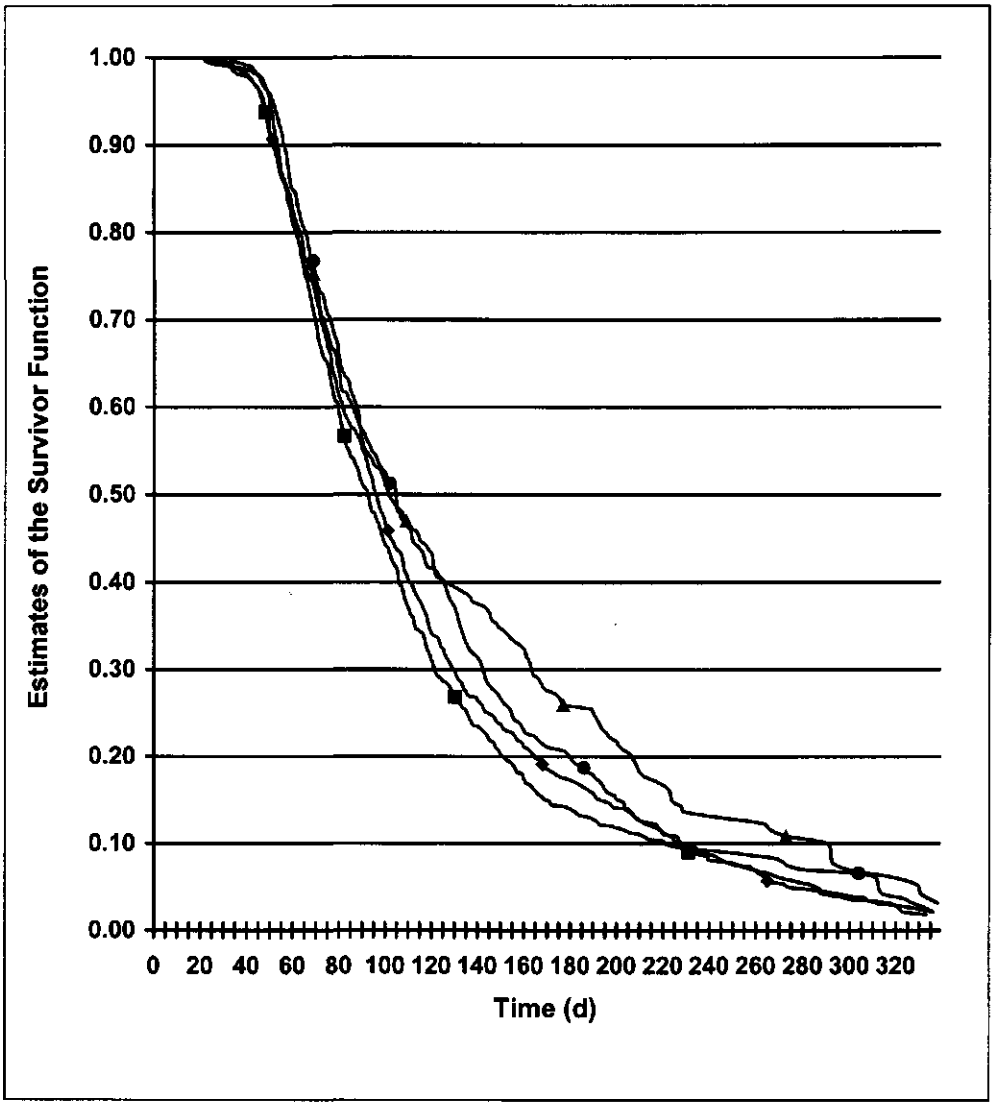


FIGURE 2. Kaplan-Meier estimates of the survivor function for trait days open within heifer milk yield strata: C_MY1 (■), C_MY2 (◆), C_MY3 (●), and C_MY4 (▲).

3.4 CONCLUSIONS

Herd differences in body weight appear to have a significant effect on age at first calving. There is also a significant effect of body weight of individual heifers at 390 d on age at first calving. An increment in body weight increases the probability that a heifer will reach a first calving. Body weight at 390 d seems not to have a large impact on days to first breeding or days open.

Heifers from herds with higher average body weight at 390 d appeared to have a lower probability of being bred after calving, but the contrary was demonstrated for days open. Further analysis is needed to identify management practices before and after breeding that could cause this effect. Body weight of heifers at 390 d appeared not to have an important effect on reproductive performance after first calving. Heifer milk yield seemed to have a nonlinear effect on days open. Heifers with higher milk yield had a slightly lower chance of being bred; however, management practices seem to be more important for the situation analyzed here because the heifers with the lowest yield had the lowest chance of being bred and getting pregnant. Days open and days to first breeding in Costa Rica are closer to the goals than in most U.S. dairies. Management practices and production level might explain this phenomena. The differences in reproduction and performance levels are expected to have a small effect on the results of this study.

ACKNOWLEDGMENTS

The authors thank the farmers and staff at UNA for collecting the data and the financial support from Stichting Samenwerkings Verband IO-instellingen en Landbouwuniversiteit Wagenigen (SAIL), Delft, The Netherlands.

REFERENCES

1 Beaudeau, F., V. Ducrocq, C. Fourichon, and H. Seegers. 1995. Effect of disease on length of productive life of French Holstein dairy cows assessed by survival analysis. J. Dairy Sci. 78:103-117.

2 Bettenay, R.A. 1985. Effect of growth rate and mating age of dairy heifers on subsequent production over four years. Aust. J. Exp. Agric. 25:263-269.

3 Boichard, D. 1990. Estimation of the economic value of conception rate in dairy cattle. Livest. Prod. Sci. 24:187-204.

4 Cox, D. R. 1972. Regression models and life tables. J. R. Stat. Soc. Ser. B 34:187-220.

5 Darwash, A. O., G. E. Lamming, and J. A. Woolliams. 1997. Estimation of genetic variation in the interval from calving to postpartum ovulation of dairy cows. J. Dairy Sci. 80:1227-1234.

6 Ducrocq, V., and J. Solkner. 1994. "The Survival Kit"—a Fortran package for the analysis of survival data. Proc. 5th World Congr. Genet. Appl. Livest. Prod., Guelph, ON XXII:51-52.

7 Dwinger, R. H., E. Cappella, E. Pérez, M. Baaijen, and E. Muller. 1994. Application of a computerized herd management and production control program in Costa Rica. Trop. Agric. (Trinidad) 71:74-76.

8 Eicker, S. W., Y. T. Grohn, and J. A. Hertl. 1996. The association between cumulative milk yields, days open, and days to first breeding in New York Holstein cows. J. Dairy Sci. 79:235-241.

9 Grass, J. A., P. J. Hansen, J. J. Rutledge, and E. R. Hauser. 1982. Genotype x environmental interactions on reproductive traits of bovine females. I.Age at puberty as influenced by breed, breed of sire, dietary regimen and season. J. Anim. Sci. 55:1441-1457.

10 Grohn, Y.T., V. Ducrocq, and J. A. Hertl. 1997. Modeling the effect of a disease on culling: an ilustration of the use of time-dependent covariates for survival analysis. J. Dairy Sci. 80:1755-1766.

11 Harman, J. L., G. Casella, and Y. T. Grohn. 1996. The application of event-time regression techniques to the study of dairy cow interval-to-conception. Prev. Vet. Med. 26:263-274.

12 Harman, J. L., Y. T. Grohn, H. N. Erb, and G. Casella. 1996. Event-time analysis of the effect of 60-days milk production on the parturition-to-conception interval in dairy cows. Am. J. Vet. Res. 57:634-639.

13 Harman, J. L., Y. T. Grohn, H. N. Erb, and G. Casella. 1996. Event-time analysis of the effect of season of parturition, parity, and concurrent disease on parturition-to-conception interval in dairy cows. Am. J. Vet. Res. 57:640-645.

14 Jalvingh, A. W., J.A.M. van Arendonk, and A. A. Dijkhuizen. 1993. Dynamic probabilistic simulation of dairy herd management practices. I. Model description and outcome of different seasonal calving patterns. Livest. Prod. Sci. 37: 1-2, 107-131.

15 Lee, L. A., J. D. Ferguson, and D. T. Galligan. 1989. Effect of disease on days open assessed by survival analysis. J. Dairy Sci. 72:1020-1026.

16 Lin, C. Y., A. J. McAllister, T. R. Batra, and A. J. Lee. 1986. Production and reproduction of early and late bred dairy heifers. J. Dairy Sci. 69:760-768.

17 Moore, R. K., B. W. Kennedy, L. R. Schaeffer, and J. E. Moxley. 1990. Relationships between reproduction traits, age and body weight at calving, and days dry in first lactation Ayrshires and Holsteins. J. Dairy Sci. 73:835-842.

18 Mourits, M.C.M., Dijkhuizen, A.A, Huirne, R. B. M. and Galligan, D. T. 1997. Technical and economical models to support heifer management decisions: basic concepts. J. Dairy Sci. 80:1406-1415.

19 Noordhuizen, J.P.T.M, and J. Buurman. 1984. Veterinary automated management and production control program for dairy farms (VAMPP). The application of MUMPS for data processing. Vet. Q. 6:62-77.

20 Pearson de Vaccaro, L. 1990. Survival of europeans dairy breeds and their crosses with zebus in the tropics. Anim. Breed. Abstr. 58:475-494.

21 Peri, I., A. Gertler, I. Bruckental, and H. Barash. 1993. The effect of manipulation in energy allowance during the rearing period of heifers on hormone concentrations and milk production in first lactation cows. J. Dairy Sci. 76:742-751.

22 SAS® User's Guide: Statistics, Version 6.0 Edition 1990. SAS Inst., Inc., Cary, NC.

23 Van Arendonk, J.A.M., and A. A. Dijkhuizen. 1985. Studies of the replacement policies in dairy cattle. III Influence of variation in reproduction and production. Livest. Prod. Sci. 13 (4):333-349.

24 Van der Grinten, P., M.T. Baaijen, L. Villalobos, R.H. Dwinger, and L. 't. Mannetje. 1993. Utilization of kikuyu grass (*pennisetum clandestinum*) pastures and dairy production in a high altitude region of Costa Rica. Trop. Grassl. 26:255-262.

25 Vargas, B., E. Pérez, and J.A.M. van Arendonk. 1998. Analysis of test day yield data of Costa Rican dairy cattle. J. Dairy Sci. 81:255-263.

26 Vargas, B., and C. Solano. 1995. Cálculo de factores de corrección para producción diaria de leche en ganado lechero de Costa Rica. Arch. Latinoam. Prod. Anim. 3:131-148.

27 Vargas, B., and C. Solano. 1995. Tendencias genéticas y ambientales en producción de leche en ganado lechero de Costa Rica. Arch. Latinoam. Prod. Anim. 3:165-176.

Chapter 4

Modeling extended lactations of dairy cows

B. Vargas,[*] W. J. Koops,[‡] M. Herrero,[§,||] and J.A.M. Van Arendonk

[*]Escuela de Medicina Veterinaria, Universidad Nacional de Costa Rica,
PO Box 304-3000, Heredia, Costa Rica

Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences,
Wageningen Agricultural University,
PO Box 338, 6700 AH Wageningen, The Netherlands

[‡]Animal Production Systems Group, Wageningen Institute of Animal Sciences,
Wageningen Agricultural University,
PO Box 338, 6700 AH Wageningen, The Netherlands

[§]Institute of Ecology and Resource Management, The University of Edinburgh,
West Mains Road, Edinburgh EH9 3JG, United Kingdom

[||]International Livestock Research Institute,
PO Box 30709, Nairobi, Kenya.

Published in Journal of Dairy Science 83:1371-1380

ABSTRACT

Nine mathematical models were compared for their ability to predict daily milk yields (n=294,986) in standard 305-d and extended lactations of dairy cows of Costa Rica. Lactations were classified by parity (first and later), lactation length (9 to 10, 11 to 12, 13 to 14, 15 to 16, and 16 to 17 mo) and calving to conception interval (1 to 2, 3 to 4, 5 to 6, 7 to 8, and 9 to 10 mo). Of the nine models, the diphasic model and lactation persistency model resulted in the best goodness of fit as measured by adjusted coefficient of determination, residual standard deviation, and Durbin-Watson coefficient. All other models showed less accuracy and positively correlated residuals. In extended lactations, models were also fitted using only test-day records before 305 d, which resulted in a different ranking. The diphasic model showed the best prediction of milk yield in standard and extended lactations. We concluded that the diphasic model provided accurate estimates of milk yield for standard and extended lactations. Interpretation of parameters deserves further attention because of the large variation observed. As expected, calving to conception interval was found to have a negative effect on milk yield for cows with a standard lactation length. In extended lactations, these negative effects of pregnancy on milk yield were not observed.

(**Key words**: extended lactations, lactation curves, dairy cattle, milk yield).

Abbreviation key: **DW**= Durbin Watson, **RSD**= residual standard deviation, **RSS**= residual sum of squares, **LPM**= lactation persistency model, **MAD**= mean absolute deviation, **RLPM**= reduced lactation persistency model, **CC**= calving to conception, **UNA**= Universidad Nacional de Costa Rica.

4.1 INTRODUCTION

Modeling of lactation curves has been a subject of extensive study during the past decade (2, 9, 10, 12, 16, 19, 26, 27). Different models have been evaluated for their ability to describe the pattern of milk yield as well as the ability to predict 305-d cumulative milk yield from partial records of lactation. Attention has been focused on the 305-d lactation period, which implies that information collected after 305 d is usually ignored and that no attention is paid to milk yield in the period after 305-d in extended lactations. In most countries, many cows have lactations that are longer than 305 d. For example, in dairy herds of Costa Rica, more than 25% of cows are dried-off after 330 d of lactation, the average lactation length being about 328 d. Longer lactations partly result from failures to conceive at an early stage of lactation. Costs of prolonged calving interval greatly depend on milk yield in the latter part of lactation (6). This production depends on increase in lactation length and shape of lactation curve. Knowledge of lactation curves over the entire trajectory is a key element in determining optimum strategies for insemination and replacement of dairy cows (4, 5, 8, 21). An earlier study (9) has shown that lactation length has a significant effect on estimates of initial yield, peak yield, 305-d yield, time of peak and persistency. However, this analysis considered only lactation lengths less than 360 d.

Models to describe lactation have been classified into two main groups, i.e., as linear and nonlinear models (11). In linear models, parameters are linear functions of days in lactation or are a transformation of it and can be easily computed by simple linear regression techniques. Nonlinear models cannot be expressed as linear functions of parameters and, therefore, need iterative techniques to be solved (11). These models have become more popular during recent years (2, 12, 16, 19, 26, 27), especially because they are able to describe a relatively wide range of shapes in lactation curves. Iterative procedures for fitting nonlinear regression implemented in statistical software have overcome the problem of model fitting. Many existing models show systematic deviations from actual milk yield, especially at the beginning and end of lactation (9). Multiphasic models have been suggested as an option to overcome these problems (9). These models were previously implemented with success to describe growth curves in mice and chickens, and more recently, to describe standard lactations in dairy cows (3, 20). Multiphasic model considers daily milk yield as the result of an accumulation from more than one phase of lactation, intrinsically reducing correlation between subsequent residuals.

The objective of this study was to compare existing models for their ability to provide consistent predictors of partial and total milk yield in normal and extended lactations and to subsequently analyze the effect of lactation length and calving to conception (CC) interval on the lactation curve.

4.2 MATERIALS AND METHODS

4.2.1 Data Source

The analysis was performed on data provided by Universidad Nacional de Costa Rica (UNA) collected from 1987 to 1994 on dairy farms in Costa Rica. Farms participated in a project that focused on collection and analysis of data on health, milk yield, and reproduction performance to provide management support to farmers and to identify adequate management practices (7). Reproductive events, daily milk yield, and herd characteristics were entered into an improved version of VAMPP software package (14) by staff of UNA or directly by farmers.

The initial dataset consisted of 57,359 lactations of 26,072 cows. A subset of lactations was selected (Table 1), which included only Holstein cows with dates registered for conception and drying-off. Furthermore, each cow was required to have at least one test-day record in each of the following four periods: 1 to 60, 61 to 150, 151 to 240, and after 240 d in lactation. All test-day records between d 305 and the actual end of lactation were included in the analysis.

Our main interest was to find a model that provided a good description of the lactation curve for groups of cows with a range of lactation lengths and CC intervals. The results will be used in a bio-economic model to determine optimum insemination strategies. Given this objective, models were fitted to group mean yields rather than to individual lactations. Lactations were classified in two groups according to parity (first and later), five groups according to lactation length (9 to 10, 11 to 12, 13 to 14, 15 to 16 and 17 to 18 mo), and five groups according to CC interval during current lactation (1 to 2, 3 to 4, 5 to 6, 7 to 8, and 9 to 10 mo). Out of 50 possible groups ($2 \times 5 \times 5$), only those with more than 1000 test-day records were chosen for further analysis, which resulted in a total of 26 groups (Table 2).

TABLE 1.

General description of the dataset.

Parameter	Value
Herds	129
Cows	7,608
Lactations	13,752
First lactations	3573
Test day records	294,986
Records/lactation	21.5±12.9
Daily milk yield (kg)	19.6± 8.6
Lactation length (d)	328± 61.4

The number of test-day records per group was highly variable because some combinations of lactation length and CC interval were less likely to occur. Test-day records within groups were classified in 2-wk periods, and for each 2-wk period, average DIM and milk yields were obtained and used in model fitting.

TABLE 2.
Means, SD, and extreme values (Min. and Max.) for milk yield by parity, lactation length and Calving to Conception interval (CC).

Lactation length (mo)[1]	CC (mo)[2]	Milk yield (kg/d) $\bar{x}$	n	SD	min	max
		First parity				
10	2	17.5	9706	3.9	8.0	21.8
10	4	18.2	17,502	3.4	9.8	22.1
10	6	13.6	1035	2.8	6.4	17.4
12	4	17.4	16,297	4.1	7.6	22.2
12	6	17.2	9129	3.5	8.7	21.7
12	8	13.7	1444	3.9	4.6	18.6
14	6	17.1	6973	3.7	8.9	21.9
14	8	14.6	4492	3.3	7.4	19.2
14	10	12.7	1834	3.4	6.4	17.6
16	8	16.6	2803	4.2	7.0	22.3
16	10	16.2	4136	3.8	7.7	21.8
18	10	15.6	5013	3.2	9.5	20.4
		Later parities				
10	2	19.6	21,983	6.1	7.5	27.1
10	4	20.5	53,723	5.8	8.9	27.6
10	6	16.8	5363	5.7	5.8	24.2
10	8	14.9	1401	5.1	5.6	21.9
12	4	20.2	39,565	6.7	8.1	29.0
12	6	19.7	29,624	6.2	8.1	28.1
12	8	17.1	4972	6.0	5.9	26.0
12	10	15.4	1929	5.7	6.5	24.0
14	6	19.3	13,912	6.4	7.3	28.3
14	8	19.0	15,348	6.4	8.3	28.8
14	10	15.7	5143	5.6	6.4	24.5
16	8	19.1	5123	6.0	9.0	28.3
16	10	17.6	8057	6.0	7.9	27.1
18	10	17.7	8479	6.2	8.8	28.0

[1] Lactation length classes: 10= 9 and 10 mo, 12= 11 and 12 mo, 14= 13 and 14 mo, 16=15 and 16 mo, and 18= 17 and 18 mo.
[2] Calving to conception interval classes: 2= 1 and 2 mo, 4= 3 and 4 mo, 6= 5 and 6 mo, 8= 7 and 8 mo, and 10= 9 and 10 mo.

4.2.2 Model Fitting

Nine different models from the literature were analyzed (Table 3). The Wood model (27) is a gamma function, in which *a* approximates the initial milk yield after calving, *b* is the inclining slope parameter up to peak yield, and *c* is the declining slope parameter. The Cobby model (2) has the particularity that milk yield after peak is modeled as a linear decline function. The Rook model (16) describes lactation as a combination of a monotonically increasing growth function, in this case Mistcherlich function, and a monotonically decreasing death function, which in this case is exponential. The Morant model (12) assumes that the change in milk yield after peak is not constant as implied in the exponential decline function (e^{-kt}). The Wilmink model (26) is a modification of Cobby, and –0.05 is related to the moment of peak, which is about 50 d.

Models based on the logistic function, such as the monophasic (9) and diphasic (9), were introduced to overcome the problem of autocorrelation detected in models based on the gamma function. These models provided smaller and more random residuals (9). The lactation persistency model (**LPM**) (10) is also based on a logistic function and was developed in order to provide additional parameters to measure persistency, which is defined as number of days during which peak production is maintained. The reduced LPM model (**RLPM**) (10) is based on LPM model, but the number of parameters is reduced from 6 to 4.

Models were fitted to group mean yields by using a Gauss-Newton iterative method from the SAS Nonlinear procedure (18). Convergence was determined based on change (c) in residual sums of squares (**RSS**) between iteration *i* and iteration (i-1), according to:

$$(RSS_{i-1} - RSS_i)/(RSS_i + 10^{-6}) = c \qquad [1]$$

if $c < 10^{-8}$, converging criterion is met, and iteration process stops.

Goodness of fit of models was evaluated according to following criteria:

1. Adjusted multiple coefficient of determination [R^2_{adj}; (13)]:

$$R^2_{adj} = 1 - (n-1)/(n-p) \times (1 - R^2) \qquad [2]$$

where, R^2 = multiple coefficient of determination (=1-(RSS/TSS)), RSS= residual sum of squares, TSS= total sum of squares, n= number of observations, and p= number of parameters in the model.

Note that R^2 is adjusted for the number of parameters in the model (p) to make a fair comparison of models. For simplicity, R^2_{adj} will be regarded only as R^2.

TABLE 3.

Description of models under analysis.

Name	Source	Equation
Wood	Wood (27)	$a \times t^{b} \times e^{-c \times t}$
Cobby	Cobby & LeDu (2)	$a - t \times b - a \times e^{(-c \times t)}$
Wilmink	Wilmink (26)	$a + t \times b + c \times e^{t \times -0.05}$
Morant	Morant and Gnanasakthy (12)	$a \times e^{(b1 \times t'2/2 + b2/t - c \times (1+t'/2) \times t')}$, with $t' = (t-21.4)/100$
Rook	Rook et al. (16)	$a \times (1- b_1 \times e^{-b2 \times t}) \times e^{-c \times t}$
Monophasic	Grossman and Koops (9)	$a \times b\,(1- \tanh^2(b \times (t-c))$
Diphasic	Grossman and Koops (9)	$a_1 \times b\,(1- \tanh^2(b_1 \times (t-c_1)) + a_2 \times b_2 \times (1- \tan^2(b_2 \times (t-c_2))$
LPM[1]	Grossman et al. (10)	$yp + b_1 \times (t-t_1) + r_1 \times (b_2-b_1) \times \ln((e^{t/r1} + e^{t1/r1})/(1+e^{t1/r1}))$ $+ r_2 \times (b_3-b_2) \times \ln((e^{t/r2} + e^{(t1+P)/r2)}/(1+e^{(t1+P)/r2})) + r_3 \times (b_4-b_3) \times \ln((e^{(t/r3)} + e^{(t3/r3)})/(1+e^{(t3/r3)}))$
RLPM[2]	Grossman et al. (10)	$yp/t_1 \times t\text{-}yp/t_1 \times \ln(\,(e^{t}+e^{t1})/(1+e^{t1} + b_3 \times \ln((e^{t}+e^{t1+P})/(1+e^{t1+P}))$

[1] Lactation persistency model –extended.
[2] Reduced lactation persistency model.

2. First-order positive autocorrelation among residuals was assessed by Durbin Watson coefficient [**DW**; (13)]:

$$\mathrm{DW} = \frac{\sum_{t=2}^{n}(e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^{\ 2}} \qquad [3]$$

where e_t = residual at time t, and e_{t-1} = residual at time t−1. The observed value of DW was evaluated against the tabulated critical value to test for positive autocorrelation. Negative autocorrelation was not tested because a negative autocorrelation coefficient implies that residuals fluctuate in a strict "up and down" way around the actual curve, which in the particular case of lactation curves was not a problem.

3. Residual standard deviation [**RSD**;(13)] was obtained by:

$$RSD = \sqrt{RSS/(n-p)} \qquad [4]$$

For RSS, n and p, see Equation [2].

Models were categorized based on estimates of three criteria: RSD, adjusted R^2, and DW. Four categories were formed, two for models deviating less than one ('+' and '-') SD from the mean of one criterion and two for models deviating more than one SD ('++' and '--') where SD represents standard deviation across groups for each of three criteria within model.

Mean absolute deviation (**MAD**) across groups for partial and total milk yield was compared among models. The absolute difference between actual and predicted milk yield during the specified periods was calculated, and averaging these values over all groups resulted in MAD. Partial yields were calculated for periods 1 to 100 d, 101 to 200 d, 201 to 305 d, and 306 d to end of lactation. Lactation length was set to 305 d (10 mo), 365 d (12 mo), 425 d (14 mo), 486 d (16 mo), and 547 d (18 mo).

Actual daily milk yields within groups were calculated by smoothing actual milk yields with cubic splines (25) to interpolate actual records in different intervals within lactation. A maximum of 10 splines-knots, according to lactation length, were set at d 50, 100, 150, 200, 250, 305, 365, 425, 486, and 547. This procedure implied that a different cubic spline was fitted for every interval defined by the knots. Splines were required to have continuous first and second derivatives and discontinuous third derivatives.

Partial and total actual milk yields within lactation were further estimated by

$$MY_{i\text{-}n} = \sum_{t=1}^{n} y(t) \qquad [5]$$

where $MY_{i\text{-}n}$ = milk yield, i = initial day within time period (1 or 101 or 201 or 306), n = final day within time period (100, 200, or 305) or end of lactation (365, 425, 486, or 547), and y(t) = yield at day t estimated by a spline function (piecewise cubic polynomial with 6 to 10 knots).

Predicted milk yields within group were also obtained for every model using Equation [5] with substitution of y(t) by the corresponding model equation (Table 3).

The model with best overall performance according to previous criteria was selected, and residuals were plotted for all groups. Additional measures of functions of parameters were obtained to evaluate effect of lactation length, CC interval, and parity on parameters of the model and estimates of milk yield.

4.3 RESULTS AND DISCUSSION

4.3.1 Comparison of Models

All models, except that of Rook et al. (16), achieved convergence for every lactation group. The Rook model failed to achieve convergence in 3 of the 26 groups. Problems with convergence for this model have also been mentioned previously (15). Values of R^2, RSD, and DW coefficient for each model were averaged over the 26 groups (Table 4). Goodness of fit was high in general, R^2 ranged between 0.957 and 0.987, and RSD ranged from 0.42 to 0.87 kg/d. This high level of accuracy has also been reported in previous studies fitting models on mean yields (1, 17). For all but two values for DW were less than 1, which indicated positive autocorrelation of residuals for the majority of models.

The greatest R^2 values were found for the diphasic model and LPM, whereas the Wood model ranked lowest (Table 4). Similar ranking was found for RSD. In this case, LPM had, on average, a lower value of RSD than diphasic; however, RSD values obtained for the latter showed a lower standard deviation (0.13 vs. 0.26), which reflects a better performance across groups.

TABLE 4.

Comparison of models according to adjusted multiple correlation coefficient (R^2), residual standard deviation (RSD), and Durbin-Watson coefficient (DW) (mean+ SD between groups).

Model	R^2	Rank	RSD	Rank	DW	Rank	n DW >0[1]
Wood	0.957±0.03	--	0.87±0.22	--	0.56±0.27	--	23
Cobby	0.961±0.04	-	0.78±0.28	-	0.90±0.48	-	15
Wilmink	0.968±0.03	-	0.70±0.22	-	0.81±0.46	-	17
Morant	0.973±0.02	+	0.66±0.17	+	0.86±0.42	-	16
Rook	0.961±0.03	-	0.83±0.19	-	0.74±0.27	-	17
Monophasic	0.965±0.02	-	0.80±0.16	-	0.91±0.29	-	16
Diphasic	0.987±0.01	++	0.48±0.13	++	1.74±0.44	++	1
LPM[2]	0.985±0.03	++	0.42±0.26	++	1.79±0.60	++	2
RLPM[3]	0.969±0.03	-	0.69±0.22	+	0.85±0.48	-	15
Average	0.969±0.01		0.69±0.15		1.02±0.44		

[1] Number of runs (n) out of 26 with significant positive autocorrelation.
[2] Lactation persistency model– extended.
[3] Reduced lactation persistency model.

Positive autocorrelation between residuals was detected in all models except diphasic and LPM. Other models presented problems of positive autocorrelation among residuals for more than half of the groups (Table 4). Problems with positive autocorrelation have already been reported for the Wood and Monophasic models (9). Absence of autocorrelation for the diphasic model is in agreement with Grossman and Koops (9) for standard 305-d lactations.

Additional analysis was performed to check parameter estimates for stability across groups. Results indicated that LPM, even though with a high general goodness of fit, often resulted in atypical parameters, e.g., negative values for parameter P (persistency). All other models seemed to provide more reasonable estimates of parameters, even though they also presented a wide variation.

Table 5 shows MAD for different periods and models. Models with low MAD were ranked at the top (++). Predictive performance for most of models was highly variable for different periods within lactation. Models with a consistently good performance over all periods were diphasic and LPM, which is in agreement with earlier results on standard 305-d lactations (20). The LPM was more accurate than diphasic for 1 to 100 d and 201 to 305 d, whereas diphasic was more accurate for 101 to 200 d and 306 to the end of lactation. All other models performed irregularly, ranking poorly for one or more stages within lactation, which reinforces the fact that exponential models usually fail to model peak of lactation (9, 20). It is important to notice that differences in accuracy of prediction between LPM and diphasic compared with other models is especially large for last period of lactation (305 d to end). For this period, only diphasic, LPM, and Morant models rank positively. This finding reflects that multiphasic models are intrinsically more suitable to describe extended lactations.

Further analysis showed that standard deviations of MAD across groups were, in general, higher for LPM compared with the diphasic model (Table 5). This result might also be related to the lack of stability observed for estimates of parameters using LPM model and might indicate a serious drawback of LPM compared with the diphasic model.

Analysis of predicted milk yield using diphasic curves showed some systematic deviations with respect to actual milk yield. For 1 to100 d all models, except diphasic and that of Wilmink, underestimated milk yield; for 101 to 200 d all models, except the Cobby and diphasic, overestimated milk yield. For 201 to 305 d all models, except diphasic and LPM underestimated milk yield for the final period (306 d to end) all models, except diphasic and LPM overestimated milk yield.

In extended lactations, an additional comparison of models was also performed, eliminating all test-day records after 305 d. Models were fitted again to group mean yields. As expected, R^2 were higher and RSD lower, in general, because of reduction in length of lactations. One important result was that the frequency of cases in which a positive autocorrelation was detected was reduced considerably (29 vs. 122). By considering only 305-d lactations the ranking of models based on MAD changed (results not shown). For 101 to 200 d and 201 to 305 d, diphasic and LPM were still better than the others, but relative differences were reduced substantially. For 1 to 100 d, the top 5 models were Rook (31.1), LPM (34.5), Wilmink (34.6), diphasic (36.3), and Wood (41.6), all of them scored as +. The results of our model comparison, based on standard 305-d lactations, are very similar to earlier findings (20).

TABLE 5.

Comparison of models according to mean absolute deviation (MAD)[1] in different parts of the lactation.[2]

	1 to 100 d		101 to 200 d		201 to 305 d		306 to end of lactation	
Model	MAD	Rank	MAD (kg)	Rank	MAD (kg)	Rank	MAD (kg)	Rank
Wood	45.8±14.9	+	42.7±15.0	-	80.7±41.0	--	115.9±56.8	--
Cobby	100.0±18.9	--	33.6±18.7	+	66.8±43.2	-	93.3±59.0	-
Wilmink	38.2±21.1	+	33.9±12.8	+	63.4±39.9	-	88.0±57.9	-
Morant	58.2±12.3	+	38.1±16.1	-	53.3±31.8	+	84.1±47.2	-
Rook	61.0±19.2	+	42.8±15.9	-	68.1±36.5	-	101.0±54.7	-
Monophasic	85.5±26.8	-	43.9±14.9	--	54.3±31.8	+	82.1±47.2	+
Diphasic	46.1±27.5	+	17.7±8.2	++	26.8±17.0	++	43.2±28.2	++
LPM[3]	36.1±30.5	++	18.3±21.8	++	22.6±16.5	++	50.4±59.4	++
RLPM[4]	118.5±21.6	--	36.7±19.0	-	60.1±36.7	-	86.0±56.2	-
Average MAD	65.5±29.2		34.2±9.9		55.1±19.1		82.7±22.9	

[1] MAD is calculated as the sum of daily absolute deviations (predicted – actual milk yield) for the period specified.
[2] Ranks are given according to relative performance by standardizing the criteria according to average MAD across groups.
[3] Lactation persistency model– extended.
[4] Reduced lactation persistency model.

From our analysis, it is clear that models that are suitable to describe standard 305-d lactations are not necessarily adequate to describe extended lactations.

In summary, the diphasic model was found to best describe normal and extended lactations, showing a high R^2, low RSD, uncorrelated errors according to DW test, more regular estimates of parameters for almost every group, and a similar performance along the whole lactation period. More detailed information on this model is given in next section.

4.3.2 Final Model

Estimates of residuals using the diphasic model were plotted for all groups of lactation length and CC interval within first parity (Figure 1). In general, residuals were randomly distributed. Residuals ranged between −1.5 and 1.5 kg/d. Significant positive autocorrelation was detected only for higher parity cows with a lactation length of 18 mo (Table 6). For this group, the model had problems in fitting the two phases, which resulted in inconsistent parameter estimates. A similar problem was found among first lactation cows with long lactations.

Estimated parameters for the diphasic model are given in Table 6. Values still showed a wide range of variation, which suggests that the shape of the curve greatly depends on lactation length, parity, and CC interval. Grossman and Koops (9) introduced the parameter duration of each phase, defined as days required to attain about 75% of asymptotic total yield during that phase and computed as $2b_i^{-1}$. For 305-d lactations of Dutch Black and White cows, they found duration of 198 and 415 d for the first and second phases, respectively. This finding agrees closely with our findings for cows with a lactation length of 12 mo. Duration of the second phase increased with lactation length, and to a much lesser extent, with CC interval. Duration of the first phase showed a different pattern in first and second lactation cows.

Based on criteria to measure goodness of fit, it can be concluded that the applied multiphasic concept for describing lactation also works well with extended lactations. However, parameters of the model still fluctuate too much with lactation length and, to a lesser extent, with CC interval. This fluctuation seriously limits application of the model and might be partly due to the choice of the logistic function, which is symmetric.

TABLE 6. Goodness of fit, estimated parameters, and cumulative milk yield predicted with diphasic model for cows with different lactation length (LL), calving to conception interval (CC), and parity.[1]

Group		Goodness of fit			Estimated parameters[2]								Predicted milk yield[3]		
					First phase				Second phase				<100	<305	>306
LL (mo)	CC (mo)	R^2	RSD	DW	a_1	b_1	c_1	DUR_1	a_2	b_2	c_2	DUR_2	(%)	(%)	(kg)
10	2	0.981	0.53	2.36	2091.5	0.0093	46.0	216	1453.8	0.0092	210.3	217	2085	5310	...
10	4	0.981	0.47	1.54	2398.5	0.0083	45.2	241	1492.8	0.0088	225.0	226	2	4	...
10	6	0.953	0.60	2.20	3011.8	0.0054	30.6	372	564.0	0.0107	230.6	187	-22	-22	...
12	4	0.988	0.45	1.89	2420.3	0.0079	43.2	254	1916.3	0.0072	242.7	278	2	8	592
12	6	0.977	0.53	1.36	1086.1	0.0114	33.9	175	3333.5	0.0050	203.7	399	-1	6	670
12	8	0.972	0.65	1.77	2301.9	0.0075	50.6	268	1122.7	0.0083	256.0	241	-15	-14	431
14	6	0.980	0.53	1.17	1799.7	0.0087	36.4	229	3035.7	0.0053	249.1	380	1	9	1369
14	8	0.990	0.33	1.94	1479.0	0.0086	25.9	233	2970.1	0.0045	244.1	443	-12	-7	1222
14	10	0.989	0.35	2.08	2777.0	0.0056	29.7	359	1468.1	0.0055	298.9	361	-19	-17	1014
16	8	0.972	0.71	1.75	3790.6	0.0051	39.3	394	2183.7	0.0055	325.7	363	1	11	2188
16	10	0.985	0.47	1.59	3628.2	0.0053	37.9	376	2203.0	0.0055	340.5	364	-1	6	2219
18	10	0.980	0.44	1.36	-4435.6	0.0045	194.4	441	12,117.8	0.0031	167.0	643	-7	3	3096
10	2	0.996	0.37	2.14	2130.8	0.0104	27.9	193	1931.2	0.0082	180.1	243	2575	5940	...
10	4	0.996	0.39	2.15	2086.9	0.0105	29.8	191	2180.5	0.0076	184.8	263	2	4	...
10	6	0.991	0.52	1.96	2077.0	0.0096	25.6	209	1579.9	0.0077	182.8	260	-11	-14	...
10	8	0.994	0.41	2.22	3709.1	0.0056	1.9	359	654.6	0.0077	206.5	261	-21	-24	...
12	4	0.997	0.35	1.48	1296.5	0.0124	26.3	161	3694.1	0.0056	163.6	360	7	14	559
12	6	0.996	0.37	1.32	1466.0	0.0112	25.8	179	3621.1	0.0051	173.1	391	4	10	602
12	8	0.993	0.50	1.27	888.6	0.0136	29.5	148	3726.5	0.0046	140.0	437	-6	-4	504
12	10	0.992	0.51	1.90	64.0	0.0501	38.5	40	5287.8	0.0040	48.3	504	-15	-13	426
14	6	0.996	0.43	1.53	2281.4	0.0089	28.2	224	3220.8	0.0052	219.7	382	5	14	1223
14	8	0.995	0.43	1.17	876.3	0.0132	34.4	152	5152.0	0.0039	152.6	510	5	14	1304
14	10	0.995	0.38	2.74	1183.5	0.0100	26.1	200	3981.1	0.0038	163.6	532	-11	-6	1072
16	8	0.993	0.52	1.48	617.2	0.0128	31.6	156	7147.6	0.0030	127.2	665	5	17	2168
16	10	0.995	0.41	2.08	691.7	0.0123	38.2	163	6495.7	0.0030	133.9	666	0	10	2023
18	10	0.979	0.89	0.87	$-\infty$	8698.4	$-\infty$	0	16,259.7	0.0018	-135.8	1092	3	16	2928

[1] RSD = residual standard deviation; DW= Durbin-Watson.

[2] a_i, b_i, c_i: parameters for phase i (i=1,2) of the diphasic model $\sum(a_i b_i - \tanh^2(b_i(t-c_i)))$; DUR_i: duration (d) of phase i ($2b_i^{-1}$) (9).

[3] Change in cumulative milk yield of a group given as % of milk yield in the first group within parity. Absolute milk yield (kg) is given for first group (LL=10, CC=2).

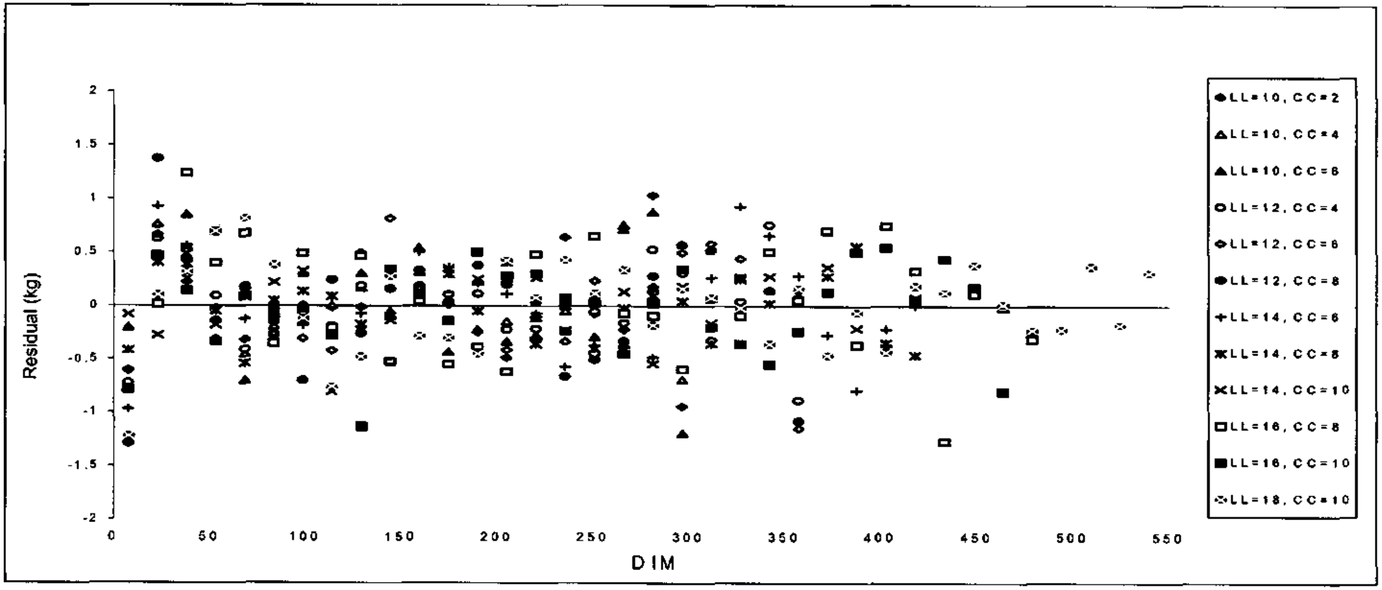
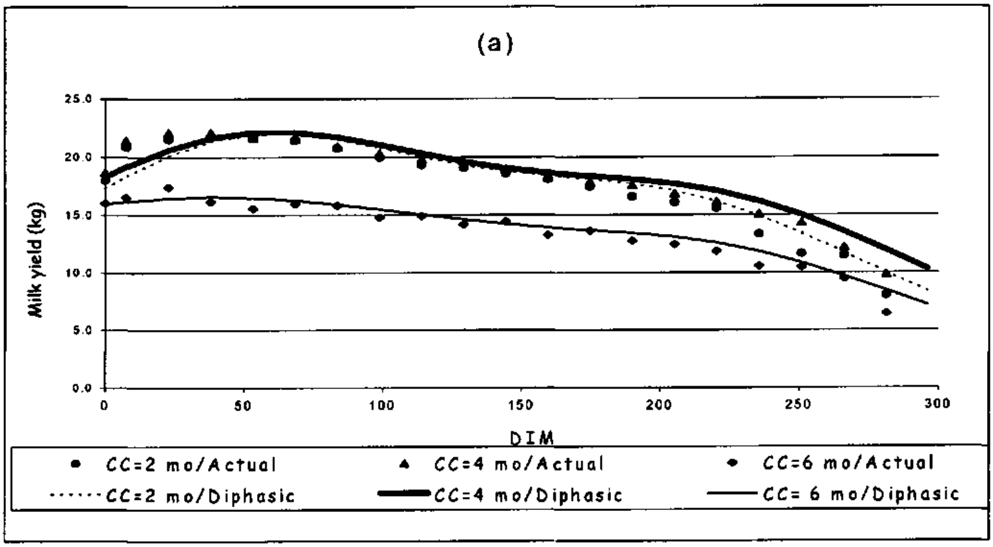


FIGURE 1. Residuals obtained from fitting the diphasic model to mean group yields of first parity lactations grouped by length (LL;mo) and calving to conception interval (CC; mo).

Problems observed with very long lactations (Table 6) are likely caused by the symmetric nature of the applied function. Use of a nonsymmetric function, such as the Weibull model, could solve this problem. A second alternative would be to extend the number of phases of the model, which would be difficult to justify from a biological point of view. Finally, one could try to restrict some of the parameters to achieve more stable values for some of the parameters. For example, one might want to restrict duration of first peak. Results of this study might serve as a starting point for improving interpretation of parameters.

For cows with a 10-mo lactation, lactation curves with a CC interval of 2 and 4 mo showed a similar pattern (Figure 2a). Nevertheless, it could be observed that cows with 4-mo CC interval have a higher production during the last part of lactation (after 200 d). The cumulative difference in estimates of 305-d milk yield is about 4% (Table 6). In previous research (1), pregnancy had an effect on parameters of the curve related to last part of the standard 305-d lactation, and a lower milk yield was found when CC interval was lower. This result is in line with results found in the present study for 2 and 4-mo CC. Lactation curves for cows with 6-mo CC is considerably lower and flatter than the others (Figure 2a). This result might be due to the way in which cows are grouped, i.e., we were looking at cows with a high CC but a relatively short lactation. In addition, differences in management strategies between herds might have influenced our results. For example, cows with high CC and relatively short lactation might be a reflection of a poorly managed herd.

For cows with a lactation length of 12 mo, the increase in CC interval from 4 to 6 mo did not cause a major effect on milk yield (Table 6). On the contrary, when CC increases to 8 mo the curve was significantly lower (Figure 2b). For cows with longer lactations (14 mo and higher) the general trend was that milk yield (100 and 305 d) decreased as CC increased. It is certainly difficult to find a biological explanation for this reduction. The antagonistic relationship between milk yield and reproduction would lead to an increase rather than a decrease in milk yield. However, a negative effect of pregnancy on milk yield is only expected during the last part of the gestation period and, consequently, would only affect 305-d milk yield for cows which get pregnant during the first 3 months of lactation (22, 23, 24), as observed in our study. Within lactation length, we did not find a negative effect of pregnancy, but we did find it across lactation lengths.



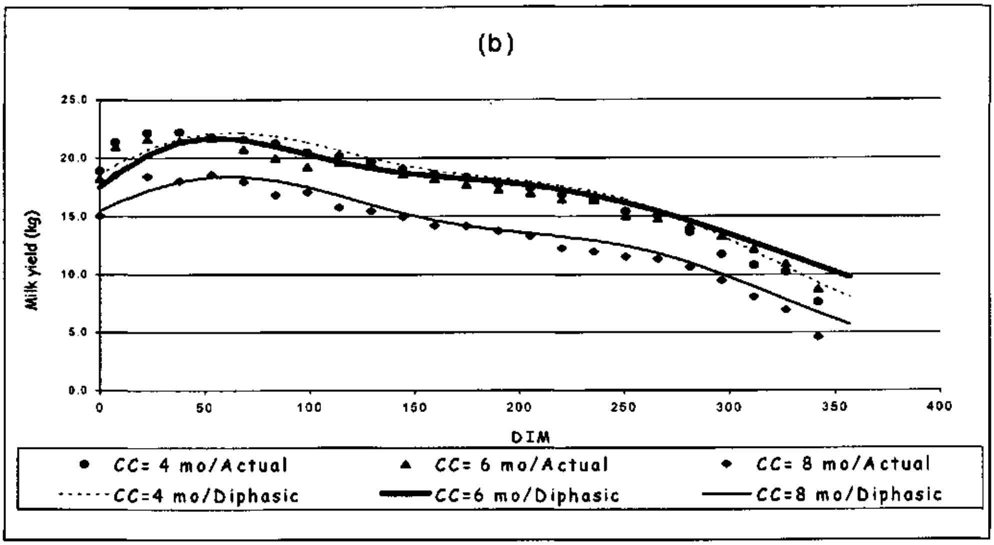


FIGURE 2. Actual yields vs. diphasic curves for first parity lactations grouped by calving to conception interval (CC) of cows with (a) 10-mo lactation or (b) 12-mo lactation.

The way data is presented certainly has an effect on the reduction observed for cows with large CC intervals. The number of test day records for extended lactations or larger CC intervals was much lower (Table 2), as they were more unlikely to happen. Cows with specific health conditions or special treatments could be included in those groups and could certainly have an effect on the results. Also, differences in management strategies between farms might influence our results. Identification of such cases was not possible with this data set.

As expected, for cows with a given CC interval, there is generally an increase in milk yield as lactation length increases (Table 6, Figure 3a and 3b). Low producing cows with less persistent lactations are likely to be dried off earlier than high producing cows with persistent lactations. Consequently, lactation curves for cows with shorter lactations within a given CC interval tend to be lower (Figure 3a and 3b).

Milk yield beyond 305 d for cows with different lactation length and CC interval, was very similar in first and later parity cows (Table 6). This finding reflects the effect of a flatter and more persistent lactation curve during first lactation, which has also been mentioned in earlier studies (19). Cows with a lactation length of 16 mo produced, on average, 2200 kg of milk after 305 d, which corresponds to as much as 26% of total milk yield. This finding arises the question of what the effects are of increased lactation length on lactation revenues. Economic consequences of a prolonged calving interval greatly depend on persistency of production and increase in lactation length with an increase in CC interval (6). These are factors that can be manipulated to some extent by breeding or feeding strategies. The effect on milk yield during next lactation must be also taken into account. Based on data from individual cows we observed an increase in lactation of 0.62 and 0.56 d for each additional day open in first and later parity cows, respectively. Further research must evaluate the profitability of extended lactations by using the results produced in the present study. Our findings could also have implications for the application of test-day models for the genetic evaluation of milk production; nevertheless, that is out of the scope of the present study.

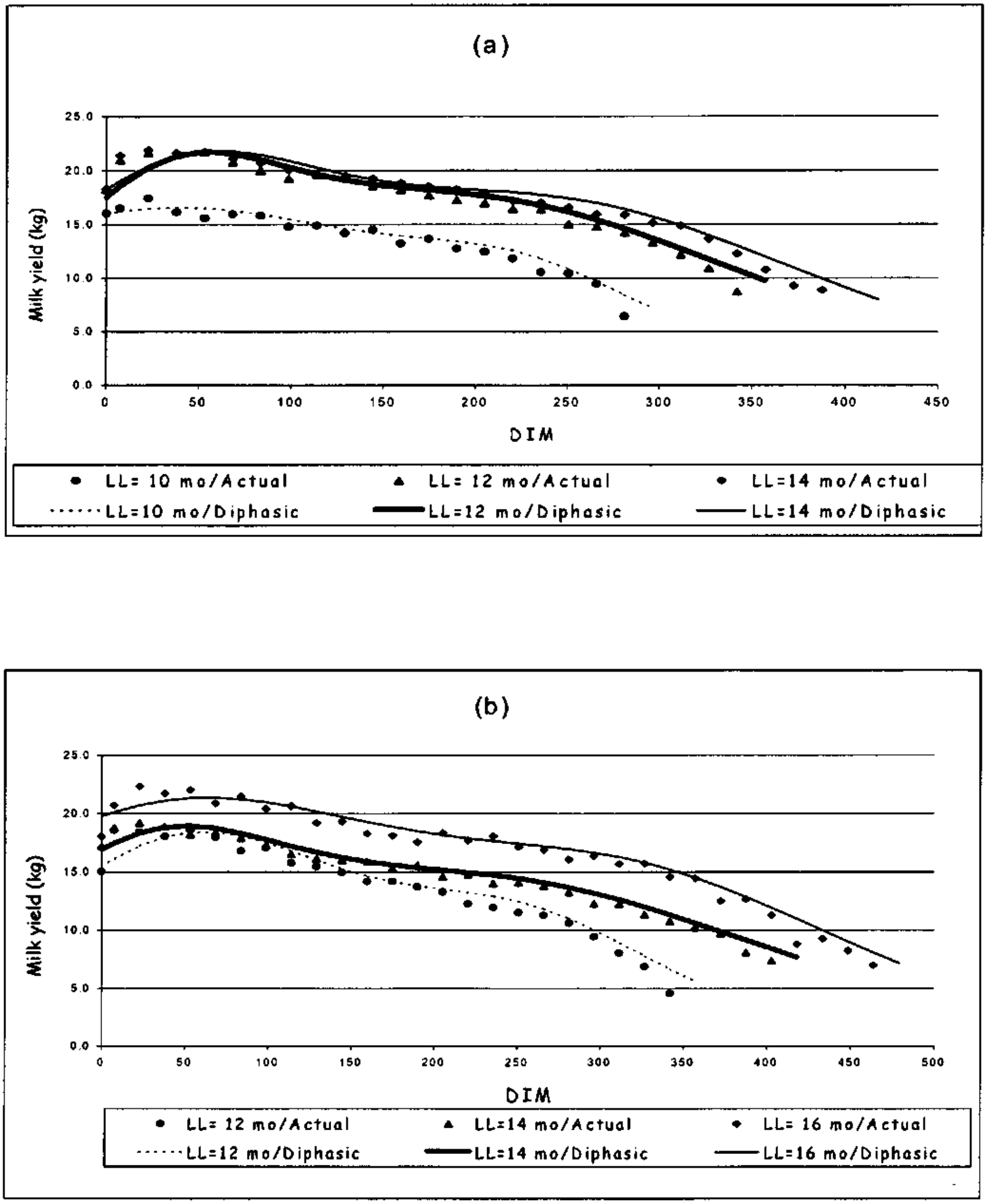


FIGURE 3. Actual yields vs. diphasic curves for first-parity lactations grouped by lactation length (LL) for cows with (a) 6-mo or (b) 8-mo calving to conception interval.

4.4 CONCLUSIONS

Our results show that the diphasic model adequately fits lactations with variable length and variable CC interval. Accurate estimates of milk yield at later stages within lactation can be obtained. These results will be used in a bio-economic model to determine optimum insemination strategies, taking into account variation in lactation length between cows. Modifications are needed to improve consistency of parameters over a range of lactation lengths. Ranking of models changed when only standard 305-d records only were analyzed, which supports the fact that further research is needed on modeling of extended lactations. As expected, CC interval was found to have a negative effect on milk yield for cows with a standard (10 mo) lactation length. In extended lactations, these negative effects of pregnancy on milk yield are no longer observed.

ACKNOWLEDGMENTS

The authors thank the farmers and staff at UNA for collecting the data and the financial support from Stichting Samenwerkings Verband IO-instellingen en LUW (SAIL), Delft, The Netherlands.

REFERENCES

1 Batra, T.R. 1986. Comparison of two mathemathical models in fitting lactation curves for pureline and crossline dairy cows. Can. J. Anim. Sci. 66:405-414.

2 Cobby J.M., and Y. L. P. Le Du. 1978. On fitting curves to lactation data. Anim. Prod., 26:127-133.

3 De Boer, J. A., Weller, J.I., Gipson, T.A., and M. Grossman. 1989. Multiphasic analysis of milk and fat yield curves of Israeli Holstein. J. Dairy Sci. 72:2143-2152.

4 Dekkers, J.C.M. 1991. Estimation of economic values for dairy cattle breeding goals: bias due to sub-optimal management policies. Livest. Prod. Sci. 29:131-149.

5 De Lorenzo, M.A., Spreen, T.H., Bryan, G.R., Beed, D.K., and J.A.M van Arendonk. 1992. Optimizing model:insemination, replacement, seasonal production, and cash flow. J. Dairy Sci. 75: 885-896.

6 Dijkhuizen, A.A., Renkema, J.A., and J. Stelwagen. 1985. Economic aspects of reproductive failure in dairy cattle. II. The decision to replace animals. Prev. Vet. Med. 3:265-276.

7 Dwinger, R.H., Cappella, E., Pérez, E., Baaijen, M., and E. Muller. 1994. Application of a computerized herd management and production control program in Costa Rica. Trop. Agric. (Trinidad) 71:74-76.

8 Freeze, B.; and T. Richards. 1992. Lactation curve estimation for use in economic optimization models in the dairy industry. J. Dairy Sci. 75:2984-2989.

9 Grossman, M., and W. J. Koops. 1988. Multiphasic analysis of lactation curves in dairy cattle. J. Dairy Sci. 71:1598-1608.

10 Grossman, M., Hartz, S. M., and W. J. Koops. 1999. Persistency of lactation production: A novel approach. J. Dairy Sci. 82:2192-2197.

11 Masselin, S., Sauvant, P., Chapoutot, D., and D. Milan. 1987. Les modeles d'ajustment des courbes de lactation. Ann. Zootech. 36 (2): 171-206.

12 Morant, S. V., and A. Gnanasakthy. 1989. A new approach to the mathematical formulation of lactation curves. Anim. Prod. 49:151-162.

13 Neter, J., Wasserman, W., and M. H. Kutner. 1985. Applied statistical methods. 2nd. Ed. Richard D. Irwin, Inc. Homewood, IL.

14 Noordhuizen, J.P.T.M, and J. Buurman. 1984. Veterinary automated management and production control program for dairy farms (VAMPP). The application of MUMPS for data processing. Vet. Q. 6, 62-77.

15 Pérochon, L., Coulon, J.B., and F. Lescouret. 1996. Modelling lactation curves of dairy cows with emphasis on individual variability. Anim. Sci. 63:189-200.

16 Rook, A.J., France, J., and M. S. Dhanoa. 1993. On the mathematical description of lactation curves. J. of Agric. Sci., Cambridge 121:97-102.

17 Schaeffer, L.R., Minder, C.E., McMillan, I., and E. B. Burnside 1977. Non linear techniques for predicting 305-days lactation production of Holsteins and Jerseys. J. Dairy Sci. 60:1636-1644.

18 SAS® User's Guide: Statistics, Version 6.0 Edition 1990. SAS Inst., Inc., Cary, NC.

19 Shanks, R.D.; Berger, P.J.; Freeman, A.E., and F. N. Dickinson. 1981. Genetic aspects of lactation curves. J. Dairy Sci. 64:1852-1860.

20 Sherchand, L., McNew, R. W., Kellog, D. W., and Z. B. Johnson. 1995. Selection of a mathemathical model to generate lactation curves using daily milk yields of Holstein cows. J. Dairy Sci. 78:2507-2513.

21 Van Arendonk, J. A. M. 1988. Management guides for insemination and replacement decisions. J. Dairy Sci. 71:1050-1057.

22 Vargas, B., and C. Solano. 1995. Cálculo de factores de corrección para producción diaria de leche en ganado lechero de Costa Rica. Arch. Latinoam. Prod. Anim. 3:131-148.

23 Vargas, B., and C. Solano. 1995. Factores de proyección y de corrección para producción por lactancia en vacas lecheras de Costa Rica. Arch. Latinoam. Prod. Anim. 3:149-164.

24 Vargas, B., van der Lende, T., Baaijen, M., and J. A. M. van Arendonk. 1998. Event-time analysis of reproductive traits of dairy heifers. J. Dairy Sci. 81:2881-2889.

25 White, I.M.S.; Thompson, R.; and S. Brotherstone. 1999. Genetic and environmental smoothing of lactation curves with cubic splines. J. Dairy Sci. 82:632-638.

26 Wilmink, J.B.M. 1987. Comparison of different methods of predicting 305-day milk using means calculated from within herd lactation curves. Livest. Prod. Sci. 17:1-17.

27 Wood, P. D. P. 1967. Algebraic model of the lactation curve in cattle. Nature, Lond., 216:164-165.

The first requisite for success is the ability to apply your physical and mental energies to one problem incessantly without growing weary.
T.A. Edisson

Chapter 5

Interactions between optimal replacement policies and feeding strategies in dairy herds

B. Vargas,[*,†] M. Herrero,[‡,§] and J.A.M. van Arendonk[†]

[*]Escuela de Medicina Veterinaria, Universidad Nacional de Costa Rica,

PO Box 304-3000, Heredia, Costa Rica

[†]Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences,

Wageningen University, PO Box 338, 6700 AH Wageningen, The Netherlands

[‡] Institute of Ecology and Resource Management, The University of Edinburgh,

West Mains Road, Edinburgh EH9 3JG, United Kingdom.

[§] International Livestock Research Institute,

PO Box 30709, Nairobi, Kenya.

Livestock Production Science (in press)

ABSTRACT

A dynamic performance model was integrated to a model that optimized culling and insemination policies in dairy herds using dynamic programming. The performance model estimated daily feed intake, milk yield and body weight change of dairy cows on the basis of availability and quality of feed and potential milk yield. A set of cow-states was defined by lactation number (1 to 12), calving interval (11 to 16 months), potential milk yield (15 levels) and stage of lactation (months 1 to 16). Actual performance was obtained taking into account potential performance, feed properties, and feed intake constraints. Biological and economical parameters used in the model represented actual production circumstances in Costa Rican herds. Eight feeding strategies combining two forages and four concentrate allocation systems were simulated. Different feeding strategies resulted in maximal changes of 6.8 mo in optimal average herd-life, US$26.1 in monthly income per cow and 1.9% in replacement rates, while average calving interval was not affected. The main difference was found between feeding strategies based on flat ratios of concentrate compared to feeding strategies based on daily milk yield. Feeding flat ratios altered the course of profitability due to restricting variation in feeding costs between cows and its effect on animal performance. Average herd-life and monthly income under the optimal feeding strategy were highly sensitive to changes in milk price, but less sensitive to changes in price of concentrates or price of forage. Calving interval was not sensitive to any of the factors. Comparison of optimal policies against actual parameters obtained from field data indicated that cows are being culled close to the optimal herd-life with calving intervals longer than optimal. The model is an efficient tool to study interactions between nutrition, reproduction and breeding at the animal and herd level.

(**Key words**: Dynamic programming, dairy cattle, optimization, breeding policies, intake prediction).

5.1 INTRODUCTION

The theory of optimal culling policies in dairy farming is largely developed (12, 15, 22, 24, 26). Some practical applications have already been introduced in commercial dairies (7, 17). This theory relies on the use of dynamic programming and the principle of optimality (4). According to this principle, a cow of a particular age should be kept in the herd as long as her marginal profit is greater than the expected average profit of a young replacement cow (16). The principle has been extended to determine the optimum time to inseminate a cow. In that case, the expected present value of the cash flow when the cow was inseminated is compared with that if she had been open at the same time (17, 25). A cow should be inseminated if the anticipated loss from a longer calving interval is less than that of leaving the cow open and replacing her later in the lactation.

Culling and insemination policies have a direct effect on the profitability of the dairy enterprise (16, 27). Sub-optimal decisions will reduce the profitability of the dairy enterprise, the degree of reduction may vary according to production circumstances. These production circumstances determine to some extent the optimum policies (17, 24, 27).

So far optimization of replacement policies is based on animal performance models in which production determines feed intake. In nutritional models, however, it is often assumed that the production potential, intake capacity and the feeding regime determine the actual intake and production. The relationships among production potential, intake capacity and actual performance is ignored in most models describing the performance of animals (e.g. Van Arendonk, 23). Knowledge of these relationships is essential to quantify the impact of different feeding regimes with variation in feed quality on optimal management strategies for cows.

Dairy farming in Costa Rica is characterized by large variation in production circumstances, especially with regard to feeding strategies (3, 11, 28). As a consequence, production costs and productivity also vary among farms. Feeding strategies depend on factors such as farm location, season, prices and availability of local by-products. Tools for determining optimal culling and insemination policies are not yet available for these farms and decisions are currently made in an empirical way. For such a tool to be developed and applied at farm level, it must be flexible enough to account for all possible variation in production circumstances, in particular the feeding regime. Recently, an animal performance model that incorporates relationships between potential production, feeding regime and actual production has been developed (8, 9). The model uses information on feed and animals to predict intake of grass and supplements intake, as well as milk yield and body weight change in dairy cows.

The objective of the present study was to integrate the animal performance model of Herrero (9) with the replacement model of Van Arendonk and Dijkhuizen (25) into a Culling and Insemination Decision Support System (C&I-DSS). The model was to be used to determine the impact of feeding strategy on optimization of replacement and insemination policies in Costa Rican dairies.

5.2 MATERIAL AND METHODS

5.2.1 Information Sources

The study used information on production circumstances on dairy farms of Costa Rica, although the method can be applied to different situations. Biological parameters required as input to C&I-DSS were calculated from data provided by Universidad Nacional de Costa Rica (UNA) and have been reported in previous studies (9, 11, 21, 29, 30, 31, 32, 33, 34). Data for these studies were collected from 1985 to 1997 on dairy farms in Costa Rica, which had participated in a project that focused on the collection and analysis of data related to health, milk yield, and reproduction performance in order to provide advice to farmers and to identify adequate management practices (18). Additional data related to current production circumstances, feed properties, and prices were collected from the local dairy industry or from governmental institutions.

5.2.2 General Approach

The C&I-DSS is composed of two complementary models (Figure 1). Details on these two models are described in the literature (9, 23). We will give a general description here and details on parameters and components that were modified in order to integrate models and fit local circumstances.

The first model, animal performance model, was a modification of a nutritional model developed by Herrero (9). This model uses information for a user-defined feeding strategy for the farm and animal characteristics (e.g., status of cow) to provide estimates of feed intake and animal performance.

The second model, the replacement model, was a modification of a model developed by Van Arendonk and Dijkhuizen (25) to optimize culling and insemination policies. Their model uses information provided by the animal performance model to find an optimum set of culling and insemination policies making use of dynamic programming methodology. The replacement model also uses economic parameters, conception probabilities, involuntary culling rates and production transition probabilities. Optimum culling and insemination policies obtained from the replacement model for every herd feeding strategy were summarized and compared.

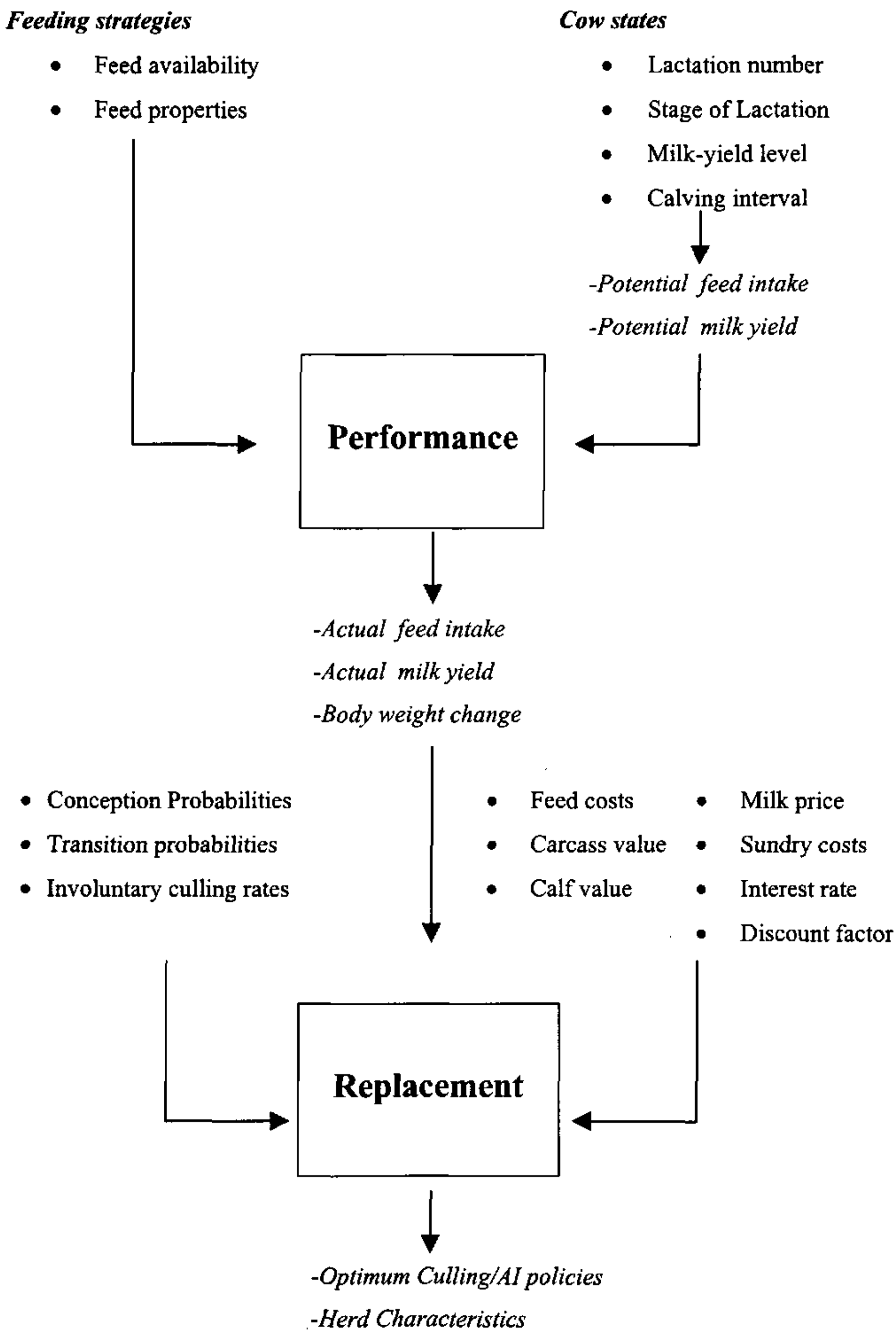


FIGURE 1. General structure of the Culling and Insemination Decision Support System (C&I-DSS)

5.2.3 Feeding Strategies

Eight different feeding strategies were evaluated (Table 1). These strategies were applied on a herd basis and were based on information collected in earlier studies (3, 11, 28). These strategies represent different degrees of nutritional management found in Costa Rican dairies. The strategies differed in the type of forage on which cows were grazing, the quantity of concentrates cows were given and the way the concentrate was allocated during three different stages of lactation. Two different grasses were considered in combination with four different concentrate allocation systems.

TABLE 1.

Feeding strategies used as input for the Animal Performance model.

Strategy	Grass[a]	Stage of lactation		
		0-100 d	101-200 d	201 d- end of lactation
BAS	Kikuyu	MC2:1[b]	MC3:1	MC4:1
COM	Kikuyu	MC3:1	MC3:1	FR3
FIX	Kikuyu	FR6[c]	FR4	FR2
REL	Kikuyu	MC4:1	MC4:1	MC4:1
BAS2	Star	MC2:1	MC3:1	MC4:1
COM2	Star	MC3:1	MC3:1	FR3
FIX2	Star	FR6	FR4	FR2
REL2	Star	MC4:1	MC4:1	MC4:1

[a] Grasses: Kikuyu grass (*Pennisetum clandestinum*); 600 g NDF/kg DM; 16% CP, potential degradability of NDF=58%, degradation rate of NDF = 3.8%/h. Star grass (*Cynodon nlemfuensis*); 800 g NDF/Kg DM; 7% CP, potential degradability of NDF= 50%, degradation rate of NDF= 3.0%/h. Degradation rate of soluble carbohydrate= 15%/h for both grasses. Solubility and total digestibility of CP were estimated at 30% and 80%, respectively for both grasses.

[b] MC: Milk-Concentrate ratio, for each 'n' kg/day of milk, 1 kg of concentrate (NDF = 120 g/kg DM, soluble carbohydrate = 570 g/kg DM of which 70% present as starch, CP = 180 g/kg DM, solubility of CP = 33%, Total digestibility of CP = 85%, Fat = 30 g/kg DM) was offered.

[c] FR 2,3,4,6:Flat Ratio. A fixed amount of 2,3,4,5 kg of concentrate, respectively, offered in the daily ration.

A basic strategy (BAS) was defined reflecting the most common practice found in dairy farms in Costa Rica, in which cows are fed according to milk yield (milk:concentrate ratio, see notes Table 1) in three consecutive stages of lactation (0-100 d; 101-200 d; 201 d-end of lactation), as described in a previous study (1). A second strategy (COM) was evaluated in which concentrate was fed using milk:concentrate ratios during the first 2 stages in lactation (0-100 d; 101-200 d) with a fixed amount (flat ratio) fed during the third stage (after 200 d). Two further strategies were analyzed; one was based on a regular milk:concentrate ratio (REL) identified as an optimal strategy in an earlier study (Herrero et al., 1999); and the other was based on a flat ratio (FIX). During the dry period, all cows were assumed to eat grass only.

5.2.4 Cow Status

Status of cows was described by four state variables (Table 2), namely lactation number (1 to 12), stage of lactation (1 to 16 mo), potential milk yield level (0.70 to 1.30, see Table 2) and calving interval (11 to 16 months).

TABLE 2.

Description of input and output variables used in the Animal Performance model.

Variable	Units	Possible values
Input variables		
- Lactation number	...	1 to 12
- Stage of lactation [a]	mo	1 to 16
- Milk-yield level [b]	fraction	0.7 to 1.3
- Calving interval classes	mo	11 to 16 (+ open cows)
Output variables		
-Body weight change	kg/d	dynamic
-Actual forage intake	kg DM/cow/day	dynamic
-Actual concentrate intake	kg DM/cow/day	dynamic
-Actual milk yield	kg/cow/day	dynamic

[a] Maximal number of lactation stages depended upon the calving interval class.
[b] 15 classes obtained as a fraction of mature equivalent milk production (level 1.0).

5.2.5 Structure of the C&I-DSS

Animal Performance Model. The model is designed to predict feed intake, digestion and animal performance of dairy cows, consuming grass, grains and other supplements (9). The rationale behind the model is that a ruminant of a given body size, in a known physiological state, and with a target milk-yield level, will have an actual forage intake determined by physical or metabolic constraints imposed both by feed properties and animal status (9, 10). The model was largely based on the work on previous research (1, 13, 14, 19, 20); and can be divided into two functional sections.

First, a dynamic section predicts actual feed intake and digestibility as a function of the nutritional quality of feeds on offer and a range of possible cow states (9). The model simulates the flow and digestion of feeds through the gastrointestinal tract and consequent supply of nutrients to the animal. This section uses a series of first-order differential equations estimating intake, pool sizes of feed fractions in the rumen, small and large intestines, pools of digested material and excretion of indigestible residues. This intake section of the model has previously been tested with data from 23 tropical and temperate forages and the mean prediction error was 7% (9).

Secondly, a static section of the model predicts nutrient requirements and animal performance, i.e., actual milk yield and body weight changes, on a daily basis from the estimates of feed intake and nutrients supplied obtained from the dynamic section. Body reserve tissues are mobilized or deposited, depending on whether the energy balance is negative or positive. Two pathways controlling intake are used in the model. The first control is the physical constraint on intake caused primarily by low digestibility, while the second control is a metabolic constraint, i.e., if the supply of nutrients equals the requirements, the cow stops eating. This section of animal performance has been previously tested on data obtained from Costa Rican farms (9).

Estimates of daily feed intake, milk yield and body weight change are subsequently summed on a monthly basis, as required by the replacement model.

Most important input and output parameters of this model are specified in Table 2. For more specific details, see Herrero (9).

Model specification. Biological parameters used as input to the model were to represent the situation of the Holstein cattle population in Costa Rica. Mature equivalent milk production was set to 6392 kg/cow/lactation with 12.1% milk solids, 3.6% fat, 3.0% protein and 4.5% lactose (2), produced by an average cow (milk-yield level 1.00) in sixth lactation, with a one-year calving interval in the absence of genetic improvement and voluntary replacement. The lactation curve was described by a diphasic model ($a_1 \times b_1$ (1- $\tanh^2(b_1 \times (t-c_1)) + a_2 \times b_2 \times$ (1- $\tan^2(b_2 \times (t-c_2))$,)), which was chosen on the basis of a previous study

(34). Parameters a_1, b_1, c_1, a_2, b_2, c_2 were set to 436.0, 0.01537, 41.7365, 4590.5, 0.003854 and 154.9 respectively, for first lactation, and 349.8, 0.01894, 37.9415, 5446.8, 0.00409 and 98.7 for second and later lactations (34). Age correction factors for milk yield and milk components (Appendix A1) were taken from earlier studies (2, 30).

To calculate the mean and limits of the remaining milk-yield levels, i.e., below or above 1.00, a normal distribution of production across milk-yield levels was assumed, with a coefficient of variation of 12% (24). This figure corresponds to the variation expected within the herd.The range of variation comprised 15 levels, which ranged from 0.70 to 1.30 times the average mature equivalent production.

Body weights of cows at the beginning of each lactation (Appendix A1) were established according to a Brody function fitted to growth data of local Holstein cattle, with y (kg)=$578.3(1-.944\times \exp^{(-.0098\ t)})$ with t= age in weeks (21). Changes in body weight were restricted to a maximum of 10% of the body weight at the beginning of the lactation. In addition, body weight change was restricted to a maximum of 0.8 kg/d. These restrictions were defined on the basis of actual variation in body weight observed for Holstein cattle in Costa Rica (21).

Replacement model. Information on feed intake, milk yield, body weight change and carcass value obtained from the animal performance model, and economic parameters, allowed estimation of monthly costs and revenues for each cow state. Optimal culling and insemination policies were obtained using this information by dynamic programming (4). The model used was based on Van Arendonk and Dijkhuizen (25). With this model, the objective function to be maximized is the total expected discounted returns of present and replacement cows over a given planning horizon. In the present study, the planning horizon was set to 180 one-month long stages (15 yr), and the monthly discount factor was set to $0.95^{1/12}$.

Optimization was performed by iteration on values (15) starting at the end of the planning horizon, when the value of any cow is equal to her carcass value (24). Using this information the maximum present value of net returns anticipated from cows and the corresponding optimum decisions were determined at the start of the preceding stage. The process was continued backwards, stage by stage, until the present time was reached.

One-month long stages were chosen, in such a way that decision on culling or insemination could be made at monthly intervals (25). Voluntary replacement or insemination of a cow was not considered up to 2 mo. after calving. From mo. 2 to 7 after calving the optimum decision for an open cow was chosen from 3 alternatives: inseminate the cow with a calculated probability of success, leave her open, or replace her immediately. For the remaining months of the lactation of open and pregnant cows the alternatives were to keep or to replace the cow.

Parameters used in the replacement model are given in Table 3. In addition to performance and prices, the model needs information on conception probabilities, transition probabilities and marginal rates of involuntary culling. Marginal conception probabilities for different months within lactation (Appendix A.2) were calculated from data on 37,236 parities of Holstein cows in Costa Rica (unpublished data). Production level of a cow was assumed to remain constant during the lactation and transition occurred only at the start of a new lactation. Transition probabilities for production level, i.e., the probability of a heifer/cow with milk-yield level m to have milk-yield level m' in the next lactation, was calculated as specified by Van Arendonk (24), assuming a repeatability for lactation production of 0.55 and 0.50 at intervals of one and two years. The marginal rates of involuntary disposal (Appendix A.2) were calculated from data on 910 culled cows in Costa Rica (unpublished data). Marginal rates of involuntary disposal for months 1 to 10 within the lactation, calculated on the same data, were set to 0.07, 0.03, 0.03, 0.03, 0.04, 0.06, 0.07, 0.06, 0.10, and 0.08. Due to lack of empirical data, the value for later months (11 to 16) were set to 0, i.e., all culling was assumed voluntary. Reasons for involuntary disposal were those not related to decision making in the replacement model, such as cow mortality, disease, mastitis, temperament, or udder and teat problems. Culling for reproductive problems was included in the decision-making process. Cows that were still open at the 8th mo of lactation were considered infertile and were included in the involuntary culling rate, however, these cows remained in the herd until the optimal time for replacement was reached.

The average optimal herd-life was calculated for an average heifer entering the herd, based on the probabilities of realization of each state that resulted from the transition probabilities (production, reproduction and involuntary culling) and the optimal decisions (25). Distribution of costs and revenues for an average cow in a herd under optimal culling and insemination policies was calculated in the same way. For further information on the replacement model, see Van Arendonk and Dijkhuizen (25).

TABLE 3.

Description of input parameters used in dynamic programming.

Variable	Units	Possible values
Age at first calving[a]	mo	28.0
Milk price[b]	US$/kg solids	2.23
Forage price[c]		
-Kikuyu grass	US$/kg DM	.0342
-Star grass	US$/kg DM	.0479
Concentrate price	US$/kg	.16
Price of replacement heifer	US$	1000
Carcass value[d]	US$/kg	1.05
Calves	US$/unit	30.0
Sundry costs[e]	US$/cow/mo	26
Discount rate	%/mo.	$.95^{1/12}$

[a] Age at first calving (29, 32).
[b] Milk price: According to the local pricing system, producers are paid by kg of milk solids.
[c] Estimated according to production costs, labour plus fertilisation (11) .
[d] 60% of male carcass price (US$1.6), dressing percentage 52%.
[e] From Herrero et al. (11).

A comparison was made between herd-life, calving interval and replacement rates for different feeding strategies, obtained from the replacement model, and actual rates calculated from field data on 910 Holstein cows.

5.2.6 Sensitivity analysis

Analysis of sensitivity of results to changes in prices of milk, concentrate and forage was performed with results for feeding strategy REL as the basis for comparison. Changes (+20% and –20%) were done one at a time, keeping all other parameters at their original value. The effects of these changes on average herd-life, monthly income and calving interval were assessed.

An additional sensitivity analysis was done to assess the effect of cow fertility on monthly income and average herd-life of a herd under optimal culling policies. Changes in fertility were associated with changes in conception probabilities (see Appendix A.2). First, all cows were assumed to have a calving interval of 11 mo by setting conception probabilities at month 2 after calving equal to 1.0, while those for months 3 to 7 were set to .0. The same procedure was applied for months 3 to 7, changing the conception probabilities of the respective month to 1.0 (see Appendix A.2), while the remaining were set to .0. In this way, fixed calving intervals between 12 and 16 mo were simulated.

5.3 RESULTS AND DISCUSSION

5.3.1 Potential versus Actual Performance

The use of different feeding strategies had a direct effect on milk yield and body weight change, as shown in Figure 2 for a cow in 6th lactation with a 12-mo calving interval. Three production levels (0.7, 1.0 and 1.3) in combination with four diets (BAS, COM, FIX and REL) are illustrated. Potential milk yield was achieved only when nutrients from feeds were available in the quantity and quality necessary to fulfil the requirements of a cow. If the requirements were not fulfilled, the cow showed a decrease in milk yield and growth, which was the case for strategies REL (Figure 2 a,b) and FIX (Figure 2 c,d,e,f). In case the requirements were fulfilled, as with strategies BAS and COM, the cow was able to reach its potential milk yield (Figure 2 a,c,e) and, when there was a surplus, also gained weight by fat deposition within the limits imposed by metabolic constraints (Figure 2 b,d,f).

None of the feeding strategies was able to provide all nutrients required to produce the potential milk yield for all possible cow-states, as illustrated for milk-yield levels 0.7, 1.0 and 1.3 (Table 4). The frequency of states in negative balance ranged from 2.3% for cows with low milk-yield level (0.7) under strategy COM, to 100% for strategy FIX2 for cows with high milk-yield level (1.3). The absolute reduction in milk yield averaged across cow-states ranged from 0.9 kg/d for strategy COM with average milk-yield level (1.0) to 9.7 kg/d for strategy FIX2 with high milk-yield level (1.3). Occurrence of negative energy balance was more likely for cows with higher milk-yield levels (Table 4). Better performance, i.e. a lower proportion of cow-states with a negative energy balance, was achieved for strategies using Kikuyu grass compared to strategies using Star grass. This trend was consistent across milk-yield levels. The reason for this difference is due to the composition of the two forages. Kikuyu in general terms has a higher quality than Star grass (Table 1). Star grass has 7% lower protein content than Kikuyu grass and therefore results in less effective rumen degradable protein, which leads to a lower microbial production in comparison to Kikuyu grass.

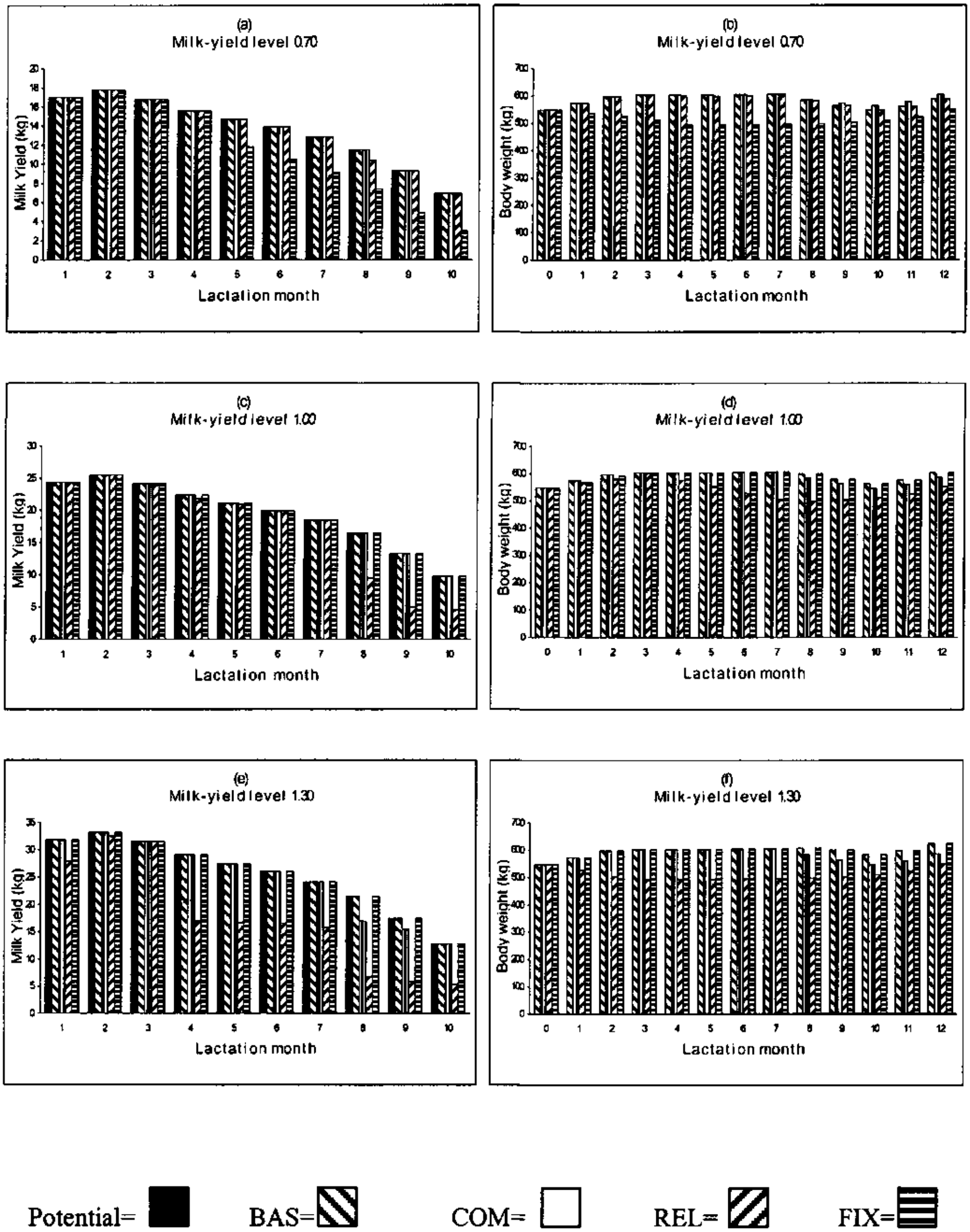


FIGURE 2. Milk yield (a,c,e) and body weight change (b,d,f) of cows in 6th lactation, 12 mo. calving interval and milk-yield levels 0.70 (a, b), 1.00 (c, d) and 1.30 (e, f) consuming Kikuyu grass plus a commercial concentrate offered in four different allocation systems (BAS, COM, FIX and REL).

Star grass also has higher NDF concentration, which together with a lower rate of cell wall degradation exerts a more pronounced physical constraint on intake and digestion than Kikuyu grass. As a consequence, the lower quality of Star grass increased in the frequency of cow-states with a negative energy balance.

TABLE 4.
Percentage of cow-states in a negative energy balance and average reduction (kg/d) in milk yield per milk-yield level and feeding strategy.

Strategy	Milk-yield level					
	Cow-states with negative balance (%)			Reduction in milk yield (kg/d)		
	0.70	1.00	1.30	0.70	1.00	1.30
BAS	17.2	8.8	3.5	1.9	1.8	1.3
COM	2.3	12.3	29.17	1.5	0.9	2.7
FIX	28.6	57.5	90.3	1.4	5.3	8.2
REL	72.2	20.4	6.0	4.1	2.7	2.8
BAS2	25.6	17.1	19.7	1.9	1.8	1.1
COM2	4.0	19.1	33.4	2.7	1.4	3.3
FIX2	37.5	92.8	100.0	2.3	5.0	9.7
REL2	85.1	75.7	78.8	4.4	2.4	2.4

5.3.2 Change in Parameters Describing Optimal Policies

The effects of feeding strategies on parameters describing optimal replacement and insemination policies are shown in Table 5.

The parameter showing the most variation was average monthly income per cow, which ranged from US$33.5 for strategy FIX2 to US$59.6 for strategy REL. Strategy REL resulted in the highest monthly income (Table 5), even though nutrient requirements were not efficiently fulfilled (Table 4), because the reduction in milk yield is also compensated by a reduction in feed. An earlier study (11) found that this strategy was also the most efficient when considering simultaneously the substitution effects between concentrate and pasture intake, and patterns of growth and utilization of Kikuyu grass in a highland region of Costa Rica. Overall, this strategy lead to the most efficient use of land, labour and other resources for meeting milk quotas. Strategy COM resulted in the second highest monthly income because of the low incidence of cow-states with a negative energy balance and lower feed costs compared to strategy BAS. The most common practiced in specialized dairy herds in Costa Rica, BAS and BAS2, were more efficient in fulfilling nutritional requirements (Table 4). However, as a result of the low milk:concentrate ratio (2:1) during the first stage in lactation, there was an excess of nutrients, which made these strategies more expensive in comparison to COM or REL. An earlier study (3) also showed the oversupplementation with concentrates in these herds.

TABLE 5.

Parameters describing optimal culling and insemination policies for a herd of a fixed size according to feeding strategy.

Parameter	Feeding Strategy							
	BAS	COM	FIX	REL	BAS2	COM2	FIX2	REL2
Herd-life (mo)	64.1	63.4	67.4	63.8	63.3	63.0	69.8	64.0
Calving Interval (mo)	370.3	369.4	368.7	369.9	369.6	369.3	369.5	369.9
Replacement rate (%)	18.7	18.9	17.8	18.8	19.0	19.1	17.2	18.8
- Voluntary (%)	8.5	8.8	7.2	8.3	8.7	8.9	6.2	8.2
- Involuntary (%)	10.2	10.1	10.6	10.5	10.1	10.2	11.0	10.4
Time to culling (d after calving)	247.5	217.0	220.0	218.9	235.9	211.1	226.1	219.1
Monthly income (US$/cow)	55.7	59.1	48.2	59.6	53.0	55.7	33.5	47.3

Strategies based on fixed ratios, i.e., FIX and FIX2, were less profitable because they did not fulfil requirements of nutrients for a large proportion of cow-states (Table 4). The large reduction in milk yield and body weight was not compensated by the reduction in feed costs. Strategy REL2 also resulted in the second lowest monthly income due to poor performance on Star grass, which resulted in a higher incidence of cow-states with negative energy balance.

The second parameter consistently affected by feeding strategy was herd-life. Optimal average herd-life ranged between 63.0 mo for strategy COM2 and 69.8 mo for strategy FIX2 (Table 5). The main difference in estimates of herd-life was between strategies based on fixed ratios, FIX and FIX2, and the remaining strategies. When fixed amounts of concentrate were given in the daily ration, regardless of the production potential of the cow, profitability followed a different pattern from the case when cows were fed according to production. Fixation of feeding costs resulted in slightly lower optimal replacement rates (Table 5), which as a consequence increases herd-life.

Other parameters were less affected by feeding strategies. The optimal calving interval ranged between 368.7 for FIX and 370.3 d for BAS (Table 5). This narrow range was expected because this parameter relates to culling and conception probabilities used as input to the model (25), and which were kept at the same level for all feeding strategies. A more realistic approach would have been to reduce conception probabilities for cow-states depending on the size of the negative energy balance.

For herd-life, values of 44 mo (25) and 32 mo (17) have been found for Holstein cattle in temperate countries. An estimate of 54.9 mo for Holstein-Friesian cattle has been reported for the south-eastern region of Brazil (6), which is closer to our results. For Holstein cattle in Costa Rica, however, several factors differed significantly, such as lower mature equivalent production, lower body weight curves and lower conception probabilities. Analysis of local data indicated that the actual average herd-life in Costa Rican Holstein cattle was about 61 mo corresponding to a replacement rate of 19.6%. The average calving interval was 385 d and cows were culled after 4.7 lactations on average. Comparing actual data with the results presented in Table 5 show that, regardless of the feeding strategy, cows were culled close to the optimal time and with a longer than optimum calving interval. However, this result might also be due to the fact that long calving intervals, i.e., above 16 mo, were not allowed in the model.

The distribution of costs and revenues for an average cow in a herd of a fixed size after applying optimal insemination and culling policies is given in Table 6. To obtain these results the probability of realization of each cow-state is implemented in calculation of average performance, which provides a better understanding of the interaction between feeding strategies and culling policies and the final effect on revenues for an average cow when optimal culling policies are applied.

TABLE 6.

Average performance, feed intake and distribution of costs and revenues for a cow in a herd of a fixed size with optimum culling and insemination policies according to feeding strategy.

Parameter	Feeding Strategy							
	BAS	COM	FIX	REL	BAS2	COM2	FIX2	REL2
Potential milk yield (kg/mo)	502.8	503.6	502.8	503.3	503.6	503.9	502.0	503.0
Realized milk yield (kg/mo)	502.7	499.7	430.8	492.6	502.7	497.3	381.5	457.4
-Fat (kg/mo)	18.1	18.0	15.4	17.7	18.1	17.9	13.6	16.4
-Protein (kg/mo)	15.0	14.9	12.7	14.7	15.0	14.8	11.3	13.6
Concentrate intake (kg DM/mo)	195.8	165.3	105.2	125.9	196.3	165.5	104.9	125.8
Forage intake (kg DM/mo)	194.7	208.8	218.9	223.1	190.1	203.9	212.5	215.3
Body weight (kg/cow)	583.3	574.1	515.6	549.6	578.4	573.1	509.8	538.1
Milk revenues (US$/mo)	135.4	134.5	115.5	132.6	135.4	133.8	102.2	123.1
Carcass value (US$/cow)	318.5	313.4	281.5	300.1	315.8	312.9	278.4	293.8
Calf value (US$)	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1
Costs of concentrate (US$/mo)	31.3	26.5	16.8	20.1	31.4	26.5	16.8	20.1
Cost of forage (US$/mo)	6.7	7.1	7.5	7.6	9.1	9.8	10.2	10.3
Sundry costs (US$/mo)	27.3	27.3	27.2	27.3	27.3	27.3	27.2	27.2
Replacement costs[a] US$/mo)	10.6	10.8	10.7	11.0	10.8	10.9	10.3	11.0
Average income[b] (US$/mo)	62.1	65.4	55.9	69.2	59.3	62.0	40.3	57.0

[a] Replacement cost = (Cost of replacement heifer - average carcass value)/herd-life.
[b] Income over feed, replacement and sundry costs. Involuntary culling not taken into account.

Potential milk yield was never achieved for all cow-states because of extremely high yield in some cases together with the effect exerted by metabolic constraints. However, strategy BAS was close to achieve this potential milk yield because the realized milk yield was only 0.1 kg/mo lower (Table 6). Milk production traits for cows fed FIX, FIX2 and REL2 were substantially less than others. Difference between potential and realized milk yield was over 100 kg/mo for cows given FIX2 rations. The lower quality of star grass reduced milk yield when the concentrate fed in the ration was insufficient, as occurs with strategies FIX2 and REL2.

Milk production traits did not differ substantially among strategies BAS, BAS2, COM, COM2 and REL. However, the average body weight and feed intake for cows fed BAS, BAS2, COM and COM2 were consistently higher than for those fed REL. The better quality of these feeding strategies was used mostly to increase body weight instead of milk yield. Cows fed a REL ration produced only 10 kg less milk on average and were approximately 40 kg lighter, but feed intake and costs were also substantially lower, which translated into a higher average income. Clearly the relative differences between milk price plus feed prices, carcass value and replacement costs determine to what extent a given feeding strategy will result in a higher average income. In this sense, the model successfully integrates nutritional (feeding strategies) and management aspects (replacement policies), to obtain a final estimate of profitability for a herd in equilibrium.

5.3.3 Insemination Decisions

When strategies based on milk:concentrate ratios are used, minimal milk-yield level for a profitable insemination increased as the cow became old. As illustrated in Table 7 for cows in 3rd and 7th mo after calving. For a cow in first lactation the minimal milk-yield level required for a profitable insemination at the 3rd mo after calving ranged from 0.70 for BAS, COM and BAS2; to 0.76 for REL, COM2 and REL2. For a cow in 5th lactation the minimal milk-yield level ranged from 0.80 for REL and REL2; to 0.84 for REL. At 7th mo, the differences across feeding strategies held, but the minimal milk-yield level required for a profitable insemination was higher. At later lactations, a profitable insemination was obtained only for cows with above average milk-yield levels. Earlier studies reported similar trends (5, 6, 25).

When feeding strategies based exclusively on flat ratios are used, FIX or FIX2, the trend is different (Table 7). In this case, cows with relatively low production potentials were still profitable at later lactations. As mentioned earlier, fixation of costs due to flat ratios of concentrate had a direct effect on the course of profitability for a cow. Fixed feeding means that not all cows fully express their potential and absolute differences in milk production would become smaller.

TABLE 7.

Minimal milk-yield level[a] required for an insemination at months 3 and 7 to be profitable for cows in lactation 1 to 11 (LAC) under different feeding strategies.

LAC	Month 3								Month 7							
	BAS	COM	FIX	REL	BAS2	COM2	FIX2	REL2	BAS	COM	FIX	REL	BAS2	COM2	FIX2	REL2
1	.70	.70	.70	.76	.70	.76	.70	.76	.76	.76	.70	.80	.80	.80	.70	.80
2	.76	.76	.70	.76	.76	.76	.70	.76	.76	.80	.70	.80	.80	.80	.70	.80
3	.76	.76	.70	.76	.76	.76	.70	.76	.80	.80	.70	.80	.80	.80	.70	.80
4	.76	.80	.70	.76	.76	.76	.70	.76	.84	.84	.70	.84	.84	.84	.70	.84
5	.84	.84	.70	.80	.84	.84	.70	.80	.88	.88	.88	.84	.92	.88	.70	.88
6	.88	.88	.70	.84	.88	.84	.70	.84	.92	.92	.92	.88	.96	.92	.70	.88
7	.92	.88	.70	.88	.88	.88	.70	.84	.96	.96	.96	.92	.96	.96	.70	.92
8	.96	.92	.76	.88	.92	.92	.70	.88	1.00	1.00	1.04	.96	1.00	1.00	.70	.96
9	1.00	.96	.76	.92	.96	.96	.70	.92	1.04	1.04	1.12	1.00	1.04	1.04	.96	1.00
10	1.04	1.00	.80	.96	1.04	1.00	.70	.96	1.04	1.08	1.24	1.04	1.08	1.12	1.12	1.04
11	1.30	1.08	.84	1.00	1.12	1.04	.70	1.00	1.16	1.16	1.30	1.12	1.12	1.16	1.12	1.08

[a]Milk-yield level is given as a fraction relative to the mature equivalent milk yield.

When the production potential of the cow was low, the relatively high amount of concentrate on offer increased feeding costs. On the other hand, if the production potential was high, the cow would tend to compensate for lack of nutrients by increasing grass consumption. When this was not possible, milk yield was reduced with direct consequences on profitability.

For cows voluntary culled, the optimal time to cull after calving ranged from 211.1 for COM2 to 247.5 d for BAS. For Holstein cattle, estimates of 234 d (17) and 235.4 (6) have been reported. For crossbred Holstein × Zebu cattle an estimate of 181 d was found (5). The actual time to culling after calving for Costa Rican Holsteins was 257 d, which is higher than the range found for the present study, meaning that the cows are milked longer than the optimum before being culled. The reason might be a lack of replacement heifers.

5.3.4 Sensitivity Analysis

A sensitivity analysis on feed prices was performed using the strategy with the maximum monthly income, REL, as a basis for comparison (Table 8).

Decreasing the forage price by 20% caused only a US$1.4 increase in monthly income, while other parameters stayed unchanged. Increasing forage price by 20% caused a reduction of US$1.4 in monthly income and a decrease in replacement rate by 1%. The small changes in the parameters were due to relatively low costs of forage.

TABLE 8.

Sensitivity analysis on effect of prices of feed and milk on parameters describing optimal replacement policies in a herd of a fixed size.

Parameter	Alternative scenarios						
	Initial (REL)	Forage Price		Milk Price		Concentrate Price	
		-20%	+20%	-20%	+20%	-20%	+20%
Herd-life (mo)	63.8	63.8	63.7	67.2	59.7	63.8	64.1
Calving interval (mo)	369.9	369.9	369.9	370.2	369.5	369.9	369.9
Replacement rate (%)	18.8	18.8	17.8	17.9	20.1	18.8	18.7
Voluntary replacement rate (%)	8.3	8.3	7.1	7.1	9.8	8.3	8.2
Monthly income (US$)	59.6	61.0	58.2	33.9	85.4	63.6	55.6

Milk price was the parameter with the greatest effect on replacement policies. A decrease in milk price of 20% caused an increase of 3.4 mo in optimal herd life and decreased the replacement rate by 0.9%, while monthly income was also reduced by US$26.7. An increase of 20% in milk price caused a reduction of 4.1 mo in optimal herd-life, while replacement rate and monthly income were increased by 1.3% and US$25.8, respectively. No significant changes were observed in average calving interval. These results have also been found in previous studies (5, 24).

A decrease in price of concentrates did not change estimates of optimal herd-life, calving interval or replacement rate, but monthly income was increased by US$4. An increase the price of concentrates caused a small increase of 0.3 mo in herd-life and reduced monthly income by US$4. Calving interval and replacement rate were almost unchanged. Similar results have bee reported previously for changes in feed prices (24). Low sensitivity to changes in concentrate price in the present study can be due to the fact that the diet used as a basis for comparison was REL, which maximized forage intake. In summary, optimal herd-life, monthly income and replacement rates showed high sensitivity to changes in milk price, and low sensitivity to changes in price of concentrates or price of forage. Calving interval was not sensitive to any of the factors.

Results of sensitivity analysis of cow fertility to monthly income and herd-life estimates are shown in Table 9. Maximum income was achieved with the shortest calving interval and the lowest herd-life. The reduction in monthly income when calving interval increased from 11 to 12 mo was only 1.3% and increased to 16.8% when calving interval was set to 16 mo. The reduction became larger for longer calving intervals. Comparison of these results to the estimate of US$59.6 obtained when using actual conception probabilities, shows that the additional increase in monthly income that can be achieved by further reduction of the calving interval is somewhere less than US$4. The extent to which this extra-profit might be cost-effective depends greatly on the costs needed to increase fertility levels.

TABLE 9.

Sensitivity analysis on effect of fertility on estimates of monthly income and herd-life for an average cow in a herd of a fixed size under optimal replacement policies and using feeding strategy REL.

Parameter	Actual Fertility[a]	Fixed Calving Interval (mo)[b]					
		11	12	13	14	15	16
Montly income (US$/cow)	59.6	63.37	62.56	60.93	58.65	55.97	52.70
Herd-life (mo)	63.8	65.53	69.71	72.57	77.43	81.23	80.85

[a] Actual conception probabilities were used (see Appendix A.2).
[b] Fixed calving intervals were assumed by setting the conception probabilities of the respective column in Appendix A.2 to 1.0, while keeping the remaining at .0.

5.4 CONCLUSIONS

The present results indicate that feeding strategies have an important effect on optimum average herd-life and monthly income. Feeding strategies affect herd-life by changing the optimal time of insemination, optimal time to culling within the lactation and minimal milk-yield level needed for a profitable insemination. The course of profitability for a cow along the lactation clearly varies according to the feeding strategy, especially when comparing restricted against production-based feeding strategies. Restricted feeding alters the normal course of profitability because of fixation of feeding costs and its effect on production. Individual feeding is not a feasible practice in Costa Rican dairies. Therefore, the course of profitability for an individual cow within the herd can be far from optimum. Insemination and culling decisions should be made with this fact taken into account.

Comparison of the results for optimal policies obtained in the present study to the actual situation in Costa Rican Holstein cattle indicates that actual average herd-life is close to the optimum, but that calving interval is too long. According to the present results, lifetime profitability of cows from Costa Rican herds could be raised by increasing levels of fertility.

The integration of the performance and the replacement models provides an efficient tool to study the effect on cow profitability of interactions between nutrition, reproduction and breeding at the animal and herd level. These models can be used to find adequate management practices for a broad range of production circumstances, including sub-optimal feeding practices. Further parameterisation of the effects of sub-optimal production circumstances on biological parameters included in the model is still needed.

ACKNOWLEDGEMENTS

The authors thank Stichting Samenwerkings Verband IO-instellingen & Wageningen University (SAIL), The Netherlands, for financial support.

REFERENCES

1 AFRC, 1993. Energy and protein requirements of ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB International, Wallingford, UK.

2 AMHL, 1992. Technical report. Asociación de Mejoramiento de Hatos Lecheros -Costa Rica. 31 p.

3 Baars, R.M.T., 1998. Nutrition management, nitrogen efficiency and income over feed cost on dairy farms in Costa Rica. J. Dairy Sci. 81:801-806.

4 Bellman, R., 1957. Dynamic programming. Princeton University Press, Princeton, NJ.

5 Cardoso, V.L., Ramos Nogueira, J., and J.A.M. van Arendonk. 1999a. Optimum replacement and insemination policies for crossbred cattle (Holstein Friesian × Zebu) in the south-east region of Brazil. Livest. Prod. Sci. 58:95-105.

6 Cardoso, V.L., Ramos Nogueira, J., and J.A.M. van Arendonk. 1999b. Optimal replacement and insemination policies for Holstein cattle in the southeastern region of Brazil: the effect of selling animals for production. J. Dairy Sci. 82: 1449-1458.

7 DeLorenzo, M.A., Spreen,T.H., Bryan, G.R., Beede, D.K., and J.A.M. van Arendonk. 1992. Optimising model: insemination, replacement, seasonal production, and cash flow. J. Dairy Sci. 75:885-896.

8 Herrero, M., Fawcett, R.H., and J.B. Dent. 1996. Integrating simulation models to optimise nutrition and management for dairy farms: A methodology. In: Livestock Farming Systems: Research, Socio-Economics and the Land Manager. J.B. Dent et al. (eds.). EAAP publication No. 79. Wageningen, The Netherlands: Wageningen Pers, pp. 322-326.

9 Herrero, M., 1997. Modelling dairy grazing systems: an integrated approach. PhD thesis. University of Edinburgh, UK.

10 Herrero, M., Dent, J.B., and R.H. Fawcett. 1998. The plant-animal interface in models of grazing systems In: B. Currie and R. Peart. Eds. Agricultural Systems Modelling and Simulation. Marcel Dekker Publishers, New York. pp. 495-542.

11 Herrero, M., Fawcett, R.H., and J.B. Dent. 1999. Bioeconomic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. Agric. Systems 62:169-188.

12 Houben E.H.P, Huirne R.B.M., Dijkhuizen A.A, and A.R. Kristensen. 1994. Optimal replacement of mastitic cows determined by a hierarchic Markov process. J. Dairy Sci. 77:2975-2993.

13 Illius, A.W., and I.J. Gordon. 1991. Prediction of intake and digestion in ruminants by a model of rumen kinetics integrating animal size and plant characteristics. J. Agric. Sci. 116:145-157.

14 Illius, A.W., and I.J. Gordon. 1992. Modelling the nutritional ecology of ungulate herbivores: evolution of body size and competitive interactions. Oecologia 89:428-434.

15 Kristensen, A.R., 1994. A survey of Markov decision programming techniques applied to the animal replacement problem. European Review of Agricultural Economics 21:73-93.

16 Lehenbauer, T. and J.W. Oltjen. 1998. Dairy cow culling strategies: making economical culling decisions. J. Dairy Sci. 81:264-271.

17 McCullough, D.A., and M.A. DeLorenzo. 1996. Evaluation of a stochastic dynamic replacement and insemination model for dairy cattle. J. Dairy Sci. 79:50-61.

18 Pérez, E., Baaijen, M.T., Cappella, E., and H. Barkema. 1989. Development of a livestock information system for Costa Rica. In: *Livestock Production_and Diseases in the Tropics*. Proceedings of the VIth International Conference of Institutes for Tropical Veterinary Medicine. (Editors: Kuil,H.; Paling, R.W. and Huhn, J.E.). Utrecht, The Netherlands, pp. 221-224.

19 Russell, J.B., O'Connor, J.D., Fox, D.G., Van Soest, P.J., and C.J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70:3551-3561.

20 Sniffen, C.J., O'Connor, J.D., Van Soest, P.J., Fox, D.G., and J.B. Russell. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci. 70:3562-3577.

21 Solano, C., and B. Vargas. 1997. Growth of dairy replacement heifers of Costa Rican dairy farms 1. Mathematical description of the growth of Holstein and Jersey heifers. Arch. Latinoam. Prod. Anim. 5:21-36.

22 Van Arendonk, J.A.M. 1984. Studies on the replacement policies in dairy cattle. I. Evaluation of techniques to determine the optimum time for replacement and to rank cows on future profitability. Zeitschrift für Tierzüchtung und Züchtungsbiologie 101:330-340.

23 Van Arendonk, J.A.M. 1985a. A model to estimate the performance, revenues and costs of dairy cows under different production and price situations. Agric. Systems 16:157-189.

24 Van Arendonk, J.A.M. 1985b. Studies of the replacement policies in dairy cattle. II Optimum policy and influence of changes in production and prices. Livest. Prod. Sci. 13:101-121.

25 Van Arendonk, J.A.M., and A.A. Dijkhuizen. 1985. Studies of the replacement policies in dairy cattle. III Influence of variation in reproduction and production. Livest. Prod. Sci. 13:333-349.

26 Van Arendonk, J.A.M. 1986. Studies on the replacement policies in dairy cattle. IV. Influence of seasonal variation in performance and prices. Livest. Prod. Sci. 14:15-28.

27 Van Arendonk, J.A.M. 1987. Contribution of variables to the optimum policy for insemination and replacement of dairy cows. J. Anim. Breed. Genet. 104:35-43.

28 Van der Grinten, P., Baaijen, M.T.,Villalobos, L., Dwinger, R.H., and L. 't. Mannetje. 1993. Utilization of kikuyu grass (pennisetum clandestinum) pastures and dairy production in a high altitude region of Costa Rica. Trop. Grass. 26:255-262.

29 Vargas, B., and C. Solano. 1995a. Projection and adjustment factors for lactational milk production of dairy cows in Costa Rica. Arch. Latinoam. Prod. Anim. 3:131-148.

30 Vargas, B., and C. Solano. 1995b. Calculation of correction factors for daily milk production in dairy cattle of Costa Rica. Arch. Latinoam. Prod. Anim. 3:149-164.

31 Vargas, B., and C. Solano. 1995c. Genetic and environmental trends in milk production of dairy cattle in Costa Rica. Arch. Latinoam. Prod. Anim. 3:165-176.

32 Vargas, B., Pérez, E., and J.A.M. van Arendonk. 1998a. Analysis of test day yield data of Costa Rican dairy cattle. J. Dairy Sci. 81:255-263.

33 Vargas, B., van der Lende, T., Baaijen, M., and J.A.M. van Arendonk. 1998b. Event-time analysis of reproductive traits of dairy heifers. J. Dairy Sci. 81:2881-2889.

34 Vargas, B., Koops, W., Herrero, M., and J.A.M van Arendonk. 2000. Modeling extended lactations of dairy cows. J. Dairy Sci. 83:1371-1380.

Appendix A.1

Multiplicative age adjustment factors for milk components[a] (fat and protein) and body weight[b] at calving.

Lactation	Milk yield	Fat content	Protein content	Body weight (kg)
1	.795	1.015	.951	412
2	.944	1.045	.986	485
3	1.010	1.045	.994	526
4	1.020	1.060	1.000	548
5	1.041	1.000	1.000	548
6	1.000	.998	.999	548
7	.993	.993	.996	548
8	.986	.987	.992	548
9	.976	.979	.988	548
10	.962	.971	.983	548
11	.946	.961	.977	548
12	.926	.951	.971	548

[a] Factors for milk yield were taken from Vargas and Solano (30), fat and protein content from AMHL (2).
[b] Body weight per lactation from Solano and Vargas (21). Changes in body weight within lactation according to the growth curve (21) and feeding strategy.

Appendix A.2

Marginal conception probabilities per lactation and insemination month, marginal involuntary culling rates (ICR,%) per lactation and reduction in milk production (%) per lactation caused by involuntary culling.

Lactation	Conception probabilities (mo 2 to 7)						ICR (%)	Reduction in milk (%)
	2rd mo	3th mo	4th mo	5th mo	6th mo	7th mo		
1	.37	.45	.41	.40	.35	.35	.08	30
2	.40	.48	.45	.45	.39	.43	.10	32
3	.41	.48	.48	.46	.41	.40	.15	34
4	.39	.51	.47	.46	.40	.45	.13	36
5	.37	.47	.45	.46	.42	.36	.22	38
6	.39	.46	.43	.43	.41	.42	.29	40
7	.38	.45	.44	.45	.40	.41	.31	40
8	.35	.47	.38	.46	.51	.50	.33	40
9	.29	.46	.49	.51	.48	.47	.35	40
10	.27	.44	.47	.49	.47	.45	.37	40
11	.26	.43	.45	.47	.45	.43	.39	40
12	.25	.41	.43	.45	.43	.41	.41	40

The illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn.

A. Toffler

Chapter 6

Economic values for production and functional traits in Holstein cattle of Costa Rica

Bernardo Vargas,[*,†] Ab Groen,[†] Mario Herrero,[‡,§]

and Johan A.M. Van Arendonk[†]

[*] Escuela de Medicina Veterinaria, Universidad Nacional de Costa Rica,
PO Box 304-3000, Heredia, Costa Rica

[†]Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences,
Wageningen University, PO Box 338, 6700 AH Wageningen, The Netherlands

[‡]Institute of Ecology and Resource Management, The University of Edinburgh,
West Mains Road,
Edinburgh EH9 3JG, United Kingdom

[§]International Livestock Research Institute, PO Box 30709, Nairobi, Kenya.

Submitted to Livestock Production Science

ABSTRACT

Economic values for production traits (carrier, fat, protein, and dressing percentage) and functional traits (conception rate, survival rate, body weight, and rumen capacity) were calculated for Holstein cattle of Costa Rica. Economic values were derived using a bio-economic model that combined genetic potential performance, feeding strategies and optimum culling and insemination policies to obtain actual phenotypic performance. Three evaluation bases were considered: fixed herd-size, fixed concentrate-input and fixed milk-output. With a fixed herd-size economic values were 0.04 (carrier), 5.25 (fat), 3.95 (protein), 0.92 (dressing percentage), 1.30 (conception rate) 2.42 (survival rate), 0.81 (body weight) and 84.53 (rumen capacity). With a concentrate-input limitation all traits except body weight and rumen capacity had lower economic values compared to fixed herd-size. The economic values were, in the same order: -0.02, 3.51, 2.83, 0.79, 0.82, 3.11, 0.81 and 84.53. With a milk-output limitation, economic values were also lower than for fixed herd-size. The respective values were -0.04, 3.53, 2.91, 0.88, 0.85, 3.18, 0.51 and 45.59. Sensitivity analysis indicated that economic values of fat, protein and rumen capacity increased significantly with higher prices of milk solids. Other traits were less sensitive to change in price of milk solids. Changes in price of concentrate or forage did not alter economic values significantly. When a poorer feeding strategy was used, the economic values for functional traits increased substantially, while those for production traits decreased. The results of this analysis suggest that genetic improvement of fertility, health and cow-efficiency traits will have a positive significant effect on profitability of Holstein cows in Costa Rica, especially when feeding conditions are not optimal

Key words: (Economic values, production traits, functional traits, dairy cattle, Costa Rica).

6.1 INTRODUCTION

Milk production in Costa Rica is an activity of increasing economical and social importance. Costa Rica is the only country is Central America that is self sufficient for milk production, with a consumption per capita of 152 kg, among the three highest in Latin America (27). There are currently 35,000 farms producing approximately 600,000 TM of milk per year, with an estimate of 60% of this milk being processed. Specialized dairy farms in the highlands are responsible for the production of a significant proportion of the processed milk. The total number of specialized dairy cows is above 200 000 heads, of which about 80% are Holstein cows.

Although there has been a substantial increase in average milk yield per cow, this has been achieved mainly by the improvement of management conditions and to a lesser extent by breeding (32). In the past, breeding of specialized dairy cattle in Costa Rica has relied mainly on importation of germsplasm from temperate countries. It is important to know whether there is compatibility among the breeding goal in Costa Rica and the exporting countries, in order to determine the weight that should be given to information from imported sires. Besides, there is some evidence of substantial G×E effect on the performance of imported sires (24, 26, 32). It is compelling, therefore, to evaluate the possibility for the implementation of a local breeding programme within the specialized dairy cattle population.

A first step in developing such a programme would be to consider current and future production circumstances in the dairy sector in order to define the type of cow that will better suit the future market conditions. A suitable breeding goal for the local population has to be defined, given emphasis to functional as well as production traits, in order to achieve a more sustainable production (18). For a sustainable production, traits that have been identified as important for selection are adaptability, reproduction, milk yield, and growth performance (10, 18, 19). Some research has been addressed to the analysis of functional traits such as fertility (4) and cow-efficiency (9, 16, 28, 35).

The theory of calculating economic values for situations with different selection interests and production circumstances has been extensively analysed (2, 5, 6, 7, 8, 10, 22). The economic value of a trait has been defined as the change in profit of the farm expressed per average present lactating cow per year, as a consequence of one unit of change in genetic merit of the trait considered (7). Production circumstances in Costa Rica indicate the importance of breeding workable cows that are able to efficiently use the abundant grass available, while still producing at a profitable level. Recently, a bio-economic model was developed for Costa Rican conditions (11, 12, 34). The model combines aspects of nutrition, reproduction, production and economics at the animal and farm level, which makes it especially suitable for calculating economic values. The model predicts feed intake and cow performance on the basis of availability and quality of grass and other supplements; and optimizes insemination and culling policies (34). Costs and revenues are obtained on the basis of real phenotypic performance, which not only depends on genetic potential performance, but also on availability of feed resources and feed intake capacity. In the past, economic values have usually been estimated with models that derive feed intake directly from nutrient requirements only. The use of an integrated model, as developed by Vargas et al. (34) could have an important impact on estimates of economic values for production, and especially for functional traits.

In the present study, biological and economical parameters reflecting the situation of Holstein dairy cattle in Costa Rica were entered into the bio-economic model by Vargas et al. (34) in order to obtain estimates of economic values for production traits (milk and beef), and functional traits (survival rate, conception rate, body weight, rumen capacity).

6.2 MATERIALS AND METHODS

This study was performed using the bio-economic model developed by Vargas et al. (34). An additional section was added to calculate economic values, based on previous research (7, 8). In this paper, this model will be described in general terms. For more detailed information, readers are referred to Vargas et al. (2000b).

Next, a description is given on the general model, followed by a description of the method used for calculating economic values. Subsequently, an accurate definition is given of the traits under analysis, the profit equation being applied, and the production circumstances for which the economic values were calculated.

6.2.1 General model

The present study used a normative approach (data simulation) to obtain the economic values for the traits under analysis. This approach is regarded as the most suitable when there is sufficient knowledge of the system under analysis (10). The availability of a bio-economic model adapted to the local production circumstances (34) provided this knowledge and facilitated the analysis of different production circumstances. The selection interest assumed for this analysis was the maximization of profit at the farm level (10). This interest was selected because output and input limitations for milk production in Costa Rica are usually imposed at the farm level. Besides, it is normally the farmer who takes breeding decisions.

The general structure of the model used for calculating the economic values is given in Figure 1. The model started with a given genetic potential for milk and beef production of a dairy cow. Next, potential phenotypic performance was defined by a set of cow-states as defined by Vargas et al. (34).

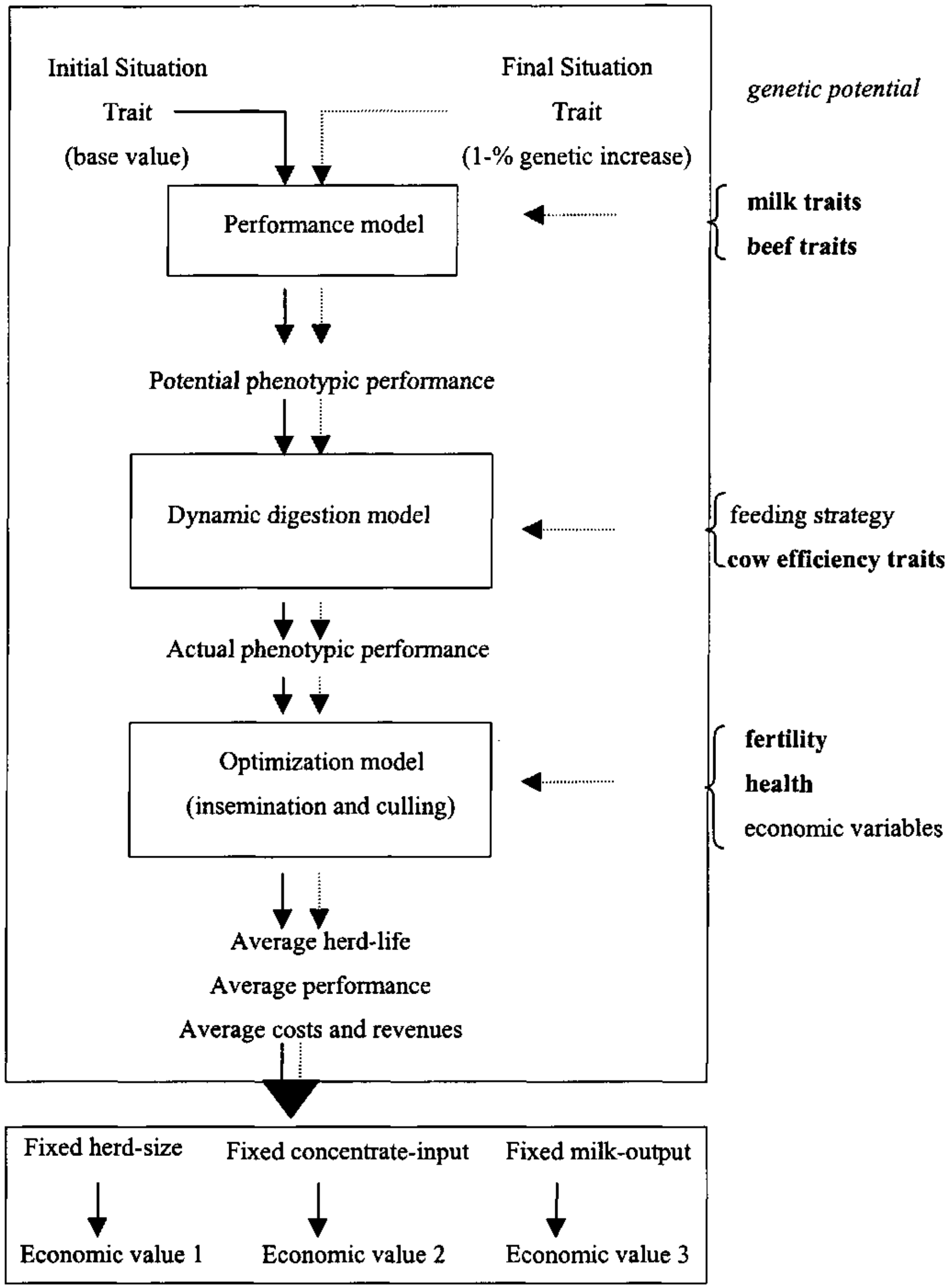


FIGURE 1. General structure of the model used in the calculation of economic values for production and functional traits.

Cow-states were given by four class-variables: milk-yield level (15 classes), lactation number (12 classes), lactation stage (16 classes) and calving interval (6 classes). Next, the potential phenotypic performance defined by the cow-states was entered into a dynamic module of digestion (see 12, 34). This module predicted the actual phenotypic performance of the cow on the basis of potential phenotypic milk production, availability and quality of feeds; and genetic potential for cow-efficiency variables, i.e. body weight and feed intake capacity. Subsequently, the information on actual phenotypic performance was entered into a dynamic programming model to optimize culling and insemination policies at the herd level, given a certain genetic potential for cow-fertility traits, and economic parameters. From this model, the actual phenotypic performance of an average cow for a herd in equilibrium was obtained together with the average costs and revenues on a single-cow basis. This first part of the model was run for two different situations, i.e. an initial situation where the trait under analysis was set to its current value within the population, and a final situation in which a 1-% increase in the genetic merit of the respective trait was assumed. Changes in genetic level were made for each trait separately, but the final phenotypic changes could involve more than one trait as a result of interactions between feeding, production, health and fertility.

6.2.2 Definition of Traits

Reference values for traits under analysis in the initial situation, i.e. before genetic improvement, and final situation, i.e. after genetic improvement, are in Table 1. These reference values corresponded to a Holstein heifer of average production level in Costa Rica, with an age at first calving of 28 mo and one-year calving interval.

Production traits. This group included milk and beef traits. Milk traits considered in the present analysis were 305-d carrier (CARR), fat (FAT) and protein (PROT) yield of a Holstein heifer (see clarifications Table 1). Lactation yield was obtained from the average lactation curve for Holstein cows in first and later lactations. Lactation curves were obtained by fitting a diphasic model to test day records obtained from the local Holstein population (33) with age adjustment factors obtained in an earlier study (31). A total of 15 production levels were simulated on the basis of the average lactation curve following the methodology described by Vargas et al. (34). Total protein yield (kg) and fat yield (kg) during the lactation were derived from total milk yield on the basis of average protein and fat content obtained from local data (1, 33). Correction factors for age and stage of lactation for fat and protein yield were also obtained from local data (1).

TABLE 1.

Reference values for the initial and final situation of genetic potential for production and functional traits considered for calculation of economic values.

Parameter	Code	Reference value	
		Initial situation	Increase (1%)
Production traits			
Carrier (kg)	CARR	5170.30 [a]	51.7
Fat yield (kg)	FAT	202.10 [a]	2.0
Protein yield (kg)	PROT	157.80 [a]	1.6
Dressing percentage (%)	DRPR	52.40 [b]	0.52
Functional traits			
Marginal conception rate (%)	CR	36.60 [c]	0.40
Survival rate (%)	SR	92.0 [d]	0.92
Heifer body weight (kg)	BW	412.00 [e]	4.1
Rumen capacity (kg DM)	RC	8.652 [g]	0.087

[a] 28 mo. old Holstein heifer, one-yr calving interval, producing 5530.2 kg 305-d milk yield, fat content 3.65%, protein content 2.85%.
[b] Average dressing percentage for a heifer was 52.4%.
[c] Marginal conception rate for a Holstein heifer, 2nd mo after calving.
[d] Probability of a Holstein heifer not to be culled by mortality, health, disease or udder and teats problems.
[e] Body weight of a heifer (28 mo. old).
[f] Obtained as 0.021 × heifer body weight.

The only beef trait included in this analysis was dressing percentage (DRPR). Average dressing percentage for the local population was obtained from data provided by slaughterhouses. Age adjustment factors for dressing percentage were not available for the local population, therefore, factors were obtained from literature (29). Genetic improvement of this trait was assumed by increasing the dressing percentage while keeping body weight at its original value.

Functional traits. Marginal conception rate (CR) for inseminated cows was selected as a fertility trait. This trait was defined as the probability of a cow to become pregnant after insemination, which was dependent upon parity number and month after calving. The conception probabilities used in this analysis were based on local data (34).

The trait selected as representative of health status was survival rate (SR). This trait was defined as the probability for a cow to stay in the herd without being involuntarily culled by health reasons, e.g. mastitis, diseases, mortality, or udder and teats problems. This probability was also dependent on parity number. Values used in this study were derived from involuntary culling rates calculated on actual lifetime records of the Holstein population in Costa Rica (34).

The way in which cow-efficiency traits were included in this study deserves special attention. The traits chosen were body weight (BW) and rumen capacity (RC). Body weight was simulated first by fitting an age-dependent Brody function to local data from the Holstein population (23). Secondly, body weight changes within the lactation due to feed intake, or body-tissue deposition and mobilization, with adjustment for effect of pregnancy, were simulated on the basis of a dynamic model of digestion (12). The use of this model allowed the estimation of body weight changes for situations with restricted feeding strategies, as described by Vargas et al. (34). Genetic increase of heifer body weight was obtained by increasing the mature body weight parameter of the growth curve by one percent, i.e a shift in the entire growth curve.

Feed intake capacity of dairy cows depends on three factors, i.e. feed, management and animal factors (2). Feed factors are those related to feed composition and physical form; management factors are those related to feeding strategy, i.e. restricted vs. *ad libitum*; and animal factors are those related to production level, size, age, physiological stage and genetic merit for feed intake. Earlier studies calculating the economic value of feed intake capacity for dairy cows (9, 16) were based on bioeconomic models in which actual feed intake is set equal to nutrient requirements norms. This assumption is not realistic for the production circumstances found in Costa Rica, where restricted feeding is the most common practice.

Rumen capacity in the present study was defined as the maximum load of dry matter in the rumen at any moment, as implemented in the dynamic model of digestion (12). This model estimated feed intake capacity on the basis of the allometric coefficient found earlier (11), in which dry matter content in the rumen scales to 0.021 × body weight. Further adjustments are made taking into account animal factors other than size, i.e. production level and pregnancy; and feed and management factors. In order to simulate an increase in the genetic merit for rumen capacity the allometric coefficient was increased, this is assuming that the cow would be able to store a larger amount of feed without increasing body size.

6.2.3 Definition of the Profit Equation

The profit equation used in the present analysis was defined following the approach by Groen et al. (10), i.e. variable and fixed costs were given on a cow and farm basis. The basic profit equation used in the calculation of economic values was as follows:

$$P = R - C \qquad [1]$$

where:

P = farm profit (US$/farm/year);

R = farm revenues (US$/farm/year);

C = farm-costs (US$/farm/year).

Farm revenues (R) were calculated using the equation:

$$R = N \times \left[(KFAT+KPRO+KLAC) \times pSOL + KFAT \times pFAT + (CALF/LIF \times pCALF) + (CAR/LIF \times pCAR)\right] \qquad [2]$$

where;

N	=	number of present cows in the herd (lactating + dry cows);
KFAT	=	fat yield (kg/cow/yr);
KPRO	=	protein yield (kg/cow/yr);
KLAC	=	other solids (kg/cow/yr);
PSOL	=	price per kg of milk solids (US$);
PFAT	=	extra-price per kg of fat yield (US$);
CALF	=	average number of calves per cow per lifetime;
PCALF	=	price new-born calves (US$);

LIF = cow herd-life (yr);

CAR = average carcass weight culled cows (kg);

PCAR = carcass price (US$/kg).

Costs (C) were derived from the following equation:

$$C = N \times \left[CONC \times pCON + (FOR + RFOR) \times pFOR + REP/LIF + LAB \times pLAB + SUNC\right] + FIXF \quad [3]$$

where;

CONC = intake of concentrate (kg/cow/yr);

PCON = price of concentrate (US$/kg);

FOR = forage intake (kg/cow/yr);

RFOR = residual forage (kg DM/cow/yr);

PFOR = price of forage (US$/kg);

REP = price replacement heifer (US$/heifer);

LAB = time contracted labor (h/cow/yr);

PLAB = price contracted labor (US$/h);

SUNC = sundry costs (US$/cow/yr);

FIXF = fixed farm-costs (administration and financial costs; US$/farm/yr).

CONC, FOR, RFOR and REP were variable cow-costs, while LAB and SUN were fixed cow-costs. Information on prices and costs per unit of production factor used in the present study is given in Table 2.

Forage produced within the farm was given a cost according to forage-production parameters and fertilization practices normally found in highland dairies of Costa Rica (12, 13). Residual forage (RFOR), e.g. the forage that was not consumed by the cows, was estimated as the difference in kg/cow/yr between forage available and forage consumed. The total amount of forage produced at the farm level was assumed as fixed, but the relative quantities of forage consumed vs. residual forage differed at the cow level. Therefore, this cost was considered as a cow-variable cost within the profit equation. Rearing costs (feeding, labor, sundries) were all considered within the replacement costs (REP), assuming an unlimited external supply of heifers independent of genetic merit.

TABLE 2.

Parameters used in the calculation of economic values.

Parameter	Value
Price milk solids (pSOL, US$/kg) [a]	2.178
Extra-price kg fat yield (pFAT, US$/kg) [a]	0.331
Price concentrate (pCON, US$/kg)	0.16
Price forage (pFOR, US$/kg) [b]	0.0342
Price replacement heifer (REP, US$)	1000.0
Sundry costs (SUNC, US$/cow/yr)	327.0
Fixed farm-costs (FIXF, US$/farm/yr) [c]	9670.0
Price new-born calf (pCALF, US$)	30.0
Number of calves (CALF)	4.77
Carcass price (pCAR, US$/kg)	1.05
Labor costs (pLAB, US$/h)	1.20
Production of forage (kg green DM/ha/yr) [b]	20,857
Stocking rate (AU/ha)	3.5

[a] Local payment system: US$2.178 × kg milk solids + US$0.331× kg fat.
[b] Assuming 2000 kg DM/ha per grazing period with 150 kg/ha/yr nitrogen fertilisation. Rest period between consecutive grazing periods set to 35 d (see 12, 13).
[c] Fixed farm-costs: administration costs (US$3744/yr), linear depreciation (US$2238/yr) and 7.0% annual interest rate on investments (US$7432/yr). Production factors (land, housing, machinery and labor) used for these calculations were only those directly related to production.

6.2.4 Feeding Strategy and Production Limitations

As described in an earlier section, the actual performance of the cow also depended on the feeding strategy. For the present analysis, cows were assumed to have unlimited access to graze kikuyu grass (*Pennisetum clandestinum,* 600 g NDF/kg DM, 16% CP, 58% potential degradability of NDF and 3.8%/h degradation rate of NDF) while offered a supplementation based on a 4:1 milk-concentrate relation. This is, a lactating cow was given 1 kg of concentrate (120 g NDF/kg DM, 570 g soluble carbohydrate/kg DM, 180 g CP/kg DM, 33% solubility of

CP, 85% digestibility of CP, 30 g fat/kg DM) per 4 kg of potential phenotypic milk yield. This feeding strategy, denoted from here onwards as REL, was selected on the basis of previous research (13, 34) that identified this relation as the more profitable on a farm basis.

Economic values for the traits described earlier were calculated for three different evaluation bases: fixed herd-size, fixed concentrate-input and fixed milk-output. Economic values for different evaluation bases were derived as described in previous research (2, 5, 6, 8, 9, 10, 22). For the case assuming a fixed herd-size, the economic values were derived from the equation:

$$EV = (1/N) \times (\delta R - \delta C) \qquad [4]$$

with EV being the economic value for the trait under analysis, N being the herd-size, and R and C as described in Equation [1].

Next, economic values were recalculated assuming a concentrate-input limitation. For this case, the economic value of the traits was obtained as:

$$EV = (P_2/N_2 - P_1/N_1) + RF \times (P_2/N_2) \qquad [5]$$

with P as defined in eq.1. Thus, P/N denoted the net profit per cow (US$/yr) with subscripts 1 and 2 standing for the initial and final situation. RF was a rescaling factor (8) introduced in order to account for a change in size of the enterprise, due to occur when an input/output limitation apply. This is, concentrate input was assumed fixed at the farm level, but the number of present cows changed as a result of the increment in the genetic merit for a certain trait. RF was therefore dependent on the production factor being limited, and can be obtained from the following equation:

$$RF = -1 \times [(F_2 - F_1)/F_2] \qquad [6]$$

where F stands for the factor being restricted, in this case the input of concentrate (kg/cow/yr) before (1) and after (2) genetic improvement of the trait under analysis, respectively.

Finally, a situation with milk-output limitation was assumed. In this case, economic values were obtained from eq. 5. RF was defined as in equation 6, with F_1 and F_2 equal to the level of milk output (kg/cow/yr) before and after genetic improvement of the trait under analysis, respectively.

6.2.5 Change in Prices and Feeding Strategy

Additional analysis was performed on the sensitivity of the economic values to changes in price of milk solids, concentrate and forage. Changes of (-/+)20% with respect to the original values were considered, under the three evaluation basis: fixed herd-size, fixed concentrate-input and fixed milk-output. Changes were performed one at the time, keeping all other parameters at their original value.

Economic values were also recalculated for all traits assuming a change in the feeding strategy. The new strategy was selected on the basis of a previous study (Vargas et al., 2000b), in which feeding strategies were compared on the basis of their efficiency to fulfil nutrient requirements of dairy cows in a wide range of production status. The strategy with the poorest performance, i.e. FIX, was selected for the recalculation of economic values assuming a fixed herd-size base of evaluation. According to strategy FIX cows were fed fixed quantities of 6, 4 and 2 kg of concentrate during 0-100, 101-200 and >200 d of lactation, respectively. As with strategy REL, cows were assumed to graze on kikuyu grass.

6.3 RESULTS AND DISCUSSION

6.3.1 Initial Situation

After running the model for the initial situation, the average present cow in the herd was characterized (Table 3). This cow had an average herd-life of 4.92 yr, and was able to produce 5929.4 kg FPCM/yr from a potential phenotypic production of 6055.6 kg FPCM/yr. This average present cow produced 212.9 kg fat/yr, 176.4 kg protein/yr and 327.8 kg of other solids/yr. Concentrate intake of the average cow was 1514.5 kg DM and forage intake was 2679.0 kg DM/yr. Given that the energy content of concentrate was approximately 12.00 MJ ME/kg DM and assuming an average energy content of 6.52 MJ ME/kg DM for kikuyu grass (12), this would mean that approximately 49.0% of the energy supply was obtained from the forage. For culled cows, the average body weight in the initial situation was 551.3 kg, with a carcass weight of 283.5 kg.

TABLE 3.

Initial potential and actual phenotypic performance of an average Holstein cow, and marginal changes after 1-% increase in genetic merit for production and functional traits.

Parameter	Initial	Marginal (δ) change after 1-% increase in genetic merit							
		CARR	FAT	PROT	DRPR	CR	SR	BW	RC
Herd-life (yr)	4.92	0.14	-0.01	-0.01	-0.01	0.02	0.16	0.00	0.01
Potential FPCM yield (kg/yr)	6055.6	21.36	25.08	12.48	0.12	1.20	-4.92	0.00	0.12
Actual FPCM yield (kg/yr)	5929.4	30.84	25.08	12.24	0.12	1.32	-5.16	9.12	24.84
Fat yield (kg/yr)	212.9	-0.96	2.88	0.36	0.00	0.00	-0.24	0.36	0.96
Protein yield (kg/yr)	176.4	-0.72	0.72	2.16	0.00	0.00	-0.12	0.24	0.72
Others solids (kg/yr)	327.8	1.70	1.38	0.67	0.01	0.07	-0.28	0.50	1.37
Concentrate intake (kg DM/yr)	1514.5	5.64	6.48	3.36	0.12	0.36	-1.20	0.00	0.00
Forage intake (kg DM/yr)	2679.0	1.68	2.40	1.08	0.00	0.24	0.00	24.60	33.12
Residual forage (kg/yr)[a]	3286.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Body weight (kg)	551.3	1.26	-0.11	-0.01	0.08	0.08	-0.30	6.36	2.46
Carcass weight (kg)	283.5	0.56	-0.05	0.00	2.89	0.06	-0.10	3.26	1.25

[a] Residual forage (kg/cow/yr) was re-adjusted when herd-size changed as a result of production limitations.

Initial distribution of farm costs and revenues is given in Table 4. As observed, milk and beef revenues represent 94.8% and 5.2% of the total revenues, respectively. Variable cow-costs represent 46.9% of the total costs, with feed costs being the most important variable cost (24.1%). Fixed cow-cost represented almost 33.7%, with sundry costs being the most important fixed-cost (23.6%). Labor costs represented about 10% of the total costs. Production cost per kg of milk was about US$0.234. The current price paid to farmers is around US$0.275/kg milk (15). Therefore, the profit per kg of milk for the initial situation was about 18.0%, without considering revenues/costs from other by-products. These figures are close to profitability estimates of highlands dairies in Costa Rica (36).

6.3.2 Fixed Herd-size

At the farm level, the increase of genetic merit of a certain trait under a fixed herd-size base of evaluation affected total revenues and variable cow-costs (Table 4). Due to the fixed number of cows assumed under this approach, fixed cow-costs and farm fixed-costs did not change after increasing genetic merit. Therefore, these costs did not have any effect on economic values. The economic value of a trait under this evaluation base was directly related to the marginal cow-profit.

Our results indicated that CARR had an economic value close to zero (Table 4). Selection on CARR has an effect on cow-performance and optimum herd-life (Table 3). There is a significant increase in potential and actual phenotypic milk yield (Table 3). However, this increase occurred mainly within the non-valuable components of milk. The valuable components, i.e. fat and protein, actually decreased (Table 3), which is due to the increase in herd-life and the consequent change in herd composition. The increase in herd-life may be caused by the fact that culling is performed at a later stage in lactation (216 vs. 206 d), due to increased production. Despite the decrease in milk and beef revenues, the economic value of CARR is still slightly positive, due to a significant reduction of replacement costs caused by decreased replacement rates. As observed in Table 3, there is also an increase in BW. This increase is caused by a higher availability of nutrients for body weight gain because, as stated earlier, the increase in milk yield is mainly in volume rather than solids. Economic values for CARR reported in the literature are usually negative (6, 8, 20, 25, 37). Most of these studies, however, considered a negative base price for milk, and the decrease of replacements costs after genetic improvement was not included. Nevertheless, the economic value found in our study was also close to zero.

As expected, FAT and PROT resulted in positive economic values. Selection for FAT and PROT increased mainly milk revenues, and beef revenues to a lesser extent (Table 4). Increase in milk revenues was mainly related to an increase in average fat and protein yield (see Table 3). Feed costs also increased as a result of higher concentrate and forage intake, which were related to increased milk yield. Smaller effects on beef revenues were related to a minimal reduction in herd-life (Table 3). Notice that calf and carcass values are divided by herd-life in Equation [3]. The change in herd-life also originates the observed increase in replacement costs (see Equation [4]). Earlier studies generally reported higher economic values for protein compared to fat (6, 8, 20, 25, 37). The opposite situation was observed in our study, and this is because fat is paid at a higher price than protein in Costa Rica (see Table 2).

TABLE 4.

Initial distribution of costs and revenues per farm per year, and marginal changes and economic values after 1-% increase in genetic merit for production and functional traits under a fixed-herd-size base of evaluation.

Parameter	Initial	Marginal (δ) change after 1-% increase in genetic merit							
		CARR	FAT	PROT	DRPR	CR	SR	BW	RC
Herd-size	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Milk revenues (US$/yr)	81430.1	-14.1	589.9	353.7	0.7	7.9	-60.0	125.9	347.7
Beef revenues (US$/yr)	4437.4	-119.1	9.3	8.3	36.1	-15.1	-18.8	30.2	8.0
1)Total revenues (US$/yr)	**85,867.6**	**-133.2**	**599.2**	**362.0**	**36.8**	**-7.2**	**-78.8**	**156.1**	**355.7**
Feed costs (US$/yr)	16,697.3	48.0	55.9	28.6	1.0	3.3	-57.6	42.1	56.6
Residual forage costs (US$/yr)	5619.3	-2.8	-4.2	-1.8	0.0	-0.4	2.9	-42.1	-56.6
Replacement costs (US$/yr)	10,160.9	-286.0	22.6	19.0	12.0	-36.0	-27.6	-10.3	-12.0
a)Variable cow-costs (US$/yr)	*32,477.4*	*-240.8*	*74.3*	*45.8*	*13.0*	*-33.1*	*-82.3*	*-10.3*	*-12.0*
b)Fixed cow-costs (US$/yr)	*23,358.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
c)Fixed farm-costs (US$/yr)	*13,414.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
2)Total costs (US$/yr) (*a+b+c*)	**69,249.4**	**-240.8**	**74.3**	**45.8**	**13.0**	**-33.1**	**-82.3**	**-10.3**	**-12.0**
Net effect [a] (US$/farm/yr)	16,618.1	107.6	524.9	316.2	23.8	25.9	3.5	166.4	367.7
Gross profit (US$/yr) (*1 – a – b*)	30,032.1	107.6	524.9	316.2	23.8	25.9	3.5	166.4	367.7
Production cost (US$/100 kg milk) [b]	**23.4**	**-0.2**	**-0.1**	**-0.1**	**0.0**	**-0.1**	**0.1**	**-0.1**	**-0.1**
Cow-profit [c]	600.6	2.2	10.5	6.3	0.5	0.5	0.1	3.3	7.4
Economic value [d] (US$/cow/yr)		0.04	5.25	3.95	0.92	1.30	2.42	0.81	84.53

[a] Net effect: [δ milk revenues – δ beef revenues – δ variable cow costs]

[b] Production cost: total costs (US$/farm/yr)/ total milk yield (kg/100/farm/yr)

[c] Cow-profit : Gross profit (US$/farm/yr)/herd-size

[d] Economic value: Net effect/ initial herd-size/increment in trait (see eq. 4 and table 1)

DRPR had a positive economic value of 0.92 (Table 4). This economic value originates mainly on the increase in beef revenues as a consequence of the increase in average carcass weight of culled cows (Table 3). There is also an increase in replacement costs, which is caused by the small reduction in herd-life. Due to the low carcass price (US$1.05/kg), the economic value for this trait is low, but still positive (Table 4).

CR had a positive economic value of 1.30. In our model, marginal conception probabilities are added during the optimization process (see Figure 1), therefore CR has an effect mainly on the optimal herd composition. CR directly affects herd-life and indirectly affects calf value, carcass value, and replacement costs (see eq. 2 and 3). As a result of an increase in CR, there is an increase in average herd-life (Table 3) that results in a decrease in replacement costs and beef revenues (Table 4). There is also a small increase in average milk yield and milk revenues (Table 3). This increase is caused by a slightly different distribution of cows within age-classes, as a result of the increase in herd-life. Methods and definitions used in calculating economic values for fertility differ substantially in previous research, making the comparison difficult. A previous study (4) found an economic value for CR that ranged from US$1.14 to US$2.14/cow/yr per 1-% increase in CR, which is in agreement with our results.

SR also had a positive economic value of 2.42. The effect of an increased SR is mainly exerted through changes in herd composition, rather than changes in individual performance. When SR increases, the average replacement rate becomes lower and optimum herd-life increases (Table 3). Although cows are older on average, there are also more cows in late lactations and dry period, which reduces milk revenues. However, the reduction in revenues was compensated by a more significant reduction in variable cow-costs, which leads to a positive economic value (Table 4). This is, cows are more cost-effective, as can be seen from the positive cow-profit in Table 4. Rogers et al. (21) reported an increase of US$22 in net revenue per cow per year, after a decrease of 2.9% in involuntary culling rates. Visscher et al. (37) reported economic values for survival rate in the range of US$1.35 to US$4.9/cow/yr per 1-% increase in SR, similar to what we found in the present study.

Important results of this study were the economic values for traits related to cow-efficiency, i.e. body weight (BW) and rumen capacity (RC). A low positive economic value was found for BW (Table 4). This value was mainly caused by increases in beef and milk revenues. Beef revenues increased as a result of the larger body size, but the marginal change was low as a consequence of the low carcass price. Increase in milk revenues originates in higher actual milk yield (Table 3). According to the results of the dynamic digestion model, cows with a higher BW were closer to their potential milk yield. In this study, intake of concentrate was defined according to potential milk yield (see earlier section) and remains constant before and after 1-% increase of genetic merit for BW (Table 3). Therefore, the increase in milk yield was caused by the increase in forage intake. Large cows eat more than small cows, and this is an important factor when the production potential of the cow is not fully expressed due to size-related limitations. The increase in feed costs was caused by higher forage intake, but this increase in feed costs is counterbalanced by an equal reduction in residual forage costs (Table 4). This is, the cows consume more forage, and less residual forage is left on the ground (Table 3). In previous studies, the economic value reported for BW was negative (7, 8, 16, 25, 37). These studies, however, were based on models that assumed a feeding strategy based on nutrient requirements only. Therefore, larger cows required more nutrients for maintenance, and the intake was increased resulting in higher feed costs. Recently, dynamic models of digestion, as used in the present study, are being developed. In these models, the approach followed is opposite to models based on nutrient requirements (see 12, 14). These models allow for the specification of a general feeding strategy for a herd, and the actual performance of the individual cows is calculated on the basis of feed availability, feed quality and the production potential of the cow. This characteristic is of great importance when analyzing the effect of interaction between genetic potential and feeding level (17). For the present analysis, cows were fed based on their potential milk yield using a fixed 4:1 milk-concentrate ratio. This means that the change in feeding costs after increasing BW was only associated with the increase in forage intake (potential milk yield does not change with increased BW), and forage is a cheaper food resource. Some authors stated that large animals have a greater advantage when cell wall digestion rates are low because of their longer retention time and hence more extensive digestion; conversely, the shorter retention times of small animals allow a lower extent of digestion of slowly fermenting forages (14). For the present study, it seems that increasing BW by genetic means is still profitable for a pasture-based dairy production system under the production circumstances already described.

A genetic increase in RC also resulted in a positive economic value. This value was related to an increase in milk revenues originated in higher actual milk yield and higher forage intake (Table 3). The increase in beef revenues was due to a larger body weight (Table 3), which was mainly related to a higher intake capacity and lower body weight losses during lactation. The dynamic model of digestion takes into account changes in body weight on a daily basis, therefore changes in intake capacity are reflected in the average BW. Feed costs increased as a result of a higher forage intake, but there was again an equal reduction in residual forage costs. It is important to notice that by giving a value to the residual forage, the economic value of BW and RC increases, due to a more efficient utilisation of the forage resource. Similar findings have been previously reported (9, 35). An earlier study (16) found that economic values for feed intake capacity reported in the literature ranged between US$0 and US$71.3 cow/yr per 1 kg increase in feed intake. Despite the difference in the way of measuring feed intake capacity used in our study, the results also indicate a high economic value for this trait, which stresses the importance of increased feed intake capacity for pasture-based dairy production systems.

6.3.3 Fixed Concentrate-input and Fixed Milk-output

Increase of genetic merit of a trait under fixed concentrate-input and fixed milk-output evaluation-bases changed herd-size according to the re-scaling factor (see Equation [6]).

For this study, concentrate intake was directly related to the potential phenotypic milk yield of the cows. Therefore, with a concentrate-input limitation, a change in herd-size was observed when the trait had an effect on the potential phenotypic milk yield (and concentrate intake) of the individual cow (see Table 3). Van Arendonk and Brascamp (30) suggested that economic values should be calculated from product profitability. For comparison, profit per kg of concentrate is also given in Table 5. As shown, the economic value for a trait was negative when the profit per kg of concentrate was lower after increasing genetic merit. This demonstrates the equivalence between rescaling and product profitability in calculating economic values.

TABLE 5.

Initial distribution of costs and revenues per farm per year, and marginal changes and economic values after 1-% increase in genetic merit for production and functional traits under a fixed concentrate-input base of evaluation.

Parameter	Initial	Marginal (δ) change after 1-% increase in genetic merit							
		CARR	FAT	PROT	DRPR	CR	SR	BW	RC
Herd-size	50.0	-0.186	-0.213	-0.111	-0.004	-0.012	0.040	0.000	0.000
Milk revenues (US$/yr)	81,430.1	-316.2	240.5	172.7	-5.7	-11.4	-9.6	125.9	347.6
Beef revenues (US$/yr)	4437.4	-135.1	-9.7	-1.6	35.7	-16.2	-134.5	30.2	8.1
1)Total revenues (US$/yr)	**85,867.6**	**-451.3**	**230.8**	**171.1**	**30.0**	**-27.6**	**-144.1**	**156.1**	**355.7**
Feed costs (US$/yr)	16,697.3	-14.1	-15.4	-8.3	-0.4	-0.7	3.6	42.1	56.6
Residual forage costs (US$/yr)	5619.3	14.1	15.4	8.3	0.4	0.7	-3.6	-42.1	-56.6
Replacement costs (US$/yr)	10,160.9	-322.6	-21.0	-3.6	11.3	-38.4	-305.7	-10.3	-12.0
a)Variable cow-costs (US$/yr)	*32,477.4*	*-322.6*	*-21.0*	*-3.6*	*11.3*	*-38.4*	*-305.7*	*-10.3*	*-12.0*
Labor costs (US$/yr)	7008.0	-26.0	-29.9	-15.5	-0.6	-1.7	5.5	0.0	0.0
Sundry costs (US$/yr)	16,350.0	-60.7	-69.6	-36.2	-1.3	-3.9	13.0	0.0	0.0
b)Fixed cow-costs (US$/yr)	*23,358.0*	*-86.7*	*-99.5*	*-51.7*	*-1.9*	*-5.6*	*18.5*	*0.0*	*0.0*
c)Fixed farm-costs (US$/yr)	*13,414.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
2)Total costs (US$/yr) (*a*+*b*+*c*)	**69,249.4**	**-409.3**	**-120.5**	**-55.3**	**9.4**	**-44.0**	**-287.2**	**-10.3**	**-12.0**
Net effect [a] (US$/farm/yr)	16,618.1	-42.0	351.3	226.4	20.6	16.4	143.1	166.4	367.7
Gross profit (US$/yr) (*1 – a – b*)	30,032.1	-42.0	351.3	226.4	20.6	16.4	143.1	166.4	367.7
Cost (US$/100 kg milk) [b]	23.4	-0.2	0.0	-0.1	0.0	-0.1	-0.1	-0.1	-0.1
Profit per 100 kg conc. [c] (US$)	**39.7**	**-0.1**	**0.0**	**0.3**	**0.0**	**0.0**	**0.1**	**0.2**	**0.4**
Economic value [d] (US$/cow/yr)		-0.02	3.51	2.83	0.79	0.82	3.11	0.81	84.53

[a] Net effect: [δ milk revenues – δ beef revenues – δ variable cow-costs – δ fixed cow costs]

[b] Production cost: total costs (US$/farm/yr)/ total milk yield (kg/100/farm/yr)

[c] Profit per 100 kg concentrate: Gross margin (US$/farm/yr)/ total amount of concentrate (kg/100/farm/yr)

[d] Economic value: [δ cow-profit + RF × final cow-profit] /increment in trait (see eq. 5 and table 1)

Similarly, with a milk-output restriction, the reduction in herd-size was observed when the trait had an effect on the actual milk yield of the individual cow. The economic value for this situation can also be related to the profit per kg of the limiting factor, e.g. per kg of milk (Table 6). The economic value for a trait was negative when the profit per kg of milk was lower after increasing genetic merit.

In general, for both evaluation bases, fixed cow-costs are always lower as a result of the decrease in herd-size. An exception occurs for SR, which causes an increase rather than a reduction in herd-size. Variable cow-costs and revenues from milk and beef present marginal changes according to the trait being improved.

CARR had a negative economic value in both cases (Tables 5 and 6). There is a decrease in milk revenues that cannot be counterbalanced by the reduction in replacement costs. Improvement of FAT and PROT significantly increased the potential phenotypic milk yield (Table 3), and consequently caused a larger reduction in herd-size and marginal changes in revenues and costs. In our model, DRPR only affected beef production traits, and therefore there was only a minor change in herd-size after 1-% increase in genetic merit (Table 5 and 6). Conception (CR) and survival (SR) are implemented within the optimization model, and consequently only exert a minimal effect on milk yield by changing optimal herd composition (see Figure 1). Therefore, the change in herd-size after selection for CR and SR was also minimal (Tables 5 and 6).

After selection for SR, an increase of herd-size was observed. This increase occurs because the level of the restricted factors, i.e. concentrate-input and milk-output, is lower after selection (Table 3). The increase of survival rate may result in a higher ratio between non-productive vs. productive days during the lifetime of an average cow after the optimization process (see Figure 1); and this may cause the reduction in both factors.

Efficiency traits (BW and RC) are implemented within the dynamic digestion model and therefore exert an effect on actual phenotypic milk yield, not on potential milk yield (Table 3). Consequently, the herd-size did not change after imposing a concentrate-input limitation (Table 5), and the economic values were the same as those calculated assuming a fixed herd-size base of evaluation. On the opposite, BW and RC had a significant effect on actual milk yield and therefore caused a reduction in herd-size and economic values (Table 6).

TABLE 6.

Initial distribution of costs and revenues per farm per year, and marginal changes and economic values after 1-% increase in genetic merit for production and functional traits under a fixed milk-output base of evaluation.

Parameter	Initial	Marginal (δ) change after 1-% increase in genetic merit							
		CARR	FAT	PROT	DRPR	CR	SR	BW	RC
Herd-size	50.0	-0.259	-0.211	-0.103	-0.001	-0.011	0.044	-0.077	-0.209
Milk revenues (US$/yr)	81,430.1	-435.4	244.4	185.2	-0.9	-10.2	-3.2	0.7	6.5
Beef revenues (US$/yr)	4437.4	-141.4	-9.4	-0.9	36.0	-16.1	-134.2	23.3	-10.5
1)Total revenues (US$/yr)	**85,867.6**	**-576.8**	**235.0**	**184.3**	**35.1**	**-26.3**	**-137.4**	**24.0**	**-4.0**
Feed costs (US$/yr)	16,697.3	-38.6	-14.6	-5.8	0.6	-0.4	4.9	16.4	-13.3
Residual forage costs (US$/yr)	5619.3	20.8	15.2	7.6	0.1	0.6	-4.0	-35.0	-37.3
Replacement costs (US$/yr)	10,160.9	-337.0	-20.5	-2.0	11.9	-38.3	-304.9	-25.9	-54.5
a)Variable cow-costs (US$/yr)	*32,477.4*	*-354.8*	*-19.9*	*-0.2*	*12.6*	*-38.1*	*-303.9*	*-44.5*	*-105.0*
Labor costs (US$/yr)	7008.0	-36.3	-29.5	-14.4	-0.2	-1.6	6.1	-10.8	-29.2
Sundry costs (US$/yr)	16,350.0	-84.6	-68.9	-33.7	-0.3	-3.6	14.2	-25.1	-68.2
b)Fixed cow-costs (US$/yr)	*23,358.0*	*-120.9*	*-98.4*	*-48.1*	*-0.5*	*-5.2*	*20.3*	*-35.9*	*-97.4*
c)Fixed farm-costs (US$/yr)	*13,414.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
2)Total costs (US$/yr) (*a*+*b*+*c*)	**69,249.4**	**-475.7**	**-118.3**	**-48.3**	**12.1**	**-43.3**	**-283.6**	**-80.4**	**-202.4**
Net effect[a] (US$/farm/yr)	16,618.1	-101.1	353.3	232.6	23.0	17.0	146.2	104.4	198.3
Gross margin (US$/yr) *1 – a – b*	30,032.1	-101.1	353.3	232.6	23.0	17.0	146.2	104.4	198.3
Cost (US$/100 kg milk)[b]	23.4	-0.2	0.0	-0.1	0.0	-0.1	-0.1	-0.1	-0.1
Profit 100 kg of milk (US$)[c]	**10.13**	**-0.03**	**0.12**	**0.08**	**0.01**	**0.01**	**0.05**	**0.04**	**0.07**
Economic value[d] (US$/cow/yr)		-0.04	3.53	2.91	0.88	0.85	3.18	0.51	45.59

[a] Net effect: [δ milk revenues – δ beef revenues – δ variable cow costs – δ fixed cow costs]
[b] Production cost: total costs (US$/farm/yr)/ total milk yield (kg/100/farm/yr)
[c] Profit per 100 kg of milk: Gross margin (US$/farm/yr)/ total milk yield (kg/100/farm/yr)
[d] Economic value: [δ cow-profit + RF × final cow-profit] /increment in trait (see eq. 5 and table 1)

All economic values obtained under a fixed milk-output evaluation base were lower than the obtained for a fixed herd-size and similar to those calculated assuming a fixed concentrate-input. Variation in economic values among different evaluation bases originates in different efficiencies in the use of production factors, according to the restrictions being applied.

6.3.4 Change in Prices and Feeding Strategy

Increasing the price of milk solids under a fixed herd-size base of evaluation caused a significant rise in economic values of FAT and PROT, and to a lesser extent, CR, BW and DRPR (Figure 2). Economic value for RC also increased significantly (results not shown). Conversely, the economic value of SR decreased as the price of milk solids increased (Figure 2). Economic value for CARR did not change (Figure 2). With a fixed concentrate-input the change in economic values for FAT, PROT, SR, BW and RC followed approximately the same pattern as for fixed herd-size, while CR and DRPR decreased (results not shown). Economic value for CARR did not change significantly. With a fixed milk-output the sensitivity of economic values to changes in price of milk solids was lower (results not shown). However CARR, FAT, PROT, and SR still followed the same pattern. DRPR, BW and RC did not change; and CR showed a slight reduction. High sensitivity of economic values to price of milk solids was expected, as most of farm income comes from milk sales. For this reason the economic value of the valuable milk components are affected the most. The reduction of economic values for some traits (SR, CR, and DRPR) can be explained from the results shown in Table 4, 5 and 6. As it was explained in previous sections, increase of genetic merit for these traits may result in a decrease of milk revenues caused by an increase in the number of non-productive days. This reduction in revenues was even larger when the price of milk solids increased, which caused the decreasing trend of economic values.

Changes in price of concentrate under a fixed herd-size of evaluation did not have major effects on economic values of any of the traits included in this study. Minor reductions happened in economic values of CARR, FAT, PROT, DRPR, and CR, while SR increased slightly. Economic values of BW and RC did not change.

With a fixed concentrate-input, the changes were also minor (results not shown). With a fixed milk-output only the economic value for RC showed a significant increase (results not shown). The minor changes in economic values caused by changes in price of concentrate are due to a rise in variable costs, with a consequent reduction of the net effect. Changes are small because a major part of the energy requirements of cows are obtained from forage, given the feeding strategy that was assumed.

In the same way, changes in the price of forage under a fixed herd-size base of evaluation did not alter the economic values of any trait. The same results were found for fixed concentrate-input and milk-output evaluation bases. In this case, the lack of sensitivity was due to the fact that the residual forage was given the same price as the forage consumed. Therefore, a rise in price of forage consumed was compensated by an equal reduction in price of residual forage, leaving the economic values at the same level.

Economic values obtained under a fixed herd-size base of evaluation with feeding strategy FIX were compared to the results obtained with feeding strategy REL (Figure 3). Results are shown for all traits except RC. Economic value for CARR remained close to zero in both cases. Economic value for FAT and PROT were much lower for the poorest feeding strategy (FIX). This indicates that the genetic improvement of milk production traits is less profitable when the concentrate in the daily ration is limited. In other words, the production potential of the cow cannot be fully expressed. On the opposite, the economic value for BW (Figure 3) and RC (not shown) increased with the poorest feeding strategy. Economic values for RC were 84.53 and 189.04 for REL and FIX, respectively. This seems to indicate that genetic improvement of traits related to grazing capacity is more profitable when there is a restriction in the amount of concentrate fed in the ration. Economic value of DRPR was not substantially changed. Economic value of CR and SR also increased significantly with strategy FIX, which indicates that the genetic improvement of these traits also becomes more profitable under less favorable environmental conditions.

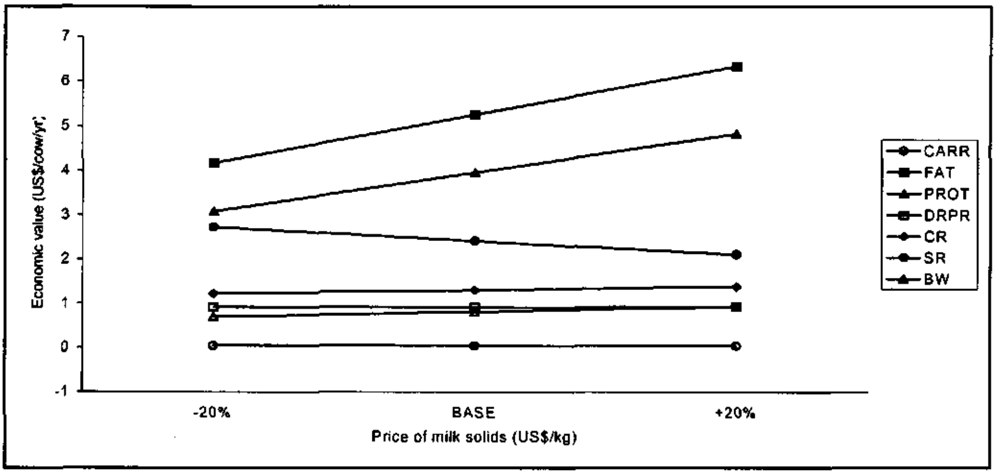


FIGURE 2. Sensitivity of economic values for production and functional traits to changes in price of milk solids (US$/kg) under a fixed herd-size base of evaluation.

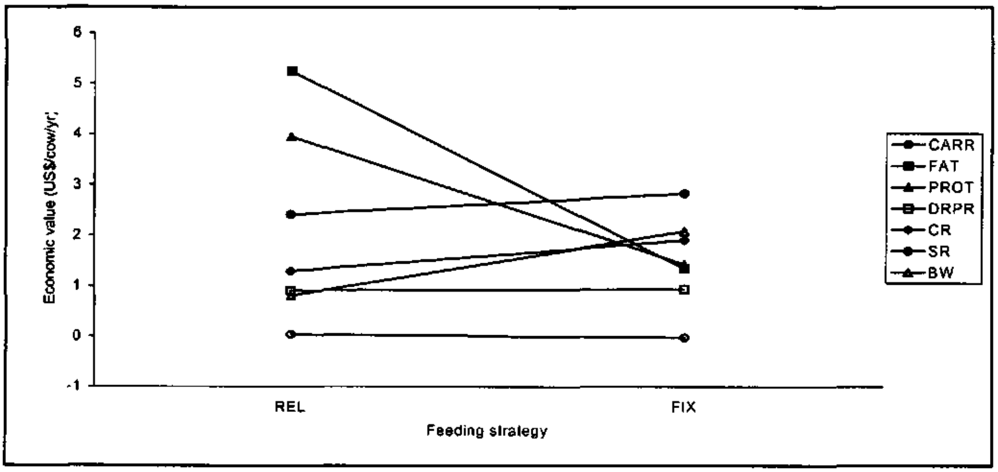


FIGURE 3. Economic values for production and functional traits of Holstein cows grazing on kikuyu (*Pennisetum clandestinum*) and fed REL (milk:concentrate equal 4:1) and FIX (6, 4, and 2 kg of concentrate during stages 0 to 100, 101 to 200, and > 200 d of lactation, respectively)..

6.4 CONCLUSIONS

Results found in this study provide important information about the type of traits that should be considered in a breeding goal for specialized dairy cattle in Costa Rica. These results can also be compared against the past and current trends in dairy breeding within this country to identify possible inconsistencies. The economic values found for milk production traits indicate that a major weight should be given to fat in relation to protein. Currently, most of the semen entering the country is coming from USA, where the selection index gives twice as much emphasis to protein compared to fat. This simple fact already shows an inconsistency in the breeding policies.

From our results it is also clear the importance of survival and conception rates as traits with positive economic values. Inclusion of health traits within the selection index in USA was done only until recently. The economic values for these traits are determined mainly by indirect effects, such as the reduction of replacement rates (and replacement costs), changes in the distribution of cows among age-classes or changes in the relative number of non-productive vs. productive days during the entire life of the cow. Although the importance of breeding for survival and fertility is clearly recognised world-wide, this becomes even more important in a developing country, where sanitary controls are less efficient and the incidence of diseases and fertility problems is higher.

Our results suggest that body weight, and especially feed intake capacity, are both traits with a positive economic value for production circumstances found in Costa Rica. Inclusion of these cow-efficiency traits in a selection index is not currently performed in USA. According to our results, these traits become even more important as the amount of forage in the daily ration increases, which is the situation found in specialized dairies of Costa Rica. Use of concentrate is not likely to increase in these farms, due to the high costs involved. On the other hand, forage can be produced at a relatively cheap price. Therefore, breeding of efficient grazers becomes of capital importance, in order to make a more efficient utilisation of this abundant feed resource.. On this sense, it is important to define the optimum size of a dairy cow for the production circumstances found in Costa Rica, in such a way that consumption of forage can be maximized. Our results indicate that breeding for higher body weight and rumen capacity can still further increase the profitability of a Holstein cow in Costa Rica.

Results found in this study also indicate that the model used was able to simulate some of the important relationships among genetic potential of a cow and its final phenotypic performance. Important interactions between breeding, nutrition, health and reproduction can be adequately translated into economical considerations at the farm level. This becomes especially important when analyzing highly variable and unpredictable production systems, such as found in Costa Rica. However, further parameterization and refinement of the model are necessary in order to improve consistency.

ACKNOWLEDGEMENTS

The authors thank the financial support from Stichting Samenwerkings Verband IO-instellingen & Wageningen University (SAIL), The Netherlands.

REFERENCES

1 AMHL, 1992. Technical report. Asociación de Mejoramiento de Hatos Lecheros -Costa Rica. 31 p.

2 Amer, P.R., and G.C. Fox. 1992. Estimation of economic weights in genetic improvement using neo-classical production theory: an alternative to rescaling. Anim. Prod. 54:341-350.

3 Bines, 1979. Voluntary food intake. In: W.H. Broster and H. Swan (Editors), Feeding strategy for the High Yielding Dairy Cow. E.A.A.P. Publ. No. 25, Granada, New York, pp. 23-48.

4 Boichard, D. 1990. Estimation of the economic value of conception rate in dairy cattle. Livest. Prod. Sci. 24:187-204.

5 Brascamp, E.W., Smith, C. and D.R. Guy. 1985. Derivation of economic weights from profit equations. Anim. Prod. 40:175-180.

6 Gibson, J.P. 1989. Selection on the major components of milk: alternative methods of deriving economic weights. J. Dairy Sci. 72:3176-3189.

7 Groen, A.F. 1989a. Economic values in cattle breeding. I. Influence of production circumstances in situations without output limitations. Livest. Prod. Sci. 22:1-16.

8 Groen, A.F. 1989b. Economic values in cattle breeding. II. Influence of production circumstances in situations with output limitations. Livest. Prod. Sci. 22:17-30.

9 Groen, A.F. and S. Korver. 1989. The economic value of feed intake capacity of dairy cows. Livest. Prod. Sci. 22:269-281.

10 Groen, A.F., Steine, T., Colleau J.J., Pedersen, J., Pribyl, J. and N. Reinsch. 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. Livest. Prod. Sci. 49:1-21.

11 Herrero, M., Fawcett, R.H. and J.B. Dent. 1996. Integrating simulation models to optimise nutrition and management for dairy farms: A methodology. In: Livestock Farming Systems: Research, Socio-Economics and the Land Manager. J.B. Dent et al. (eds.). EAAP publication No. 79. Wageningen, The Netherlands: Wageningen Pers, pp. 322-326.

12 Herrero, M., 1997. Modelling dairy grazing systems: an integrated approach. PhD thesis. University of Edinburgh, UK.

13 Herrero, M., Fawcett, R.H. and J.B. Dent. 1999. Bioeconomic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. Agric. Systems 62:169-188.

14 Illius, A.W. and I.J. Gordon. 1991. Prediction of intake and digestion in ruminants by a model of rumen kinetics integrating animal size and plant characteristics. J. Agric. Sci. 116:145-157.

15 INFOAGRO. 2000. Costa Rican-Agricultural Sector Statistics. www.infoagro.com.

16 Koenen, E.P.C., Berentsen, P.B.M. and A.F. Groen. 2000. Economic values of live weight and feed-intake capacity of dairy cattle under Dutch production circumstances. Livest. Prod. Sci. (in press).

17 Luiting, P. 1998. The role of genetic variation in feed intake and its physiological aspects: results from selection experiments. In: 5th Zodiac Symposium on Feed Intake Regulation. Wageningen, The Netherlands. April, 1998. Eds. D. van der Heidi, E.A. Huisman, E. Kanis, J.W.M. Osse and M.W.A. Verstegen. pp. 75-87.

18 Olesen, I., Groen, A.F. and B. Gjerde. 2000. Definition of animal breeding goals for sustainable production systems. J. Anim. Sci. 78:570-582.

19 Peters, K. J. 1993. Selection and breeding strategies for sustainable livestock production in developing countries, with particular reference to dairy cattle production. British Society of Animal Production, occasional publication 16:120-128.

20 Pieters, T., Canavesi, F., Cassandro, M., Dadati, E. and J.A.M. van Arendonk. 1997. Consequences of differences in pricing systems between regions on economic values and revenues of a national dairy cattle breeding scheme in Italy. Livest. Prod. Sci. 49:23-32.

21 Rogers, G.W.; van Arendonk, J.A.M., and B.T. McDaniel. 1988. Influence of involuntary culling on optimum culling rates and annualized net revenue. J. Dairy Sci. 71:3463-3469.

22 Smith, C.; James, J.W., and E.W. Brascamp. 1986. On the derivation of economic weights in livestock improvement. Anim. Prod. 43:545-551.

23 Solano, C. and B. Vargas. 1997. Growth of dairy replacement heifers of Costa Rican dairy farms 1. Mathematical description of the growth of Holstein and Jersey heifers. Arch. Latinoam. Prod. Anim. 5:21-36.

24 Stanton, T.L., Blake, R.W., Quaas, R.L., and L.D. Van Vleck. 1991. Response to selection of United States Holstein sires in Latin America. J. Dairy Sci. 74:651-664.

25 Steverink, M.H.A., Groen, A.F. and P.B.M. Berentsen. 1994. The influence of environmental policies for dairy farms on dairy cattle breeding goals. Livest. Prod. Sci. 40:251-261.

26 Syrstad, O. 1990. Dairy cattle crossbreeding in the tropics: the importance of Genotype × Environment interaction. Livest. Prod. Sci. 24:109-118.

27 Umaña, V., 1998. Comercio de productos lácteos en Centroamérica. In: La ganadería e industrias afines en centroamérica. Edited by R. Guillén et al. Unidad Regional de Asistencia Técnica (RUTA). San José, Costa Rica. 227 p.

28 Vandehaar, M.J., 1998. Efficiency of nutrient use and relationships to profitability on dairy farms. J. Dairy Sci. 81:272-282.

29 Van Arendonk, J.A.M. 1985. A model to estimate the performance, revenues and costs of dairy cows under different production and price situations. Agric. Systems 16:157-189.

30 Van Arendonk, J.A.M., and E.W. Brascamp. 1990. Economic considerations in dairy cattle breeding. Proc. 4th. World Congr. Genet. Appl. Livest. Prod., Edinburgh, Scotland, XIV:78-85.

31 Vargas, B. and C. Solano. 1995a. Projection and adjustment factors for lactational milk production of dairy cows in Costa Rica. Arch. Latinoam. Prod. Anim. 3:131-148.

32 Vargas, B. and C. Solano. 1995b. Genetic and environmental trends in milk production of dairy cattle in Costa Rica. Arch. Latinoam. Prod. Anim. 3:165-176.

33 Vargas, B., Koops, W., Herrero, M., and J.A.M. van Arendonk. 2000a. Modeling extended lactations of dairy cows. J. Dairy Sci. 83:1371-1380.

34 Vargas, B., Herrero, M. and J.A.M. van Arendonk. 2000b. Interactions between optimal replacement policies and feeding strategies in dairy herds. Livest. Prod. Sci. (in press).

35 Veerkamp, R. F. 1998. Selection for economic efficiency of dairy cattle using information on live weight and feed intake: a review. J. Dairy Sci. 81:1109-1119.

36 Vega Valverde, A. 1994. Caracterización de la actividad lechera en Costa Rica. Secretaría Ejecutiva de Planificación Sectorial Agropecuaria. 11 p. (mimeo).

37 Visscher, P.M., Bowman, P.J. and M.E. Goddard. 1994. Breeding objectives for pasture based dairy production systems. Livest. Prod. Sci. 40:123-137.

Minds are like parachutes. They only function when they are open.
Sir James Dewar

Chapter 7

Final considerations:

Implications for breeding strategy in Costa Rica

7.1 INTRODUCTION

In this thesis, a bioeconomic model is developed to support breeding and management decisions in dairy herds of Costa Rica. Chapters 1 to 4 provided some general information and input parameters for the model with regard to production and reproduction performance of dairy cows in Costa Rican farms. In chapter 5 this information was incorporated in the model for optimization of herd culling and insemination policies. Chapter 6 focussed on the use of the bio-economic model in calculating economic values for production and functional traits.

The present chapter summarises the major findings of the previous analysis, and discusses the implications of these results for the future breeding of specialized dairy cattle in Costa Rica. Several alternative breeding strategies will be presented and compared on a conceptual basis.

7.2 THE FACTS

On the basis of the information and results from previous chapters, some statements can be made regarding milk production in Costa Rica.

From chapter 1 we have learned that:

- The milk production systems in Costa Rica currently play an important economic and social role. They are responsible for the production of milk in the quantity and quality needed to satisfy the local demand, with some scope for an increased participation in markets within the region.
- There is a high diversity of climatic conditions, geographic morphology and availability of feed resources between different regions within the country. For this reason, different production systems have evolved to match the specific production conditions of each region.
- The specialized dairy production systems in the highlands of Costa Rica currently operate under medium/high cow-efficiency levels. These systems make use of exotic breeds, mainly Holstein and Jersey, to achieve production levels around 6000 kg/cow/lactation in Holstein and 4000 kg/cow/lactation in Jersey, with an age at first calving of approximately 28 mo and calving intervals around 390 days. These systems are able to meet the high milk quality standards required by the milk processing industries.

- The specialized dairy production systems make extensive use of external inputs, that leads to an increase in production costs. It is not clear whether these specialized dairy systems will be able to produce at a competitive price when current tariff-barriers disappear. It is clear that in order to survive in an open market, the specialized production systems need to concentrate on lowering the production costs by optimization of management and a transformation to a system that is less dependent on costly external inputs, i.e. concentrates. This transformation involves important changes in the fields of animal nutrition, health, reproduction and breeding.
- Past research in the area of dairy cattle breeding indicate that the increase in productivity levels found in Costa Rican farms has been caused mainly by improvement of management conditions and to a lesser extent by breeding. It seems also that G×E effects have a significant impact in these dairies.

From chapter 2 we have learned that:

- Additive genetic variance for daily milk yield in dairy cattle of Costa Rica is relatively low. Environmental factors seem to play a more important role within these production systems. Although AI is a common practice in specialized dairies, there is still a high proportion of non-AI sires being used.

From chapter 3 we have learned that:

- There is an important relation among heifer body weight and age at first calving. Heavier heifers calve earlier. There is little relation among heifer body weight and postpartum reproductive performance. Age at first calving seems to be more affected by environmental factors (herd-effects) than for heifer factors. Post-partum reproductive performance is also mainly affected by herd-related factors. There is little effect of heifer milk-yield on post partum reproductive performance. This suggests that heifer rearing-schemes should aim at higher growth rates.

From chapter 4 we have learned that:

- Extended lactations are common in Costa Rican farms. Traditional mathematical models used to describe standard lactations do not provide an adequate description of extended lactations. A diphasic model described extended lactations more precisely. There is a need to investigate the effect of extended lactations on lifetime profitability of dairy cows.

From chapter 5 we have learned that:

- Feeding strategies have an effect on optimal culling and insemination policies of dairy herds. Feeding strategies affect optimum average herd-life by changing the optimal time of insemination, optimal time to culling within the lactation and minimal milk-yield level needed for a profitable insemination. The average herd-life of cows in Costa Rican dairies is close to the optimum, but the calving interval can be further reduced to increase lifetime profitability of cows. The interaction between management practices and genetic potential of cows needs to be given more attention within these production systems. The developed bio-economic model provides important insights on this aspect.

From chapter 6 we have learned that:

- Genetic improvement of fertility, health and cow-efficiency traits will have a positive effect on profitability of Holstein cows in Costa Rica. For Costa Rican specialized dairies it is important to breed strong cows emphasising fat and protein production, grazing capabilities, fertility and survivability.

7.3 BREEDING PROGRAMME FOR DAIRY CATTLE OF COSTA RICA

Given the previous considerations it is clear that there is a need to explore the opportunities of different breeding strategies to meet the needs of the Costa Rican dairy farmers. The main question is whether the current breeding practices, based on importation of semen, should be continued; or whether there is room for a transition to a more local breeding scheme. This chapter will address this issue by taking the Holstein breed as an example.

From a conceptual point of view, importation of semen to improve the local cattle population is advised only under the following circumstances (17):

- Breeding goal for the exporting and importing populations are similar.
- Exotic stocks are better than domestic stocks for traits in the breeding goal.
- G×E effects are not important.

In the next section, we will consider a breeding goal for the Costa Rican Holstein population and this will be compared against a typical breeding goal of a country with a large breeding scheme. In these calculations, we concentrate on the principles involved in addressing the issue. A number of the input parameters need to be validated before giving a final answer.

7.3.1 Compatibility of Breeding Goals

The objective of this section is to determine the correlation between the breeding goal for Holstein cows in Costa Rica and a typical breeding goal for an exporting country. In order to perform this calculation we assumed some differences in the traits included in the breeding goal (H) and selection index of sires (I), and the relative weights given to these traits in the breeding goal. Three production traits (carrier, fat, and protein) and two functional traits (rumen capacity, survival rate) were chosen on the basis of the analysis performed by Vargas et al. (20). It was assumed that selection of sires in the exporting country is on the basis of performance of 100 daughters for production traits and survival rate. Selection in Costa Rica was also based on performance of 100 daughters for all traits, including rumen capacity. In order to determine the impact of differences in the definition of the breeding goal, the selection intensity was assumed equal to one for both countries.

Estimates of genetic and phenotypic parameters used in this analysis are given in Table 1. These are also assumed equal for both countries. Accurate estimates of heritabilities, and genetic and phenotypic correlations for all traits under analysis are not currently available for Costa Rican Holstein cattle, therefore figures were taken from the literature. Economic values for traits in the breeding goal for Holstein cattle in Costa Rica (Table 1) were calculated by Vargas et al. (20) assuming a fixed milk-output evaluation-base.

Economic values used for the exporting country (Table 1) were partly based on actual relative weights in the TPI economic index currently used for selection of Holstein cattle in USA (7, 23). However, some modifications were made in order to allow a direct comparison between countries. The TPI index includes production (fat, protein), type (type, udder, feet and legs) and health traits (productive life, somatic cells score) with relative weights of 4:2:1. No economic value is given to carrier, and the ratio between protein and fat within the production traits is 5:2. Rumen capacity (feed intake capacity) is not considered and productive life is used as an indicator of survival, with a relative weight of 0.9 within the health traits. In determining the economic values for production traits, the ratio of economic values for protein and fat in the exporting country was set equal to 5:2 and the total value (fat + protein) was assumed equal to the breeding goal for Costa Rica. An earlier study (20) determined that the economic value for survival rate in Holstein cattle of Costa Rica was in the same range as previous studies in other countries. Therefore, survival rate was given the same economic value in the exporting country and Costa Rica. Rumen capacity was assumed to have an economic value of zero in the exporting country.

TABLE 1.

Phenotypic standard deviations (σ_p), heritabilities (diagonal), phenotypic (above diagonal) and genetic (below diagonal) correlations, and economic values for traits to include in a hypothetical breeding goal for Holstein cattle in Costa Rica.

Trait	$\bar{x}$	σ_p	Carrier[1]	Fat[1]	Protein[1]	Rumen Capacity[2]	Survival Rate[3]	Economic Value	
								Costa Rica[4]	Exporting country
CARR	5170.3	1034.0	**0.30**	0.81	0.92	0.65	0.32	-0.04	0
FAT	202.1	50.5	0.73	**0.34**	0.87	0.65	0.34	3.53	1.84
PROT	157.8	39.5	0.88	0.85	**0.31**	0.65	0.33	2.91	4.60
RC	8.652	1.003	0.70	0.70	0.70	**0.25**	0.60	45.59	0
SR	92	12	0.62	0.64	0.69	0.70	**0.05**	3.18	3.18

[1] 305-d kg of carrier, fat and protein for a Holstein heifer (28 mo. old), one-yr calving interval, producing 5530.2 kg 305-d milk yield, fat content 3.65%, protein content 2.85%. Correlations and h^2 from Groen (1990).
[2] Obtained as 0.021 × heifer body weight. Correlations and h^2 obtained from Groen (4).
[3] Probability (%) of a Holstein heifer not to be culled by mortality, health, disease or udder and teats problems during one year. Correlations with carrier, fat and protein were taken from Visscher et al. (21).
[4] Economic values under a fixed milk output base of evaluation (20).

Selection index coefficients (**b**) were derived using the following equation:

$$\mathbf{b}=\mathbf{P}^{-1}\mathbf{G}\mathbf{v} \qquad [1]$$

where **P** is the variance-covariance matrix between traits in the selection index, **G** is the variance-covariance matrix between traits in the index and traits in the breeding goal, and v is a vector with economic values for traits in the breeding goal.

Correlation between the breeding goal for Costa Rica (H_{cr}) and the breeding goal in the exporting country (H_{exp}) can be derived as follows (2):

$$r_{Hcr,Hexp} = \frac{v_{cr}'\,C\,v_{exp}}{\sqrt{v_{cr}'\,C\,v_{cr}} \times \sqrt{v_{exp}'\,C v_{exp}}} \qquad [2]$$

with **C** as the variance-covariance matrix between traits in the breeding goal and **v** as defined in eq. (1). Note that **C** is equal for both countries.

We can also derive the correlation between the selection index obtained for Costa Rica (I_{cr}) and the selection index in the exporting country (I_{exp}) according to the following equation:

$$r_{Icr,Iexp} = \frac{b_{cr}' P\, b_{exp}}{\sqrt{b_{cr}' P b_{cr}} \times \sqrt{b_{exp}' P b_{exp}}} \qquad [3]$$

with **P** as defined for Equation [1]; and $\mathbf{b}_{cr}$ and $\mathbf{b}_{exp}$ are the vectors with selection index coefficients for proven sires in Costa Rica and the exporting country, respectively.

After solving Equations [1] to [3] we can compare the efficiency of both indexes for selection of sires assuming equal selection intensities. These results are shown in Table 2. The correlation between breeding goals was 0.987 and the correlation between selection indexes of sires was 0.976. This indicates that the difference in breeding goals between both countries does not result in major differences in the ranking of sires when selecting for any of the two breeding goals.

Traits with the highest contribution to the genetic gain are protein and fat (see ER, Table 2), but the relative importance differs between countries. Fat and protein account for 61.4% and 35.5% of the total response in CR, respectively, while for the exporting country the contributions are 32.5% and 63.6%, respectively. Rumen capacity contributes an additional 8.0% to the genetic response in Costa Rica, while the contribution of survival rate is less than 4% in both countries.

A comparison of the differences in breeding goals can also be based on the correlated response (CR), this is, the economic response in Costa Rica when selection of sires is on the breeding goal of the exporting country, assuming a genetic correlation of one between traits in both countries. The correlated response is shown in Table 2. In this case, the total genetic response includes the contribution of rumen capacity, which is the correlated response achieved for this trait when selecting for other traits in the breeding goal. The correlated response in Costa Rica from selection for the exporting country is 2.2% lower than the response from direct selection for the Costa Rican breeding goal. The relative contribution of traits to the total economic response is very similar for both alternatives.

TABLE 2.

Selection index coefficients (**b**) for selection of sires, genetic superiorities (GS), economic response (ER), and correlated response (CR) for breeding goals in Costa Rica and the exporting country assuming a selection intensity (*i*) equal to 1.

Parameter	Costa Rica			Exporting country			
	b_{cr}	GS[1]	ER[2]	b_{exp}	GS	ER	CR[3]
Carrier	-0.07	416.8	-16.67	-0.01	455.4	0	-18.22
Fat	6.98	27.50	97.08	3.51	26.11	48.04	92.17
Protein	5.60	19.29	56.13	8.71	20.41	93.89	59.39
Rumen Capacity	13.39	0.35	15.96	-	0.34	0	15.68
Survival rate	2.58	1.77	5.63	0.94	1.78	5.66	5.66
Total response (R)[4] (US$/cow/yr)			158.1			147.6	154.7
Standard deviation index (σ_I)	158.1			147.6			
Standard deviation breeding goal (σ_H)	167.0			156.0			
Accuracy of the index (R_{IH})	0.95			0.95			

[1] Genetic superiority (GS) = (i **b**' $\mathbf{G}_j$)/σ_I ; for j= 1 to 5, traits in the breeding goal; and $\mathbf{G}_j$ = jth column of **G**.

[2] Economic response (ER) = $GS_j\, \mathbf{v}_j$; for j= 1 to 5 (traits in the breeding goal).

[3] Correlated response (CR) in Costa Rica when selection is on breeding goal in the exporting country.

[4] Total response (R) = $i\, \sigma_I$ with i =1, R= σ_I.

In summary, we can conclude that selection for the breeding goal for the Costa Rican Holstein population would lead to similar rates of genetic response as compared to selection for the breeding goal in a exporting country. In practice, the differences between breeding objectives is not a major factor in evaluating importation of semen and breeding schemes based on the local Holstein population.

Besides the compatibility between breeding goals, two other important aspects need to be taken into account when comparing local vs. external breeding strategies, i.e. differences in genetic level and rates of genetic gain between the populations and the effect of G×E. These factors will be discussed in the next section.

7.3.2 Alternative Breeding Strategies

General concept. The objective of the following analysis was to determine the relative efficiency of alternative breeding schemes for the current Holstein population in Costa Rica using deterministic simulation. Three strategies were analyzed: semen importation (**SI**), progeny testing (**PT**) and closed nucleus breeding schemes (**CNBS**).

Economic values for Costa Rica and the exporting country and genetic parameters were given in Table 1. Information sources for the selection indexes were defined according to breeding scheme and selection path. The assumptions made for the different breeding schemes are described in the following sections.

Semen importation (**SI**). For this strategy it was assumed that genetic improvement of the local Holstein cattle population relies entirely on the importation of semen from the exporting country. This strategy has been suggested for situations in which the exotic stock suits the local production and marketing conditions and there are no major effects of G×E (17). Genetic resources available worldwide can be used locally at a reasonable price, due to the increasing number of competitors for this market (10). In the present study it was assumed that all imported semen was purchased from a single country. This country has a long-standing progeny testing scheme operating on a large dairy cow population. Cattle population parameters assumed for Costa Rica and the exporting country are given in Table 3. Figures for the exporting country were based on data for the Holstein cattle population in USA (23), which is currently the major provider of germplasm for Costa Rica. Selection intensities for the different selection paths were derived from these figures. It was also assumed that all cows in the population were inseminated using imported semen. No selection was performed within the local population, therefore genetic improvement for this strategy relied exclusively on the genetic superiority of the sires being imported. This is certainly not a realistic assumption, however the objective was to compare extreme cases, while the real situation would be at some point in between. Traits included in the selection index are given in Table 4. Genetic evaluation of sires was based on daughter performance for production traits and survival, with no measurements on rumen capacity.

Calculations for **SI** were initially performed assuming no effect of G×E and no initial difference in genetic level between populations. The effect of G×E was further examined by assuming two different levels of genetic correlations (0.50 and 0.75) between traits measured in both countries (the same genetic correlation for all traits). The effect of initial differences of 1.25, 1.50 and 2.0 standard deviations in overall genetic merit was also evaluated.

TABLE 3.

Population parameters assumed for a progeny-testing scheme for Costa Rican Holstein cattle, and selection intensities and generation intervals for selection paths sires of sons (SS), sires of daughters (SD), dams of sons (DS) and dams of daughters (DD).

Parameter	Exporting country		Costa Rica	
	Efficiency	Value	Efficiency	Value
Total population	...	4,400,000	...	200,000
Breeding population -AI + milk recording	50%	2,200,000	35%	70,000
Population of cows to select DS	10%	220,000	10%	7000
First lactation cows bred by AI[1]	25%	550,000	25%	17,500
Number of young bulls tested/yr	...	1500	...	50
Daughters/young bull[2]	...	100	...	100
Selection intensity	...		...	
SS	15/1500	2.66	4/50	1.86
SD[3]	45/1500	2.27	8/50	1.52
DS[4]	8570/220,000	2.17	286/7000	2.15
DD[5]	109/130	0.31	50/60	0.31
Generation interval (yr)				
SS	...	6.0	...	6.0
SD[6]	...	5.9	...	5.9
SS	...	5.0	...	5.0
SD	...	6.0	...	6.0

[1] All first-parity cows are assumed to be bred by young bulls

[2] Number of daughters = [Number of first-parity cows /number of young bulls] × conception rate (0.70) × sex ratio (0.50) × survival rate until first lactation (0.90) × rate of success first-lactation (0.90)

[3] It is assumed that imported semen is from sires in the top 10% of the ranking in the exporting country

[4] Number of dams = Number of young bulls / [conception rate (0.70) × sex ratio (0.50) × survivability (0.50)]

[5] Average number of heifers = [herd-size × conception rate (0.70) × sex ratio (0.50) × survivability (0.50)]. Number of heifers + later parity cows = heifers / 0.25

[6] L_{SD}= proportion young bulls (0.25) × 2.5 yr + proportion proven bulls (0.75) × 7 yr = 5.9.

Progeny-testing scheme (**PT**). For this strategy, it was assumed that a progeny-testing scheme was initiated within the local population, with genetic parameters as described in

Table 1. Progeny-testing schemes have been successfully practised for a long time in countries with a large dairy population. Selection of sires and dams can be performed directly within the same population to be improved. On the other hand, some disadvantages of this strategy are the need of a widespread milk-recording scheme and the extensive use of AI, which are not the norm in a developing country (10). Genetic gain largely depends on the effective size of the population. Besides, the inclusion of additional traits in the selection requires the implementation of a recording scheme.

Assumptions made about the size of the local population and the structure of the progeny-testing scheme are given in Table 3. Given the low population size, it is obvious that the number of bulls needed to sire all cows in the base population could be very low. Therefore, a minimum of four sires to breed sons and eight sires to breed dams was used to avoid too high rates of inbreeding. Traits in the selection index and information sources for this strategy are specified in Table 4. It was assumed that all cows under milk recording were sired by bulls selected from the local progeny-testing scheme. It was also assumed that production traits and survival rate were measured on the entire cow population participating in the breeding program, while rumen capacity was only measured on own performance of sires.

Closed Nucleus Breeding Scheme **(CNBS).** This strategy assumed that a nucleus breeding-herd was established in Costa Rica. The nucleus herd used Multiple Ovulation and Embryo Transfer (MOET). MOET nucleus breeding plans have been proposed to increase rate of gain in dairy cattle breeding by making use of increased female reproductive rate (11). Some advantages that have been mentioned for this scheme are that the entire breeding programme is operated as a single herd with a high degree of operational control over the determinants of genetic progress (10). Besides, generation intervals are shorter and important characters can be measured at a relatively low cost under the same conditions. Disadvantages that have been mentioned for this scheme are possible increase of inbreeding, major risk for spreading diseases, high initial investment and operating costs; and organisational considerations (6, 10).

In the present analysis, we considered a MOET on adult cows within a closed nucleus. Potential donors were selected on the basis of own performance during first lactation, and information on first lactation performance of full-sibs and half-sibs. Selection of sires and dams was performed only within the closed nucleus herd. Genetic gain in the base population was, therefore, entirely determined by the genetic gain within the nucleus. Data on structure and efficiency parameters assumed for the nucleus are given in Table 5 and were based on data on real schemes (10). Traits included in the selection index and information sources are given in Table 4. Note that for this strategy we assumed that rumen capacity was measured not only on males, but also in females.

TABLE 4.

Traits included in the selection index and information sources for breeding strategies based on semen importation (SI), progeny testing (PT) and closed nucleus breeding scheme (CNBS).

Breeding strategy	Traits in the selection index					Information sources
	CARR	FAT	PROT	RC	SR	
SI						
Sires-sires /Sires-dams	x	x	x	-	x	100 daughters
Dams-sires/Dams-dams	x	x	x	-	x	own performance + breeding values for sire and grandsire
PT						
Sires-sons/Sires-dams	x	x	x	x	x	own performance (rumen capacity) + 100 daughters (production traits and survival)
Dams-sires/Dams-dams	x	x	x	-	x	own performance (production traits and survival) + breeding values for sire and grandsire (all traits)
CNBS						
Sires-sons/Sires-dams	x	x	x	x	x	own performance (rumen capacity) + 4 full-sisters and 12 half-sisters (all traits)
Dams-sires/Dams-dams	x	x	x	x	x	own performance + 3 full-sisters and 12 half-sisters (all traits)

Genetic response for this strategy was compared against SI and PT assuming no initial differences in genetic merit. This is probably not a very realistic assumption, because the nucleus herd could be selected from outstanding individuals available in the exporting country (e.g. USA). This means that the initial genetic level of cows in the nucleus is much higher than the genetic level of the commercial population. The effect of this factor on the comparison between strategies will also be discussed.

TABLE 5.

Parameters assumed for a closed nucleus breeding-scheme (CNBS) in the Costa Rican Holstein population.

Parameter	Efficiency	Value
Number of cows in the nucleus herd[1]	...	256
Number of donor cows in the nucleus herd	...	32
Embryos per cow[2]	...	16
Male and female offspring per cow [3]	...	4/4
Number of full sibs per bull candidate	...	4
Number of half sibs per bull candidate	...	12
Selection intensity	...	
Males[4]	8/32	1.52
Females	32/256	1.40
Generation interval (yr)		
Males (yr)	...	3.50
Females (yr)	...	4.25

[1] Cows are assumed to be culled after their second lactation, therefore 130 replacements are needed per year

[2] Number of embryos assumes 4 flushes with 2 surviving males/females per flush

[3] Assuming only 60% conception rate after embryo transfer and 90% calf survival after birth.

[4] Eight males are selected from a total of 128 available in the herd, but a maximum of one male is allowed per full-sib family to minimise inbreeding, therefore male selection is within families and the fraction selected becomes 8/32.

Comparison criteria and sensitivity. The comparison criterion used in this analysis was the total genetic response (R) expressed in US$ per year. This was obtained from the following equation (16):

$$R=\frac{\sum_{s=1}^{4} ER_s}{\sum_{s=1}^{4} L_s} \quad [4]$$

This is, the stabilised genetic gain per year was equal to the economic responses (ER) in traits in the breeding goal summed across selection paths (s), and divided by sum of the generation intervals within selection paths. Economic response (ER) was obtained as described in Table 1 (see footnotes).

Some simplifying assumptions were made in the calculations. The change in genetic (co-) variance due to selection (1) and effects of family structure and population size on selection intensity were ignored. Inbreeding effects were only taken into account by setting a minimum number of sires to select in the progeny testing scheme and by setting a restriction of one bull selected per family in the closed nucleus scheme. The main objective of the present analysis was to provide a framework for comparing the results of alternative breeding schemes.

7.3.3 Results

Initial situation. The genetic response achieved for each breeding strategy and selection path is shown in Table 6. This table also gives information on selection intensities and accuracy of selection. Note that the results shown for SI correspond to the correlated response in Costa Rica when selection is performed in the exporting country, assuming a genetic correlation of one (no G×E effect), but different economic values for traits in the breeding goal. Strategy SI resulted in the highest rate of economic response. The response was 2.9% and 30.3% compared to CNBS and PT (Table 6). Cumulative genetic responses are plotted in Fig 1 assuming a time horizon of 25 yr and no initial genetic differences between populations. The genetic distance between populations will increase over time due to the differences in rates of genetic gain.

The advantage of SI over PT was mainly due, in this case, to the higher selection intensity for the SS and SD paths in the exporting country. This was, in part, the result of the differences in population size. The reduced size of the Holstein population in Costa Rica implies that the number of bulls that can be progeny tested is very low. The inclusion of rumen capacity in the selection index for Costa Rica did not produce a substantial increase in genetic response, due to the relatively low contribution of this trait. As previously discussed, the economic response is mainly determined by production traits. An earlier study also found a superiority of strategies based on SI over local PT schemes when genetic correlation between countries was assumed equal to one (13).

TABLE 6.

Economic response (ER, US$/yr) for strategies based on semen importation (SI), progeny testing (PT) and closed nucleus breeding scheme (CNBS) assuming a genetic correlation of 1.0 between traits in the breeding goal in both countries.

Path	σ_I	σ_H	R_{IH}	I	Genetic superiority [2]					ER	(%)
					CARR	FAT	PROT	RC	SR		
SI[1]											
SS	147.6	156.0	0.95	2.66	455.4	26.1	20.4	0.34	1.78	68.58	(42)
SD	147.6	156.0	0.95	2.27	455.4	26.1	20.4	0.34	1.78	44.82	(28)
DS	95.4	156.0	0.61	2.17	265.8	17.4	13.0	0.21	1.12	44.26	(27)
DD	95.4	156.0	0.61	0.31	265.8	17.4	13.0	0.21	1.12	5.27	(3)
										162.93	
PT											
SS	158.1	167.0	0.95	1.86	416.8	27.5	19.3	0.35	1.77	49.02	(39)
SD	158.1	167.0	0.95	1.52	416.8	27.5	19.3	0.35	1.77	25.75	(21)
DS	104.2	167.0	0.62	2.15	235.2	18.4	12.2	0.22	1.08	44.85	(36)
DD	104.2	167.0	0.62	0.31	235.2	18.4	12.2	0.22	1.08	5.39	(4)
										125.01	
CNBS											
SS	100.0	167.0	0.60	1.27	260.2	17.0	11.9	0.27	1.18	36.29	(23)
SD	100.0	167.0	0.60	1.27	260.2	17.0	11.9	0.27	1.18	36.29	(23)
DS	109.2	167.0	0.65	1.67	253.7	19.1	12.8	0.24	1.16	42.91	(27)
DD	109.2	167.0	0.65	1.67	253.7	19.1	12.8	0.24	1.16	42.91	(27)
										158.40	

[1] The response given for SI corresponds to the correlated response in Costa Rica when selection is on the breeding goal of the exporting country.

[2] Genetic superiority is given in the respective units of the trait.

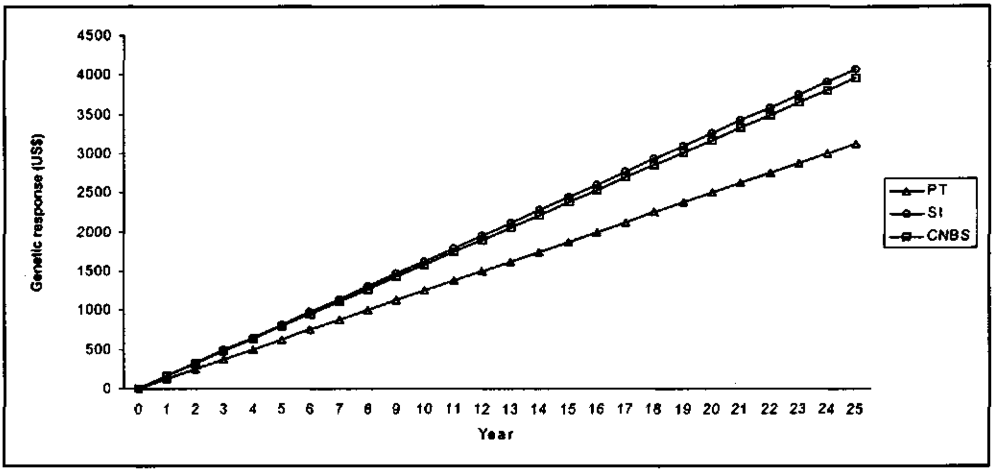


FIGURE 1. Genetic response (US$) for strategies based on progeny testing (PT), semen importation (SI) and closed nucleus breeding scheme (CNBS) assuming no G×E effect and no initial difference in genetic merit between populations.

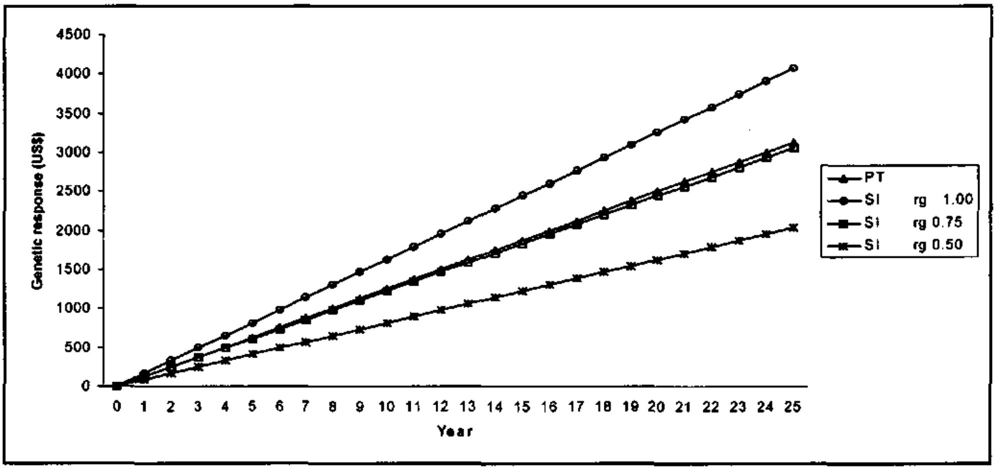


FIGURE 2. Genetic response (US$) for breeding strategies based on progeny testing (PT) and semen importation (SI) assuming genetic correlations of 1.0, 0.75 and 0.50 between traits in the breeding goals in the exporting country and Costa Rica.

From Table 6, we can also see that the superiority of CNBS over PT mainly originates from the increased reproductive capacity of females and the shorter generation intervals. As observed, most of the genetic gain was obtained through the dam paths (54%), while for SI and PT these two paths only contributed 30 and 40% of the total economic response, respectively. Superiority of CNBS over PT schemes has been reported before (9, 11, 13).

Effect of G×E. The effect of G×E was evaluated by simulating different degrees of genetic correlation between traits in the exporting country and Costa Rica. Three levels of genetic correlations were analyzed: 0.50 and 0.75 and 1.0. The genetic response for these three levels were compared against the genetic response obtained for strategy PT. The results are shown in Figure 2. As observed, when the genetic correlation was 0.50, the rate of response achieved by SI was lower than PT. With a genetic correlation of one, the genetic response from PT was 77% of the response from SI. This implies that both schemes result in the same genetic response when the genetic correlation is 0.77. As expected, the strategies SI and PT produced almost the same genetic response for a genetic correlation of 0.75 (Figure 2). Based on these results, importation of semen is justified from a genetic point of view when the genetic correlation between countries is higher than 0.75. This is in agreement with results found in previous studies (3, 13).

Initial differences in genetic merit. For strategy SI, genetic responses were also analyzed assuming initial differences in genetic merit of the population in the exporting country for a situation with a genetic correlation of 0.50 between traits in both countries. Results were compared against strategy PT for a time horizon of 15 yr only, in order to appreciate differences more clearly (Figure 3).

Initial differences in genetic merit will shift the line of economic response along the *y-axis*, but the rate of change in genetic response will remain at the same level. When the genetic correlations are high, the lines for SI and PT will never cross and SI will always be higher than PT. When genetic correlations are low, as shown in Figure 3, the line for PT will start below SI, and will intersect PT at some point in time due to the higher rate of genetic gain. The point of intersection will be determined by the initial difference in genetic merit, and can be obtained as $x = IGD/(R_{SI}-R_{PT})$, where x is the time in years, IGD is the initial difference in genetic merit for the index $[(1.25 \text{ or } 1.50 \text{ or } 2.0) \times \sigma_{H\text{-}PT}]$ (see Table 2), and $R_{SI}-R_{PT}$ is the difference in annual genetic responses between SI and PT (162.93 - 125.01). For the cases illustrated in Figure 3 the point of intersection is located at 5.5, 6.6 and 8.8 yr for 1.25, 1.50 and 2.0, respectively.

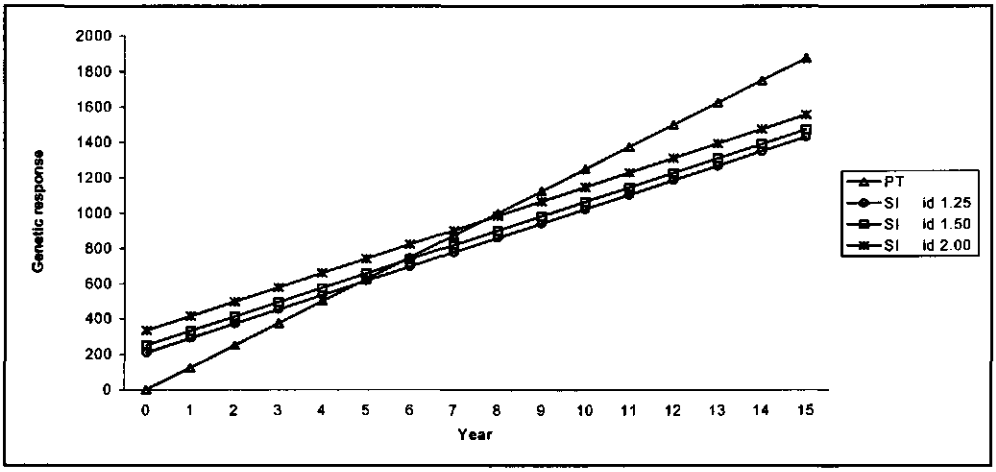


FIGURE 3. Genetic response (US$) for breeding strategies based on progeny testing (PT) and semen importation (SI) assuming initial differences (id) of 1.25, 1.50 and 2.00 genetic standard deviations in overall genetic merit for the exporting country and Costa Rica.

Other genetic considerations. The time between the start of a breeding programme and the realisation of genetic gain in the commercial cow population will differ between strategies. SI relies on the importation of semen from selected sires and has a direct effect on the commercial cow population. Genetic gain in the CNBS will take longer to reach the commercial population compared to SI and PT. These differences in timing do not affect the rate of genetic gain. The consequences can be visualised by moving the respective lines of economic response along the *x-axis*.

G×E can also be present in the CNBS, where the performance recorded on cows may not be the same in the nucleus herd compared to the commercial population. In this case, the same reasoning would apply as for SI.

7.4 IMPLICATIONS

The present results have clear implications for the design of a breeding programme for dairy cattle in a small country such as Costa Rica. For this specific case, it seems that the choice between local vs. externally based breeding programme depends largely on the level of G×E, because no major differences in breeding objectives were found. The question remains, however, on which is the current level of G×E within the population. A preliminary study found a correlation of 0.62 between breeding values of Holstein sires in USA and Costa Rica (19). However, the number of sires included in this study was low, and the only trait analyzed was milk yield. Other studies performed on AI Holstein sires from USA used in Latin America show even lower estimates (8, 14, 18). Powell et al. (14) reported a genetic correlation of 0.42 for Holstein sires evaluated in USA and Bolivia. A similar study in Brazil found genetic correlations in the range of 0.50 to 0.68 (8). Other studies, however, report correlations above 0.90 (15). If the estimate of 0.62 found for Costa Rica is close to reality, there is a clear prospect to establish a local breeding scheme.

The implementation of a progeny-testing scheme requires the participation of a large number of farmers in milk recording and artificial insemination. This might be difficult to realise given the relatively low participation of farms in milk-recording schemes. Strategies based on nucleus herd appear as a more sensible alternative. Such a scheme relies less on the collection of information in the commercial cow population. Previous research indicates that the major difficulty in establishing an effective nucleus breeding scheme in developing countries is to operate an efficient MOET programme, which requires very good nutritional and management conditions to be successful (10). In most cases, such conditions are rarely attained in developing countries. A few studies reported on the results of implementation of MOET programmes in developing countries (12, 22). Results showed large variation between countries, with low efficiency levels in general.

Apart from the technical comparison of schemes discussed so far, more general aspects needs to be taken into account when considering the future of dairy breeding in a country like Costa Rica. Current trends in dairy breeding seem to converge towards the globalization of breeding programmes. Under these circumstances, it is highly probable that international breeding companies will continue playing an important role on genetic improvement of the cattle population in developing countries. Several countries are already participating in a project for international evaluation of sires, under the guidance of INTERBULL. Access to information on genetic evaluations performed worldwide can now be easily gained through the Internet. These transformations will also have an effect on breeding of dairy cattle in developing countries, because these countries represent a potential market for international breeding programmes. However, these programmes will have to meet the requirements of the new markets, which means that the future generations of sires will have to satisfy the specific demands of specific countries and productive sectors.

Breeding programmes operating at a regional, rather than at the national level, may be a more sound option for small developing countries with similar production conditions.

Breeding companies may play a role in sponsoring these programmes and providing the necessary expertise to run it efficiently, while still making profit by fulfilling the requirements of a broader market.

REFERENCES

1 Bulmer, M. G. 1971. The effect of selection on genetic variability. The American Naturalist 105:201-211.

2 Gibson, J. P., and J.A.M van Arendonk. 1998. Introduction to the design and economics of animal breeding strategies. Lecture notes. Post-graduate course. Warsaw Agricultural University, Poland. 259 p.

3 Goddard, M.E. 1992. Optimal effective population size for the global population of black and white dairy cattle. J. Dairy. Sci 75:2902-2911.

4 Groen, A. F. 1990. Influences of production circumstances on the economic revenues of cattle breeding programmes. Anim. Prod. 51:469-480.

5 Hazel, L. N. 1943. The genetic basis for constructing selection indices. Genetics 28:476-490.

6 Hodges, J. 1989. Genetic improvement of livestock in developing countries using the Open Nucleus Breeding Systems. In: Conference on Open Nucleus Breeding Systems. Biatobrzegi (Poland), 11-19 June 1989, Ed. by M. Zurkowski; pp. 13-23.

7 Holstein USA, 2000. The new TPI index. Official website. (http://www.holsteinusa.com)

8 Houri Neto, M., Silva, H:M., and J.A.G. Bergmann. 1996. Vantagens e Desvantagens do uso do semen importado para producao de leite no Brasil. Arquivo Brasileiro de Medicina Veterinaria y Zootecnia. 48:755-762.

9 Meuwissen, T.H.E. 1990. The use of increased female reproductive rates in dairy cattle breeding schemes. Anim. Prod. 52:21.

10 McGuirk, B. 1989. The relevance of MOET programmes to developing countries. Theriogenology 31:29-40.

11 Nicholas, F.W., and C. Smith. 1983. Increased rates of genetic change in dairy cattle by embryo transfer and splitting. Anim. Prod. 26:341.

12 Niemann, H. 1992. The use of frozen/thawed embryos from livestock in developing countries. In: Potentials and limitations of biotechnology in livestock production in developing countries. Part 1: Animal Reproduction and Breeding. Proceedings of a Symposium held at the Institut fur Tierzucht und Tierverhalten (FAL), Mariensee, Germany in cooperation with the Council for Tropical and Subtropical Agricultural Research (ATSAF). Ed. by H. Niemann , H. Franzen and D. Smidt; pp. 140-147.

13 Mpofu, N., Smith, C., Van Vuuren, W., and E.B. Burnside. 1993. Breeding strategies for genetic improvement of dairy cattle in Zimbabwe 1. Genetic evaluation. J. Dairy Sci. 76:1163-1172.

14 Powell, R.L., Wiggans, G.R., and R.D. Plowman. 1990. Evaluations of Holstein bulls and cows in Ecuador. J. Dairy Sci. 73:3330-3335.

15 Powell, R.L., and G.R. Wiggans. 1991. Animal Model evaluation for Mexican Holsteins. J. Dairy Sci. 74:1420-1427.

16 Rendel, J.M., and A. Robertson. 1950. Estimation of genetic gain in milk yield by selection in a closed herd of dairy cattle. J. Genetics 50:1-8.

17 Smith, C. 1988. Genetic improvement of livestock using nucleus breeding units. World Anim. Rev. 65:2-9.

18 Stanton, T.L., Blake, R.W., Quaas, R.L., and L.D. Van Vleck. 1991. Response to selection of United States Holstein sires in Latin America. J. Dairy Sci. 74:651-664.

19 Vargas, B., and C. Solano. 1995. Genetic and environmental trends in milk production of dairy cattle in Costa Rica. Arch. Latinoam. Prod. Anim. 3:165-176.

20 Vargas, B., Groen, A., Herrero, M., and J.A.M. van Arendonk. 2000. Economic values for production and functional traits in Holstein cattle of Costa Rica. (Submitted to Livest. Prod. Sci.)

21 Visscher, P.M., and M.E. Goddard. 1995. Genetic parameters for milk yield, survival, workability and type traits for Australian Dairy Cattle. J. Dairy Sci. 78:205-220.

22 Wagner, H.G.R. 1987. Present status of embryo transfer in cattle. World Anim. Rev. 64:2-11.

23 Wiggans, G.R. 1997. Genetic evaluation systems in the United States. 32nd International Symposium, Animal Production. Advances in technology, accuracy, and management. September 29-October 1. Milan, Italy.

We think in generalities, but we live in details.
Alfred North Whitehead

Summary

The general goal of this dissertation was to develop a bio-economic model to support breeding and management in dairy herds of Costa Rica. Specific objectives were to determine important factors contributing to the variation in production and reproduction performance and to make use of this information to develop a model describing performance and merit during lifetime of a dairy cow. The resulting model was used to compare optimum replacement and insemination policies in a dairy herd used different feeding strategies. The model was also used to determine optimum recording schemes and breeding goal for Holstein cattle of Costa Rica on the basis of the relative economic values of production and functional traits. Alternative breeding strategies using this breeding goal were compared on the basis of the rate of genetic response achieved.

In **chapter 1** a general description was given of the milk production systems in Costa Rica for aspects related to management, nutrition, breeding, market structure and biological and economic efficiency. Due to the high diversity of climatic conditions, geography, and availability of feed resources, different production systems have evolved according to the specific conditions of each region. Three main production systems are identified: specialized dairy farms, lowland dairies and dual-purpose farms. Specialized dairy production systems have the highest productivity per cow and per unit of land, but production costs are the highest. Lowland dairies and dual-purpose systems are less efficient, but production costs are substantially lower. Past research in breeding of dairy cattle indicated that the increase in productivity levels found in Costa Rican farms have been caused mainly by improvement of management conditions and to a lesser extent by breeding. It seems also that Genetic × Environment effects have a significant impact in these dairies. Milk production systems in Costa Rica play an important role by providing milk in quantity and quality needed to satisfy the local demand, with some scope for an increased participation in markets within the region. Perspectives in the area of milk production were briefly analysed according to global trends in milk production and market structures. It is concluded that specialized production systems will need to be transformed into systems that are less dependent on costly external inputs.

In **chapter 2** variance components for test day yields in Holstein cows were calculated in order to assess the degree of genetic variance for milk production in the current population. Estimates of variance components for test day records were calculated with an animal model that considered multiple traits over multiple lactations, using REML methodology. Test day records were classified within first and later lactations. Missing ancestors in the relationship matrix were classified in genetic groups. Data were collected from Costa Rican dairy farms. Estimates of components for phenotypic and additive genetic variance were clearly heterogeneous during the lactation. Heritabilities for traits in first parity ranged between 0.15 and 0.23, and for later parities between 0.13 and 0.24. Higher heritabilities were found for midlactation records. Phenotypic and genetic correlations for adjacent test days were close to one. Phenotypic correlations were lower than genetic correlations. Heterogeneity of variances during the lactation suggested the adequacy of a test day model for multiple traits to describe milk yield during the lactation. When missing ancestors were allocated to a single base population, instead of genetic groups, the estimates of residual variance were lower, and the estimates of genetic variance and genetic correlations were higher. When standardized records were used instead of actual test day records, the estimates of residual and total variance were lower, and the estimates of genetic variance were higher. Consequently, estimates of heritability and genetic correlations were also higher. Therefore, the use of standardized data obtained by interpolation procedures is not advised for estimation of genetic variance components in a test day model.

In **chapter 3** an analysis was made on factors affecting reproduction performance of dairy cows of Costa Rica. Traits analysed were age at first calving, days to first breeding and days open during the first lactation of Holstein, Jersey and Brown Swiss heifers. Use was made of event-time methodologies. A proportional hazard model was used that included fixed effects of herd-year, year-season, breed type, herd weight category and heifer weight category. Body weights were recorded at 390 d of age on average. The model for days open and days to first breeding included two additional fixed effects of herd and heifer milk yield at 100 d. A significant effect of heifer weight category on age at first calving was found. The chance of calving was consistently higher for herds and heifers with higher body weight at 390 d, and decreased linearly from the top to the lowest quartiles. Effects of herd weight category on days to first breeding and days open were significant. Heifers in herds with a higher average body weight were less likely to be bred, and heifers in herds with lower average body weight were less likely to get pregnant. The effect of heifer weight category on days to first breeding or days open was not significant. The effect of herd milk yield on days to first breeding was significant. Heifers in herds with lower yield were more likely to be bred. The effect of heifer milk yield category on days to first breeding and days open was significant, but no linear trend was found for the estimates of the hazard ratios. The chance of a heifer being bred and becoming pregnant was similar among the first three quartiles, and lower for heifers in the lowest quartile. It was concluded that the probability of reaching a first calving can be improved by increasing the body weight at 390 d. Body weight at 390 d did not have a large effect on reproductive performance after first calving. High milk yield appears not to have a large negative effect on days open, within the production levels analysed in this study.

In **chapter 4** nine mathematical models were compared on their ability to predict daily milk yields in standard 305-d and extended lactations of Holstein cows of Costa Rica. Lactations were classified according to parity, lactation length and calving to conception interval. Of the nine models, the diphasic model and lactation persistency model resulted in the best goodness of fit as measured by adjusted coefficient of determination, residual standard deviation and Durbin-Watson coefficient. All other models showed a lower accuracy and residuals were positively correlated. In extended lactations, models were also fitted using only test day records before 305 d, which resulted in a different ranking. The diphasic model showed the best prediction of milk yield in standard and extended lactations. It was concluded that the diphasic model provides accurate estimates of milk yield for standard and extended lactations, although the interpretation of parameters needs further study due to the large variation observed. As expected, the interval calving to conception had a negative effect on milk yield for cows with a standard lactation length. In extended lactations, these negative effects of pregnancy on milk yield were no longer observed.

In **chapter 5** parameters calculated in the previous chapters were used to develop a bio-economic model that permits the analysis of interaction between management and breeding aspects in dairy herds. The bio-economic model was the result of the integration of a dynamic performance model and a model that optimized culling and insemination policies in dairy herds using dynamic programming. The performance model estimated daily feed intake, milk yield and body weight change of dairy cows on the basis of availability and quality of feed, potential milk yield, and feed intake constraints. A set of cow-states was defined by lactation number, calving interval, potential milk yield and stage of lactation. Biological and economical parameters used in the model represented actual production circumstances in Costa Rican herds. Eight feeding strategies combining two forages and four concentrate allocation systems were simulated. Different feeding strategies resulted in maximal changes of 6.8 mo in optimal average herd-life, US$26.1 in monthly income per cow and 1.9% in replacement rates, while average calving interval was not affected. The main difference was found between feeding strategies based on flat ratios compared to feeding strategies based on daily milk yield. Feeding flat ratios altered the course of profitability due to the restriction of feed costs and its effect on animal performance. Average herd-life and monthly income under the optimal feeding strategy were highly sensitive to changes in price of milk, and less sensitive to changes in price of concentrates or price of forage. Calving interval was not sensitive to any of the factors. Comparison of optimal policies against actual parameters obtained from field data indicated that cows are being culled close to the optimal herd-life with calving intervals longer than optimum. The model is an efficient tool to study the interactions between nutrition, reproduction and breeding at the animal and herd level.

In **chapter 6** the bio-economic model was used to analyse possible traits to be included in the breeding goal for dairy cattle in Costa Rica. Economic values for production traits (carrier, fat, protein, and dressing percentage) and functional traits (conception rate, survival rate, body weight, and rumen capacity) were calculated for Holstein cattle of Costa Rica. Three evaluation bases were considered: fixed herd-size, fixed concentrate-input and fixed milk-output. With a fixed herd-size all traits had a positive economic value. Traits with the highest economic values were rumen capacity and fat yield; followed by protein yield, survival rate, conception rate, dressing percentage and body weight. Economic value for carrier was close to zero. With a concentrate-input limitation all traits except body weight and rumen capacity had significantly lower economic values compared to fixed herd-size. Economic values for body weight and rumen capacity did not change. With a milk-output limitation, economic values for all traits were significantly lower than for fixed herd-size. Sensitivity analysis indicated that economic values of fat, protein and rumen capacity increased significantly with higher prices of milk solids. Other traits were less sensitive to change in price of milk. Changes in price of concentrate or forage did not alter economic values significantly. The results of this analysis suggest that genetic improvement of fertility, health and cow-efficiency traits will have a positive significant effect on profitability of Holstein cows in Costa Rica.

Finally, in **chapter 7** an analysis was made to compare alternative breeding strategies for Holstein cattle in Costa Rica. At first, a local breeding goal was defined on the basis of results found in chapter 6. This breeding goal was compared to a typical breeding goal for an exporting country. Efficiency of breeding goals for selection of sires was assessed on the basis of genetic response in economic units, assuming equal selection intensities, accuracy

of selection, and genetic parameters for traits in the breeding goal and selection index. Differences in genetic response were less than 3%, and the correlation between breeding goals was 0.99. Therefore it was concluded that the differences between breeding objectives is not a major factor in evaluating importation of semen and breeding schemes on the local Holstein population. An additional analysis was performed to assess the possible effect of changing the current trends in breeding of local dairy cattle, based on semen importation, against alternative breeding strategies based on selection within the local population. Local strategies considered in this analysis were a progeny testing scheme and a closed nucleus breeding scheme. Selection intensities and accuracy of selection were defined according to actual population sizes and reproduction efficiency parameters. When genetic × environment interactions were ignored semen importation was the strategy with the highest genetic response, 2.9% above closed nucleus breeding scheme and 30.3% above progeny testing. Genetic × environment interactions were considered by defining a correlation between breeding values in both countries lower than one. This resulted in permanent effects on the relative efficiencies of breeding strategies, because of the reduction in the rate of genetic response when imported semen was used. When the genetic correlation was assumed lower than 0.77, the genetic response achieved with semen importation was reduced at the same level as local progeny testing. When an initial difference in average genetic merit of the populations was assumed, this only had a temporal effect on the relative ranking of strategies, which is reverted after some years of selection because the rate of change in genetic responses remain unchanged. Given that the actual levels of genetic correlation between countries may be around 0.6, it is concluded that a local breeding scheme based on a nucleus herd could provide better results than the current strategy based on semen importation. However, the current trend towards globalisation of breeding programmes may result in more attractive alternatives within the next years.

Samenvatting

Het algemene doel van dit proefschrift was de ontwikkeling van een bio-economisch model voor beslissingsondersteuning op het gebied van genetische verbetering en management van melkveehouderijen in Costa Rica. Specifieke doelen van dit proefschrift waren de bepaling van factoren die een belangrijke rol spelen in de variatie van produktie en reproduktie van melkkoeien, en het gebruik maken van deze informatie voor de ontwikkeling van een model dat de prestatie en waarde van een melkkoe gedurende haar leven beschrijft. Dit model werd gebruikt om optimale strategieën voor vervanging en inseminatie van melkkoeien te vergelijken, afhankelijk van verschillende voersystemen in de melkveehouderij. Het model werd eveneens gebruikt voor de bepaling van een optimaal registratie-systeem en de definiëring van het fokdoel voor Holstein koeien, afhankelijk van de economische waarde van produktie en functionele diereigenschappen. Verschillende fokprogramma's die gebruik maken van het voornoemde fokdoel werden ook vergeleken op basis van de genetische respons.

In **hoofdstuk 1** is een algemene beschrijving gegeven van de verschillende melkproduktie systemen in Costa Rica, in relatie tot management, voeding, fokkerij, markt structuren, en de biologische en economische efficiëntie. Omdat er veel verschillen zijn in klimatologische omstandigheden, geografische omstandigheden, en de beschikbaarheid van voedselbronnen, zijn er, afhankelijk van de specifieke omstandigheden van elke regio, verschillende produktiesystemen ontstaan. Er worden drie algemene produktiesystemen geïdentificeerd: het gespecialiseerde melkveebedrijf, melkveebedrijven uit lage landen en dubbeldoelbedrijven. Gespecialiseerde melkveebedrijven hebben de hoogste produktiviteit per koe en per eenheid land, produktiekosten zijn echter hoger. Melkveebedrijven uit de lage landen en dubbel-doel produktiesystemen zijn minder efficiënt, maar de produktiekosten zijn behoorlijk lager. Eerder onderzoek op het gebied van genetische verbetering van melkvee levert het bewijs dat de toename van de produktie op melkveebedrijven in Costa Rica voornamelijk het resultaat is van de verbetering van management omstandigheden, meer dan van genetische verbetering. Ook bleek dat genotype × milieu-interactie een significante invloed heeft op de produktiviteit van deze produktiesystemen. Melkproduktiesystemen in Costa Rica spelen een belangrijke rol in de produktie van melk van hoge kwaliteit, die noodzakelijk is om in de lokale behoefte te voorzien, met enige ruimte voor toenemende participatie in andere markten binnen de regio. Mogelijkheden voor de toekomst van melkproduktie in Costa Rica werden kort geanalyseerd binnen de context van wereldwijde trends voor melkproduktie en de structuur van de melkmarkt. Conclusie is dat het noodzakelijk is de gespecialiseerde melkproduktie systemen van Costa Rica te transformeren, zodat afhankelijkheid van kostbare produktiefactoren vanuit het buitenland wordt geminimaliseerd.

In **hoofdstuk 2** werden variantiecomponenten voor de dagelijkse melkproduktie van Holstein koeien geschat om de mate van additief genetische variantie binnen de populatie voor melkproduktie te bepalen. Variantiecomponenten werden geschat met een diermodel voor verschillende kenmerken over lactaties, gebruikmakend van REML-methodologie. Dagprodukties werden geclassificeerd binnen de eerste en overige lactaties. Onbekende voorouders in de relatie-matrix werden geclassificeerd binnen genetische groepen. Gegevens werden verzameld van melkveebedrijven uit Costa Rica. Phenotypische en additief genetische variantie was duidelijk heterogeen voor de verschillende periodes in de lactatie. Erfelijkheidsgraden voor dagelijkse melkproduktie binnen de eerste lactatie lagen tussen 0.15 en 0.23, en voor overige lactaties tussen 0.13 en 0.24. Hogere erfelijkheidsgraden werden gevonden voor melkproduktie in het midden van de lactatie. Phenotypische en genetische correlaties voor aangrenzende dagelijkse melkproduktie waarnemingen lagen in de buurt van de één. Phenotypische correlaties waren lager dan genetische correlaties. Heterogeniteit van variantiecomponenten gedurende de lactatie betekent dat een dagproduktie model geschikt is voor het beschrijven van melkproduktie tijdens de lactatie. Wanneer onbekende voorouders werden meegenomen als basis populatie, in plaats van in genetische groepen, waren schattingen voor de rest-variantie lager, en schattingen voor de genetische variantie en de genetische correlaties waren hoger. Wanneer gestandaardiseerde melkproduktie werd gebruikt in plaats van veldgegevens, waren de schattingen voor de restvariantie, de totale variantie en de genetische variante hoger. Daarom wordt voor het schatten van genetische variantie het gebruik van gestandaardiseerde melkproduktie, berekend met behulp van interpolatie methoden, niet geadviseerd.

In **hoofdstuk 3** is een analyse gemaakt van de verschillende factoren die belangrijk zijn voor de bepaling van vruchtbaarheid van melkkoeien in Costa Rica. Kenmerken die werden geanalyseerd waren leeftijd van eerste afkalving, het interval afkalven-eerste inseminatie en het interval afkalven-conceptie van Holstein, Jersey en Brown Swiss melkvaarzen. Gebruik werd gemaakt van 'survival analyse' methoden. Een 'proportional hazard' model werd gebruikt met daarin 'fixed' effecten van bedrijf-jaar, bedrijf-seizoen, jaar-seizoen, ras, gewichtsniveau van het melkveebedrijf binnen de gehele populatie, en het gewichtsniveau van de individuele vaars binnen het bedrijf. Individuele lichaamsgewichten werden gemeten op een leeftijd van ongeveer 390 dagen. Het model voor het interval afkalven-eerste inseminatie en het interval afkalven-conceptie had twee extra effecten; melkproduktieniveau van het bedrijf en melkproduktieniveau van de individuele vaars gedurende de eerste 100 dagen van de lactatie. Er werd een significant effect van het individuele gewichtsniveau van de vaars op leeftijd van eerste afkalving gevonden. De kans op een eerste afkalving was hoger voor vaarzen van bedrijven met een hoger gewichtsniveau, en voor vaarzen met een hoger eigen gewichtsniveau. De kans op een eerste afkalving nam lineair af voor de lagere gewichtsniveaus. Effecten van gewichtsklasse van bedrijf op het interval afkalven-eerste inseminatie en het interval afkalven-conceptie waren ook significant. Vaarzen van bedrijven met een hoger gewichtsniveau hadden een lagere kans om geïnsemineerd te worden, terwijl vaarzen van bedrijven met een lagere gewichtsniveau een kleinere kans hadden om drachtig te worden. Er werden geen significante effecten van individueel gewichtsniveau op het interval afkalven-eerste inseminatie en het interval afkalven-conceptie gevonden. Een significant effect van produktieniveau van het bedrijf op het interval afkalven-eerste inseminatie werd ook geconstateerd. Vaarzen van bedrijven met een lager produktieniveau hadden een kleinere kans om drachtig te worden. Het effect van individueel produktieniveau van de vaars op het interval afkalven-eerste inseminatie en afkalven-conceptie was ook significant, hier werd geen lineaire trend gezien. De kans op inseminatie of conceptie waren gelijk voor de eerste drie produktieklassen, maar lager voor de laatste. Conclusie was dat de mogelijkheid op een eerste afkalving groter kan worden met een verhoging van het 390 dagen lichaamsgewicht van de vaars. Het gewicht van de vaars heeft geen effect op de vruchtbaarheid na het eerste afkalven. Een hogere melkproduktie bleek geen belangrijk negatief effect te hebben op het interval afkalven-conceptie, tenminste niet binnen de produktieniveaus die hier zijn onderzocht.

In **hoofdstuk 4** werden negen mathematische modellen vergeleken op basis van geschiktheid voor het voorspellen van de dagproduktie van standaard 305-dagen lactaties en lactaties langer dan 305 dagen van Holstein koeien uit Costa Rica. Lactaties waren geclassificeerd volgens lactatienummer, lengte, en interval tussen afkalven en volgende conceptie. Modellen met de beste 'goodness of fit' waren het 'diphasic' model en het 'lactatie-persistentie' model, volgens de gecorrigeerde determinatie coëfficiënt, rest standaard deviatie en Durbin-Watson coëfficiënt.

De overige modellen hadden een lagere precisie en een positieve correlatie tussen de residuen. De modellen voor lactaties langer dan 305 dagen werden ook gebruikt met alleen dagprodukties onder 305 dagen, met een andere rangschikking van de modellen als resultaat. Het 'diphasic' model resulteerde in de beste voorspelling van melkproduktie voor beide, 305 dagen lactaties en lactaties langer dan 305 dagen. Conclusie was dat het 'diphasic' model nauwkeurige schattingen van dagproductie voor standaard en verlengde lactaties geeft, hoewel verdere studie noodzakelijk is voor de interpretatie van parameters die een grote variatie hadden. Zoals verwacht, het interval afkalven-conceptie had een negatief effect op de dagproduktie voor koeien met een standaard lactatielengte. Voor lactaties langer dan 305 dagen werden deze negatieve effecten niet meer gevonden.

In **hoofdstuk 5** worden de parameters die waren berekend in de vorige hoofdstukken gebruikt voor de ontwikkeling van een bio-economische model, dat geschikt is voor de analyse van interacties tussen management en genetische verbetering in melkveebedrijven. Dit bio-economische model was het resultaat van de integratie van twee bestaande modellen, een dynamisch model voor de voorspelling van opbrengst van de melkkoeien, en een model dat ontwikkeld was om de vervanging en inseminatie tactieken van een melkveebedrijf te optimaliseren door middel van dynamisch programmeren.

Het opbrengst-model geeft schattingen van dagelijkse voeropname, melkproduktie en lichaamsgewicht van een melkkoe, op basis van beschikbaarheid en kwaliteit van voer, de potentiële melkproduktie van de koe, en beperkingen in voeropname. Een set van toestanden waarin een melkkoe zich zou kunnen bevinden, werd gedefinieerd met behulp van lactatie nummer, tussenkalftijd, potentiële melk produktie en lactatiestadium. Biologische en economische parameters die in dit model gebruikt werden staan voor reële produktie omstandigheden op melkveebedrijven uit Costa Rica. Acht verschillende voederstrategieën, een combinatie van twee grassen en vier verschillende allocatie systemen van krachtvoer, werden gesimuleerd. Verschillende voederstrategieën resulteerden in een maximaal verschil van 6.8 maanden in de optimale leeftijd van de aanwezige koeien op het melkveebedrijf, US$26.1 in maandinkomen per koe en 1.9% in vervangingspercentage, terwijl de tussenkalftijd niet werd beïnvloed. Het belangrijkste verschil werd gevonden tussen voederstrategieën die gebaseerd waren op een vaste hoeveelheid krachtvoer en strategieën die afhankelijk waren van de dagproductie van de koe. Het voeren van vastgestelde hoeveelheden krachtvoer verandert het normale verloop van de economische opbrengst van een koe gedurende haar leeftijd, doordat de voederkosten waren beperkt en dit effect heeft op de opbrengst van de koe. De gemiddelde leeftijd van de koeien op het melkveebedrijf en het maandinkomen met de optimale voederstrategie had een hoge gevoeligheid voor veranderingen in de prijzen van melk, en was minder gevoelig voor veranderingen in de prijs van kracht- en ruwvoer. De tussenkalftijd was niet gevoelig voor deze factoren. De vergelijking van optimale strategieën met reële parameters die geschat werden op basis van reële gegevens van melkveebedrijven laat zien dat de afvoer van koeien bijna gelijk is aan de optimale gemiddelde leeftijd, terwijl de tussenkalftijd langer is dan de optimale tussenkalftijd. Het ontwikkelde model is een efficiënt stuk gereedschap voor het bestuderen van interacties tussen voeding, vruchtbaarheid en genetische verbetering van het niveau van de individuele koeien en melkbedrijven.

In **hoofdstuk 6** werd het bio-economische model gebruikt voor de analyse van mogelijke kenmerken die kunnen worden bijgevoegd in een fokdoel voor melkkoeien uit Costa Rica. Economische waarden voor produktie kenmerken (carrier, vet, eiwit, uitslachtings-percentage) en functionele kenmerken (drachtigheidskans, overlevingkans, lichaamsgewicht en pens capaciteit) werden geschat voor Holstein koeien uit Costa Rica. Drie verschillende produktie beperkingen waren gesimuleerd: een vast aantal koeien op melkveehouderij, een vaste krachtvoerhoeveelheid en een vaste hoeveelheid geproduceerde melk. Bij een vast aantal koeien op melkveehouderij situatie hadden alle eigenschappen een positieve economische waarde. Eigenschappen met de hoogste economische waarden waren pens capaciteit en vetproduktie, en vervolgens eiwitproduktie, overlevingkans, drachtigheidskans, uitslachtings-percentage en lichaamsgewicht. De economische waarde voor carrier was bijna nul. Bij de situatie met een vaste krachtvoerheelheid, hadden alle eigenschappen, behalve lichaamsgewicht en pens capaciteit, lagere economische waarden. Economische waarden voor lichaamsgewicht en pens capaciteit veranderden niet. Bij de situatie met een vaste hoeveelheid geproduceerde melk waren economische waarden voor alle eigenschappen lager. Een gevoeligheidsanalyse wees uit dat de economische waarden voor vet, eiwit, en pens capaciteit stijgen als melkprijzen stijgen. Andere kenmerken waren minder gevoelig voor veranderingen van de melkprijs. Veranderingen in de prijs van kracht- of ruwvoer had geen effect op de economische waarden. Deze analyse laat zien dat de genetische verbetering van vruchtbaarheids-, gezondheids- en efficiëntie-kenmerken een positief effect hebben op de rentabiliteit van Holstein koeien in Costa Rica.

Tot slot, is in **hoofdstuk 7** een vergelijking gemaakt tussen verschillende fokprogramma's voor Holstein koeien in Costa Rica. Eerst is een lokaal fokdoel gedefinieerd op basis van de resultaten uit hoofdstuk 6. Dit fokdoel werd vergeleken met een typisch fokdoel voor een exporterend land. Efficiëntie van het selecteren van fokstieren voor beide fokdoelen werd vergeleken aan de hand van de genetische vooruitgang in economische eenheden, onder aanname van gelijke selectie-intensiteit, selectie-nauwkeurigheid, en genetische parameters voor eigenschappen in het fokdoel en selectie-index. Het verschil in genetische vooruitgang was minder dan 3% en de genetische correlatie tussen beide fokdoelen was 0.99. Conclusie was dat de verschillen tussen beide fokdoelen geen belangrijke rol spelen bij het evalueren van lokale fokprogramma's en het importeren van sperma. Verder onderzoek werd gedaan naar de verandering van huidige genetische trends, gebaseerd op het importeren van sperma en gebaseerd op selectie binnen de lokale populatie. Lokale fokprogramma's waren een nakomelingen test van proefstieren en een gesloten nucleus-programma. Selectie-intensiteit en selectie-nauwkeurigheid werden gedefinieerd vervolgens de reële grootte van de populatie en de reële reproductie efficiëntie parameters binnen de populatie. Wanneer genotype × milieu-interactie niet van toepassing was, was sperma import de strategie met de hoogste genetische vooruitgang, 2.9% boven het gesloten nucleus-programma en 30.3% boven de nakomelingen test van proefstieren. Genotype × milieu-interacties werden nagebootst door de correlatie tussen fokwaarde-schattingen van beide landen lager te maken dan één. Het resultaat was een blijvend effect over de relatieve efficiëntie van de verschillende fokprogramma's, omdat de genetische vooruitgang werd verminderd wanneer geïmporteerd sperma werd gebruikt. Wanneer de correlatie tussen landen minder dan 0.77 is, werd de genetische vooruitgang voor sperma import gelijk aan de nakomelingen test. Wanneer er een initieel verschil tussen de gemiddelde genetische waarde van beide populaties werd verondersteld, is er een tijdelijk effect op de relatieve efficiëntie van de verschillende fokprograma's. Dit wordt echter opgeheven na enkele jaren van selectie omdat de genetische vooruitgang van beide fokprograma's altijd hetzelfde is. Gegeven dat de reële genetisch correlatie tussen landen ongeveer 0.6 is, is de conclusie dat een lokaal fokprogramma gebaseerd op een gesloten nucleus een beter resultaat zou kunnen geven dan het importeren van sperma. Alhoewel de actuele globalisatie van fokprogramma's andere aantrekkelijke alternatieven zou kunnen brengen binnen de komende jaren.

Acknowledgement: Special thanks to Abe Huisman for his assistance in this translation.

Ideas occur to us when they please, not when it pleases us.
M. Weber

Resumen

El objetivo general de esta disertación ha sido desarrollar un modelo bioeconómico como herramienta de apoyo para el mejoramiento genético y el manejo de hatos de ganado lechero en Costa Rica. Los objetivos específicos fueron determinar los factores que contribuyen a la variación en comportamiento productivo y reproductivo del ganado lechero, desarrollando posteriormente un modelo que describe el comportamiento y mérito de una vaca lechera a lo largo de su vida productiva. El modelo es utilizado inicialmente para determinar políticas óptimas de reemplazo e inseminación de vacas lecheras bajo distintas estrategias de alimentación. El modelo se uilizó además para determinar rasgos productivos y funcionales de importancia económica para ser incluidos en el genotipo agregado y ser incorporados en futuros sistemas de recopilación de información. Se analizan también diferentes estrategias de mejoramiento genético basadas en el genotipo agregado determinado con anterioridad. Estas estrategias son comparadas sobre la base de la tasa de respuesta genética.

En el **capítulo 1** se presenta una descripción general de los sistemas de producción lechera en Costa Rica incluyendo aspectos de manejo, nutrición, mejoramiento genético, estructura de mercado y parámetros de eficiencia biológica y económica. Debido a la gran diversidad de condiciones ambientales y a la disponibilidad de variados recursos alimenticios se han desarrollado diversos sistemas de producción de acuerdo con las condiciones específicas de cada región. Se identifican tres sistemas de producción más importantes: lecherías especializadas de altura, lecherías de bajura y sistemas de doble propósito. Los sistemas de producción de lechería especializada presentan la mayor productividad por vaca y por unidad de área, pero los costos de producción son mayores. Las lecherías de bajura y los sistemas de doble propósito son menos eficientes, pero sus costos de producción son considerablemente menores. Estudios anteriores indican que el incremento en productividad de los hatos lecheros costarricenses ha sido causado principalmente gracias al mejoramiento de las condiciones de manejo y en un menor grado debido a mejoramiento genético. Estos estudios indican además que el impacto de interacciones genético-ambientales en estos sistemas es de importancia considerable. Los sistemas de producción de leche en Costa Rica juegan un papel importante ya que proveen leche en la cantidad y calidad necesaria para satisfacer la demanda local, con tendencia a un incremento en participación dentro de otros mercados dentro de la región. Las perspectivas en el campo de la producción de leche en Costa Rica se analizan en el contexto de las tendencias globales y las estructuras de mercado. Se concluye que los sistemas de producción de lechería especializada de necesitan ser transformados para disminuir su dependencia de factores de producción externos altamente costosos.

En el **capítulo 2** se realiza un análisis para determinar el nivel de varianza genética aditiva para producción diaria de leche presente en la población actual de vacas lecheras de Costa Rica. Los componentes de varianza se calcularon utilizando un modelo animal que incluyó rasgos y lactancias múltiples y la metodología REML. Los registros de producción diaria de leche fueron clasificados dentro de la primera y posteriores lactancia. Los ancestros desconocidos en la matriz de parentesco fueron clasificados dentro de grupos genéticos. Los componentes de varianza fenotípicos y aditivos obtenidos fueron claramente heterogéneos a lo largo de la lactancia. Los estimados de heredabilidad para rasgos de primera lactancia oscilaron entre 0.15 y 0.23. Para lactancias posteriores los estimados fueron entre 0.13 y 0.14. Se encontraron estimados de heredabilidad más altos para producción de leche en la mitad de la lactancia. Las correlaciones genéticas y fenotípicas para rasgos adyacentes fueron cercanas a 1. Las correlaciones fenotípicas fueron menores que las correlaciones genéticas. La heterogeneidad de varianza a lo largo de la lactancia sugiere la conveniencia de un modelo basado en produccines diarias en vez de producción total. Cuando los ancestros desconocidos fueron incluidos dentro de una única población base, en vez de grupos genéticos, los estimados de varianza residual fueron menores y los estimados de varianza genética y correlaciones genéticas fueron mayores. Cuando se utilizaron producciones diarias estandarizadas en vez de producciones reales, los estimados de varianza residual y total fueron menores, mientras que los estimados de varianza genética fueron mayores. En consecuencia, los estimados de heredabilidad fueron también mayores. El uso de datos estandarizados obtenidos a través de procedimientos de interpolación no se recomienda para la estimación de varianza genética aditiva en un modelo basado en producciones diarias.

En el **capítulo 3** se realiza un análisis de los factores que afectan el rendimiento reproductivo de vacas lecheras de Costa Rica. Los rasgos analizados fueron la edad al parto, el intervalo parto-concepción y el intervalo parto-primer servicio de vaquillas Holstein, Jersey y Pardo Suizo. Se utilizó la metodología del análisis de supervivencia con un modelo de riesgos proporcionales que incluyó efectos fijos de hato-año, año-época, raza, categoría de promedio de peso entre hatos y categoría de peso de la novilla dentro del hato. Los pesos corporales fueron estandarizados a 390 d de edad. El modelo para intervalo parto-concepción e intervalo parto-primer servicio incluyó los efectos fijos adicionales de nivel de producción de leche del hato y de la vaquilla durante los primeros 100 d de lactancia. La probabilidad de alcanzar un primer parto fue más alta para novillas provenientes de hatos con niveles más altos de peso corporal a 390 d y decreció en forma lineal de las categorías mayores a los menores. La misma tendencia se observó para los pesos individuales. Las vaquillas pertenecientes a hatos con un nivel de peso corporal más alto tuvieron menor probabilidad de ser servidas, y las vaquillas de hatos de menor peso promedio tuvieron menor probabilidad de preñarse. El efecto del nivel de peso de la vaquilla sobre el intervalo parto-primer servicio e intervalo parto-concepción no fue significativo. Las vaquillas pertenecientes a hatos de menor producción promedio tuvieron una mayor probabilidad de ser servidas. El efecto del nivel de producción de la vaquilla sobre el intervalo parto primer-servicio e intervalo parto-concepción fue significativo, pero no se encontró ninguna tendencia lineal en los estimados de riesgo. La probabilidad de una vaquilla de ser servida y preñarse fue similar en las tres categorías superiores y menor para la categoría inferior. Se concluyó que la probabilidad de alcanzar un primer parto puede incrementarse mediante el aumento del peso corporal a los 390 d. El peso corporal a los 390 d no tiene mayor efecto sobre el rendimiento reproductivo después del primer parto. Altas producciones de leche no parecen tener efectos negativos substanciales sobre el intervalo parto-concepción, dentro de los niveles de producción incluidos en este estudio.

En el **capítulo 4** nueve modelos matemáticos fueron comparados sobre la base de su eficiencia para predecir producciones diarias de leche en lactancias estándares de 305 d y lactancias extendidas de vacas Holstein de Costa Rica. Las lactancias fueron clasificadas según número de parto, duración total y longitud del intervalo parto-concepción. Entre los modelos analizados, el modelo difásico y el modelo de persistencia resultaron con la mejor bondad de ajuste, según los criterios de coeficiente de determinación, desviación estándar residual y el coeficiente Durbin-Watson. Los demás modelos mostraron una menor precisión y presentaron correlación positiva entre residuales. En lactancias extendidas, los modelos también fueron ajustados utilizando solo las producciones anteriores a los 305 d, dando como resultado una jerarquía diferente. Se concluyó que el modelo difásico provee la predicción más precisa de producción de leche en lactancias estándares y extendidas, pero la interpretación de los parámetros necesita de mayor estudio debido a la gran variación observada. El intervalo parto-concepción tuvo un efecto negativo sobre producción de leche para vacas con lactancias estándares. En lactancias extendidas, sin embargo, este efecto negativo de la preñez sobre la producción de leche no se observó.

En el **capítulo 5** los parámetros obtenidos en los capítulos previos fueron utilizados para el desarrollo de un modelo bioeconómico que permite el análisis de interacciones entre aspectos de manejo y mejoramiento genético en hatos lecheros. El modelo bioeconómico fue el resultado de la integración de dos modelos dinámicos. El primer modelo determina el rendimiento animal y el segundo optimiza políticas de inseminación y reemplazo.

El modelo de rendimiento estima consumo diario de alimento, producción de leche y cambio de peso de vacas lecheras sobre la base de las propiedades del alimento disponible, potencial genético para producción de leche y limitaciones físicas. Los posibles estadíos de producción de la vaca se definen según número de parto, el intervalo entre partos, el potencial genético para producción de leche y la etapa de la lactancia. Los parámetros biológicos y económicos utilizados en el modelo representan las circunstancias de producción actuales de los hatos lecheros de Costa Rica. Se simularon ocho estrategias de alimentación combinando dos forrajes y cuatro sistemas de suministro de concentrado. Las diferentes estrategias de alimentación resultaron en cambios máximos de 6.8 meses en longitud óptima de la vida productiva, US$26.1 en ingreso mensual por vaca y 1.9% en la tasa de reemplazo, mientras que el intervalo entre partos promedio no resultó afectado. Las principales diferencias se encontraron entre las estrategias de alimentación basadas en raciones fijas de concentrado comparadas con estrategias de alimentación basadas en producción diaria leche. La alimentación basada en raciones fijas altera la curva de rendimiento económico de la vaca, debido a la restricción de los costos alimenticios y a su efecto sobre la producción. El promedio de vida productiva y el ingreso mensual por vaca cuando se utilizó la estrategia de alimentación más rentable fueron altamente sensibles a cambios en el precio de la leche, y menos sensibles a cambios en el precio de los concentrados y el forraje. El intervalo entre partos no fue sensible a ninguno de los anteriores factores. La comparación de las políticas óptimas de reemplazon e inseminación contra los parámetros actuales obtenidos en hatos locales indica que las vacas están siendo desechadas cerca del momento óptimo pero con intervalos entre partos más largos del óptimo. El modelo es una herramienta eficiente para estudiar las interacciones entre nutrición, reproducción y mejoramiento genético a nivel de animal y hato.

En el **capítulo 6** el modelo bioeconómico fue utilizado para analizar posibles rasgos por incluir en un genotipo agregado para mejoramiento genético del ganado lechero de Costa Rica. Se calculó el valor económico de rasgos de producción (componente líquido, grasa, proteína y rendimiento en canal) y de rasgos funcionales (tasa de concepción, tasa de sobrevivencia, peso corporal y capacidad ruminal) en ganado Holstein de Costa Rica. Tres distintas limitaciones de producción fueron consideradas: tamaño fijo de hato, ingreso fijo de concentrado y cuota fija de producción de leche. Con tamaños de hato fijo todos los rasgos analizados presentaron valores económicos positivos. Los rasgos con los valores económicos más altos fueron capacidad ruminal y producción de grasa; seguidos por producción de proteína, tasa de sobrevivencia, tasa de concepción, rendimiento en canal y peso corporal. El valor económico para el componente líquido fue cercano a cero. Cuando se asume una limitación en el ingreso de concentrado los valores económicos de todos los rasgos, excepto peso corporal y capacidad ruminal, se reducen. Los valores económicos para peso corporal y capacidad ruminal no cambiaron. Cuando se asume una cuota de producción de leche los valores económicos para todos los rasgos fueron significativamente menores. El análisis de sensibilidad indicó que los valores económicos de grasa, proteína, y capacidad ruminal aumentan cuando el precio de sólidos se incrementa. Los demás rasgos fueron menos sensibles al cambio en el precio de la leche. El cambio en el precio del concentrado o el forraje no altera significativamente el valor económico de los rasgos analizados. Los resultados indican que el mejoramiento genético de la fertilidad, la salud y la eficiencia alimenticia tendría un efecto positivo considerable en el rendimiento de vacas Holstein de Costa Rica.

Finalmente, en el **capítulo 7** se realiza un análisis para comparar estrategias alternas de mejoramiento genético para ganado Holstein en Costa Rica. En primera instancia, se define el genotipo agregado de acuerdo con los resultados encontrados en el capítulo 6. Este se compara contra un genotipo agregado típico para un país exportador de material genético. La eficiencia de los relativa de ambos genotipos agregados para la selección de sementales se determinó sobre la base de la respuesta genética en unidades económicas producida por ambos, asumiendo la misma intensidad y confiabilidad de selección, y los mismos parámetros genéticos para los rasgos considerados. Las diferencias en respuesta genética fueron menores del 3% y la correlación obtenida entre ambos genotipos agregados fue de 0.99. Se concluye que la diferencia entre genotipos agregados no es un factor determinante a la hora de comparar estrategias de importación de semen contra estrategias locales de mejoramiento. Se realizó un análisis para determinar el efecto de un posible cambio en la tendencias actuales de mejoramiento basadas en la importación continua de semen, contra estrategias alternas basadas en programas de selección locales. Las estrategias locales que se consideraron fueron un programa de prueba de progenie y un esquema de mejoramiento basado en un hato núcleo. La intensidad y confiabilidad de selección fueron definidas de acuerdo con los tamaños reales de las poblaciones y a los parámetros de eficiencia reproductiva. Cuando las interacciones genético-ambientales son ignoradas la importación de semen es la estrategia con la respuesta genética más alta, 2.9% mayor que el esquema de hato núcleo cerrado y 30.3% superior a las pruebas de progenie. Las interacciones genético ambientales también fueron consideradas en el análisis mediante la definición de correlaciones menores que 1 entre valores genéticos en ambos países. Esto tiene un efecto permanente en la eficiencias relativas de las distintas estrategias, debido a la reducción en la tasa de respuesta genética cuando se utiliza semen importado. Cuando la correlación genética se asume menor que 0.77, la respuesta genética lograda mediante la importación de semen se reduce al mismo nivel que el programa de puebas de progenie. Cuando se asume una diferencia inicial en el mérito genético promedio de ambas poblaciones, hay un efecto en el ranqueo inicial de las estrategias, el cual se revierte después de algunos años de selección, debido a que las respuestas genéticas no son alteradas. Dado que los niveles actuales de correlación genética parecen estar alrededor de 0.60, se concluye que una estrategia local de mejoramiento basada en un hato núcleo podría proveer mejores resultados que la estrategia actual basada en la importación de semen. Sin embargo, la tendencia actual hacia la globalización de los programas de mejoramiento podría resultar en otras alternativas más atractivas en los próximos años.

Acknowledgements

This dissertation represents the final outcome of several years of hard work. As such, I want to acknowledge the collaboration of institutions and individuals that made of this not only an academic success, but also an enjoyable experience.

First, I want to thank the financial support given by Stichting Samenwerkings Verband IO-instellingen en Wagenigen Univesiteit (SAIL). The institutional support of Wageningen Universiteit and Universidad Nacional de Costa Rica, as counterparts of the project Regional Centre for Training and Research in Sustainable Animal Production (RESAP) is also appreciated.

Special thanks to the Department of Animal Breeding and Genetics. You have a very valuable group of professionals and I admire your team-work capacity, high productivity and continuous concern for providing an excellent work environment.

I want to thank also to all colleagues and friends of the formerly known Proyecto Salud de Hato, at UNA (Costa Rica), who participated in the collection and processing of the data. My gratitude also to the farmers, who were willing to provide this information.

My eternal gratitude to my promotor Johan. Very few times in life is possible to find a person with such a good combination of professional capacity and human qualities. Thanks for providing your invaluable guidance through all these years. It has been a nice experience to work with you.

Many thanks also to my co-promotor Mario, with whom I spent fruitful hours at the Institute of Ecology and Resource Management (IERM), The University of Edinburgh. Some of the most interesting results of this dissertation could not have been obtained without your collaboration.

Thank you Enrique for participating as co-promotor of this dissertation. It is clear for me that this 'adventure' was initially made possible thanks to your interest and valuable help.

The participation of Mees, Tette, Wiebe and Ab as co-authors of the papers is also specially appreciated. Thanks for your always-valuable comments and ideas.

Living in Wageningen gave me the opportunity to meet an amazing number of people from many different countries around the world. It is always good to confirm that goodwill, friendship, kindness, affection and fraternity do not have any specific nationality, language or colour of skin. It was also good to confirm that is possible to play (good!) soccer together with people from more than 20 different countries. Thanks Pharcyde for 'the most incredible soccer-adventure ever known'. Thanks also to the volleyball teams from Zodiac, with whom I enjoyed many emotive games. Special thanks to all nice people with whom I had the opportunity to share the 'corridor' (Dijkgraaf 5C and 9C), my office at Zodiac, the lunch-and-coffee tables, my apartment, or the endless latin/caribbean parties. Dear friends, I learned a lot from all of you... "old friends pass away, new friends appear, just like the days: an old day passes, a new day arrives; the important thing is to make it meaningful: a meaningful friend, or a meaningful day" (Dalai Lama). You will always be remembered.

Finalmente, mi profunda gratitud para mi familia. Vivir en el extranjero por tan largo tiempo representa un increíble sacrificio en términos de participación dentro de la vida familiar. Muchas gracias a mis padres, hermanos y hermanas no solo por su comprensión, sino también por su apoyo incondicional en esta importante etapa de mi vida.

To all of you, my eternal gratitude.

-Bernardo-

Curriculum vitae

Bernardo Vargas Leitón was born on November 23rd , 1967 in the city of Alajuela, Costa Rica; son of José Vargas García and Elida Leitón Villalobos. His elementary studies were completed at Escuela Jesús de Atenas (1978) and Liceo de Atenas (1984). His undergraduate studies were performed at Escuela Centroamericana de Ganadería- ECAG (1989), where he obtained a Higher Diplome in Animal Production. After finishing his studies, he worked for ECAG as Assistant on Teaching and Research at the Department of Dairy Cattle (1990-1991). In 1992, he was awarded a scholarship by Overseas Development Agency (ODA) to continue his studies at Universidad Autónoma de Yucatán-UADY (México), where he obtained his Master Science degree in the field of Animal Reproduction (1993). He returned to Costa Rica and worked at the Tropical Agronomic Centre for Research and Training (CATIE), as a consultant in the field of Conservation of Animal Genetic Resources (1994). In 1995, he worked at Universidad Nacional de Costa Rica (UNA), on the analysis of factors affecting production and reproduction traits of dairy cattle. At the end of 1995, he was awarded a scholarship by NUFFIC (The Netherlands) to follow further studies in the field of Animal Breeding at Wageningen University (1996). In 1997, he applied for a Ph.D position in WU as part of a joint project aiming at the creation of a Regional Centre for Training and Research in Sustainable Animal Production (RESAP). The project was finally granted by SAIL (The Netherlands) and was initiated in May,1997. After his Ph.D the author will work as academic co-ordinator of a newly developed M.Sc. Programme on Sustainable Animal Production at UNA (Costa Rica).

List of Publications

1 Vargas, B. 1989. Bio-economical analysis of a Palmito-Cheese production system from Limoncito, Cutris, San Carlos, (Costa Rica). DPA thesis. Escuela Centroamericana de Ganadería-ECAG (spanish). 80 p.

2 Vargas, B. 1993. Effect of growth rate in dairy heifers from the region of Poás (Costa Rica) on Pre and Post partum reproductive performance . MSc. thesis. Universidad Autónoma de Yucatán-UADY (spanish). 275 p.

3 Tewolde, A., and Vargas, B. 1994. Genetic progress of dairy cattle in the tropics. Paper presented in 2nd. Seminar on Animal Production Systems (held in San Jose, CR. Organised by EARTH) 8 p. (spanish).

4 Tewolde, A., and Vargas, B. 1994. Efforts on conservation of Animal Genetic Resources in Latin America. Paper presented in XIV Panamerican Congress on Veterinary Sciences. Acapulco, México. 10 p. (english).

5 Vargas, B., Rezvani, A., Tadese, M., and S. van der Beek. 1996. Estimation of breeding values for Hip Dysplasia status on a population of german shepherds dogs using categorical data and information from relatives. Animal Breeding and Genetics Group, Wageningen University. (english).

6 Vargas, B., and C. Solano. 1995. Correction factors for daily milk yield of dairy cattle of Costa Rica. Arch. Latinoam. Prod. Anim. ALPA 3(2):131-148. (spanish).

7 Vargas, B., and C. Solano. 1995. Correction and projection factors for total milk yield of dairy cattle of Costa Rica. Arch. Latinoam. Prod. Anim. ALPA 3(2):149-164. (spanish).

8 Vargas, B., and C. Solano. 1995. Genetic and environmental trends in milk yield of dairy cattle of Costa Rica. Arch. Latinoam. Prod. Anim. ALPA 3(2):165-176. (spanish).

9 Solano, C., and B. Vargas. 1997. Body growth of replacement heifers in dairy farms of Costa Rica. 1.Tipification of growth curves in Holstein and Jersey heifers. Arch. Latinoam. Prod. Anim. ALPA 5(1):21-36. (spanish).

10 Solano, C., and B. Vargas. 1997. Body growth of replacement heifers in dairy farms of Costa Rica. 2. Effect of growth rate and age at first calving on milk yield during first lactation. Arch. Latinoam. Prod. Anim. ALPA 5(1):37-50. (spanish).

11 Vargas, B., Pérez, E., and J.A.M. van Arendonk. 1997. Analysis of test day yield data of Costa Rican dairy cattle. 92nd. Annual Meeting of the American Dairy Science Association (June 22-25, Guelph, Canada). Abstract code P218 in J. Dairy Sci. 80, suppl. 1, page 197. (english).

12 Vargas, B., Pérez, E., and J.A.M. van Arendonk. 1998. Analysis of test day yield data of Costa Rican Dairy cattle. J. Dairy Sci. 81:255-263. (english).

13 Vargas, B., van der Lende, T., Baaijen, M., and J.A.M. van Arendonk. 1998. Event time analysis of reproductive traits in dairy heifers. 10th International conference on production diseases in Farm Animals (August 24-28, Utrecht, The Netherlands) Abstract code A85/p. 260 (english).

14 Vargas, B., van der Lende, T., Baaijen, M., and J.A.M van Arendonk. 1998. Event-time analysis of reproductive traits of dairy heifers. J. Dairy Sci. 81:2881-2889. (english).

15 Vargas, B., Koops, W.J., and J.A.M. van Arendonk. 1999. Modeling extended lactations of dairy cows. Book of abstracts of the 50th Annual Meeting of the European Association for Animal Production. (22-26 August, Zurich, Switzerland). Abstract code G2.17/p. 19 (english).

16 Vargas, B., Koops, W., Herrero, M., and J.A.M. van Arendonk. 2000. Modeling extended lactations of dairy cows. J. Dairy Sci. 83:1371-1380 (english).

17 Vargas, B., Herrero, M. and J.A.M. van Arendonk. 2000. Interactions between optimal culling and insemination policies and feeding strategies in dairy herds. Book of abstracts of the 51th Annual Meeting of the European Association for Animal Production. (21-24 August, The Hague, The Netherlands). Abstract code GCP3.10/p. 60 (english).

18 Vargas, B., Herrero, M. and J.A.M. van Arendonk. 2000. Interactions between optimal culling and insemination policies and feeding strategies in dairy herds. Livest. Prod. Sci. (in press).

19 Vargas, B., Groen, A., Herrero, M., and J.A.M. van Arendonk. 2000. Economic values for production and functional traits in Holstein cattle of Costa Rica. (Submitted to Livest. Prod. Sci.).