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STUDIES ON THE REPLACEMENT POLICIES IN DAIRY CATTLE

Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
in het openbaar te verdedigen
op vrijdag 8 november 1985
des namiddags te vier uur in de aula
van de Landbouwhogeschool te Wageningen

STELLINGEN

1. Ter ondersteuning van de melkveehouder bij het nemen van respectievelijk inseminatie- en vervangingsbeslissingen, verdient het aanbeveling om voor individuele melkkoeien de verwachte winst bij drachtig worden en de toekomstige winstgevendheid te berekenen.

Dit proefschrift.

2. Management- en fokkerijmaatregelen moeten worden gericht op het terugdringen van de door gezondheidsstoornissen veroorzaakte afvoer in plaats van op de maximalisatie van de gemiddelde gebruiksduur.

Dit proefschrift.

3. Burnside et al. veronderstellen ten onrechte dat bij een positieve genetische relatie tussen produktie en gebruiksduur selectie op produktie zal leiden tot een verlenging van de gemiddelde gebruiksduur.

Burnside, E.B., A.E. McClintock and K. Hammond, 1984. Animal Breeding Abstracts, 52: 711-719.

4. Bij de optimalisatie van het beleid voor inseminatie en vervanging van melkkoeien moet in de praktijk rekening worden gehouden met de seizoensvariatie in produktie en prijzen.

Dit proefschrift.

5. De selectie van stiermoeders moet worden aangepast wanneer maternale invloeden als gevolg van cytoplasmatische overerving optreden.

Huizinga, H.A., S. Korver, B.T. McDaniel and R.D. Politiek, 1985. Submitted for publication in Livestock Production Science.

6. De genetische correlatie voor een kenmerk gemeten op verschillende praktijkbedrijven, kan worden opgevat als een bovengrens voor de te verwachten relatie tussen een centraal toetsstation en de praktijk.

Brascamp, E.W., J.W.M. Merks and J.B.M. Wilmink, 1985. Livestock Production Science, 13: 135-146.

7. De onderbouwing van het geschetste belang van biotechnologische ontwikkelingen voor de fokkerij, laat vaak te wensen over.

8. Bij de definitie van het fokdoel in termen van biologische efficiëntie wordt ten onrechte voorbijgegaan aan verschillen in economisch belang van de onderliggende componenten.

9. Het beleid ten aanzien van rekenapparatuur bij de Landbouwhogeschool zou meer gericht dienen te zijn op de benutting van de capaciteit van onderzoekers dan van apparatuur.

10. Elke onderwijzende die vervangen kan worden door een computer, verdient dit.

Proefschrift van J.A.M. van Arendonk
Studies on the replacement policies in dairy cattle.
Wageningen, 8 november 1985.

aan mijn ouders

aan Thea

Arendonk, J.A.M. van, 1985. Studies on the replacement policies in dairy cattle (Onderzoek naar het vervangingsbeleid van melkkoeien).
Doctoral thesis, departments of Animal Breeding and Farm Economics, Agricultural University, Wageningen.

Voorwoord

Aan het begin van dit proefschrift wil ik graag iedereen bedanken die mij op één of andere wijze behulpzaam is geweest bij het tot stand komen ervan. Enkelen wil ik hier met name noemen.

In de eerste plaats mijn ouders die mij de gelegenheid geboden hebben te studeren en die mijn wel en wee altijd met veel belangstelling hebben gevolgd. Thea, jouw belangstelling en steun zijn voor mij zeer waardevol geweest.

Mijn promotoren, prof.dr.ir. R.D. Politiek en prof.dr.ir. J.A. Renkema, ben ik erkentelijk voor de geboden mogelijkheden en de getoonde belangstelling bij de uitvoering van het onderzoek. De bijdragen die jullie, ieder op eigen wijze, hebben geleverd aan de totstandkoming van dit proefschrift heb ik zeer op prijs gesteld.

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Een woord van waardering gaat verder uit naar C.A. Shacklady voor het corrigeren van de Engelse tekst, naar W. Heije voor het tekenen van de figuren en naar W.J.A. Valen voor het ontwerpen van de omslag. Het typewerk is op snelle en accurate wijze uitgevoerd door mw. G.L.M. Leenarts-Wiggerman, waarvoor mijn hartelijke dank.

Tevens een woord van dank aan het LEB-fonds voor de financiële ondersteuning bij de afronding van dit proefschrift.

Contents

INTRODUCTION

On average 25-30% of the cows are replaced annually in The Netherlands, with insufficient production capacity and reproductive failure as the main reasons (Sol et al., 1984). The farmer's decision is based on his expectation of the cow's performance and that of her potential replacement (Renkema and Stelwagen, 1979; Dijkhuizen, 1983). For a cow suffering from ill health, the decision to replace is generally based on the anticipation of the probability of recovery and the aftereffects of the disease. On the other hand, a healthy cow might be replaced because of low production in which case a higher income would be expected from the replacement heifer. In most instances, however, it is the health and reproductive status as well as the production that influence the decision.

A number of investigations have been made with the object of supporting the farmer to optimize the replacement policy. General guidelines were derived on the optimum annual replacement rate or, in other words, the optimum average herd life of cows and the production levels related to age below which immediate replacement was optimum. Besides decisions on immediate replacement, it is possible to determine whether insemination of a cow, with the aim of retention, is optimum from an economic point of view (Dijkhuizen, 1983). However, management guides, which rank individual cows based on their expected income, to support the farmer in making decisions about replacement or insemination, have received very little attention.

The influence of changes in a number of traits and prices for the optimum replacement policy and the corresponding income from cows was studied frequently. In this way the extent to which results depended on the price and production situation used could be investigated. In addition it allows the financial consequences of changes in the production or health status of the cows to be determined. The consequences of seasonal differences in production and prices for the optimum insemination and replacement policy have not been investigated thoroughly.

The present study was directed towards the economic optimization of the policy for replacement and insemination of dairy cows considering the variation in the performance of cows and the circumstances under which the cows produce.

A number of optimization techniques have been applied to dairy cattle replacement. They are described and evaluated in the first chapter. Attention is also paid to the opportunity the techniques offer to rank cows according to their anticipated income during their remaining herd life.

To determine the optimum replacement policy information is needed on the future performance of individual dairy cows. In chapter 2 a model is constructed and validated. This is used in the subsequent chapters for the estimation of revenues and costs. It had to take into account the variation in milk production, number of days open and month of calving.

The optimum policy for replacement of cows, taking into account the variation in milk production, is studied in chapter 3. The consequences of accounting for variation in the production of present and replacement cows were discussed. Further, the influence of changes in the involuntary replacement rate for the optimum average herd life and the average income is discussed.

In chapter 4 the optimization is extended by introducing variation in the time of conception. In addition the decision whether or not to inseminate a cow is optimized. The herd situation which would result from applying the optimum policy is investigated.

The effects of a permanent change in performance and prices have been treated frequently in the literature. However, it is not known whether these results apply also to a situation where cyclical changes occur due to season. The influence of seasonal variation on the optimum policy for insemination and replacement is considered in chapter 5. In addition the contributions of the variation in separate traits and prices are quantified.

In developing a management guide for individual cows information is needed on the contribution of different variables to the optimum policy. Chapter 6 deals with the influence of carcass value and feed costs and it provides information about the consequences of considering milk revenues only in determining the optimum policy. The average performance of cows corresponding with the alternative policies is discussed.

The possibilities of calculating management guides for individual cows, to support the dairy farmer in making decisions about insemination and replacement are discussed in the last chapter.

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Chapter 1

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

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1. Introduction

The most important goal of a commercial dairy farmer is maximization of total profit from his farm. This is, among others, reflected by the culling criteria for cows and the criteria upon which bulls are chosen. In most cases culling decisions are based on economic considerations rather than because a cow is no longer able to produce (Dijkhuizen, 1983). Culling decisions should be based on the anticipated revenues and costs. Dairy herd improvement organisations, however, mostly rank cows on their realized production capacity.

A number of investigations have been made into the optimum replacement policy for dairy cows based on expected net revenues. General guidelines for culling and culling guides for individual cows have been developed. Besides information about the optimum decisions, some techniques offer the possibility of ranking cows within a herd on future profitability. Future profitability is defined as the profit anticipated by keeping the cow until the optimum time for replacement instead of immediate replacement, taking into account the risk of involuntary disposal. It equals the maximum amount of money a farmer could afford to spend in order to keep the cow.

A number of techniques have been applied to aid decisions on dairy cattle replacement. In this paper techniques which have been used to determine the optimum replacement decision are evaluated. Some general replacement principles will be described which have been developed for the replacement of assets like machinery. Subsequently, the application of these general principles to dairy cattle will be discussed. The principles of dynamic programming and their application to dairy cattle replacement will be treated separately.

Profit equations, representing the realized profitability of cows (Pearson and Miller, 1981), have been used to determine the economic importance of herd life. The replacement principles described in this paper are also relevant for the calculation of these equations as will be shown in the last section.

This paper serves as a basis for further investigations into the optimum replacement policy in dairy cattle.

2. General concepts

The problem of determining the optimum replacement decision will be approached in terms of maximizing net revenues over time. It is assumed that the farmer is able to raise capital for investments in sufficient amounts. If this assumption does not hold, other criteria than maximization of net revenues over time might be relevant (Van Hulst, 1973; Bierman and Smidt, 1980).

In this paper the economic consequences of management decisions on the level of the individual farmer are considered. The economic consequences on other economic levels might be different (Renkema, 1980).

3. Techniques to support decision making and their application

3.1. Marginal net revenue approach

The technique for determining the optimum time for replacement of an asset depends on the shape of the marginal net revenue curve, the characteristics of the subsequent assets, the discount rate and whether or not involuntary replacement takes place (Faris, 1960; Burt, 1965; Perrin, 1972).

The net revenues of not only the present asset but rather the present and all subsequent assets are to be maximized. This implies that an infinite planning horizon has to be considered in the marginal net revenue approach (Perrin, 1972).

When no discounting or involuntary replacement takes place the optimum time for replacement occurs when the marginal net revenue from the present asset equals the maximum average net revenue anticipated from the subsequent set of identical replacement assets (Faris, 1960). When present and all subsequent assets are assumed to be identical, the optimum time for replacement is reached when the average net revenue is maximum. This is illustrated in figure 1 based on data presented by Faris (1960). The optimum time for replacement (A) is reached earlier than the time at which the total net revenue from the present asset is maximized (B). The latter represents the optimum time for replacement when one wishes to maximize the net revenue from the first asset only (Faris, 1960). The maximum average net revenue from the subsequent asset, which is used to determine the optimum time, can be interpreted as the opportunity cost of postponed replacement.

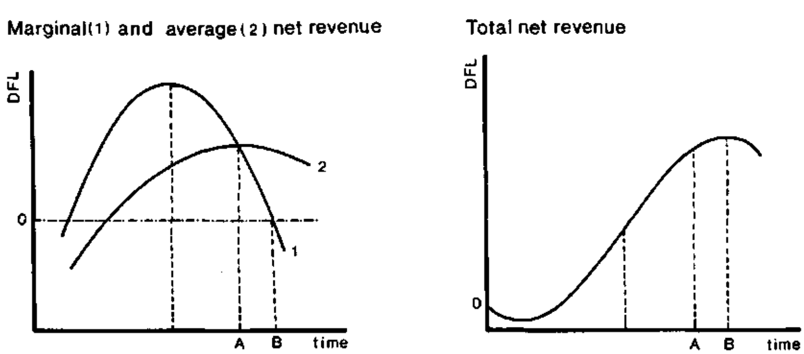

Fig. 1. Determination of the optimum time for replacement (A) in case of identical replacement.

It is possible to account for a difference between the present and all subsequent assets (Perrin, 1972). In the case of non-identical replacement, the optimum time for replacement of the present asset does not necessarily coincide with the time at which its average net revenue is maximum (figure 2). To calculate the opportunity cost of postponed replacement all subsequent assets must still be assumed identical.

When time preference of revenues occurs, comparison of anticipated revenues should be made at the same point in time. This can be achieved by discounting future revenues (Faris, 1960; Perrin, 1972). When discounting is applied, the optimum time to replace is reached when the marginal net revenue from the present asset is equal to the maximum annuity of anticipated net revenues from the subsequent assets (Faris, 1960; Burt, 1965). In this latter value the marginal net revenues and the periods of time are weighted to account for time preference.

According to Perrin (1972) a higher discount rate can result in both later as well as earlier replacement depending on the shape of the marginal net revenue curve.

Burt (1965) has extended the replacement principle to the situation in which voluntary and involuntary replacement occurs. In that case the opportunity cost of postponed replacement is also equal to the maximum annuity of the net revenues anticipated from the subsequent assets. In the calculation of an annuity, the present value of future net revenues must first be determined. The net revenues in each period are discounted and weighted for the probability of their realization. The annuity factor which converts the present value into a constant amount per period is in this case a function of the discount rate and the probabilities of realization (Burt, 1965).

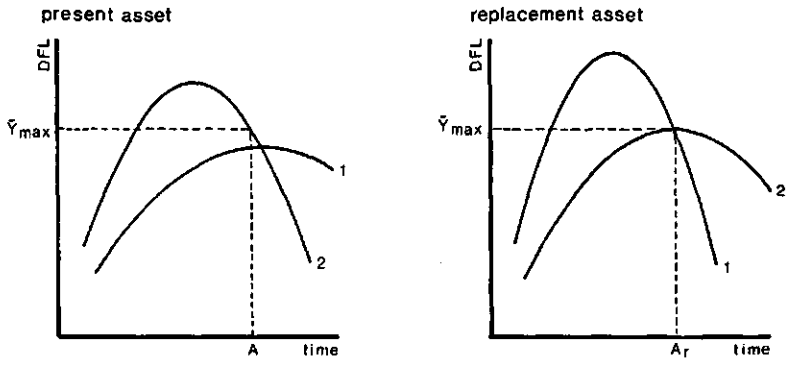

Fig. 2. The optimum time for replacement of the present asset (A) determined by the opportunity cost of postponed replacement (y_{max}) calculated from the marginal (1) and average net revenue curve (2) in case of non-identical replacement.

3.2. Applications in dairy cattle

In dairy cattle the variables affecting the revenues and costs of production have great variation. The application, of the replacement principles described in the former section, to dairy cattle is based on the expected net revenues from the present and all subsequent replacement cows. The variation which exists around these expectations has not been taken into consideration.

Cash flows originating from dairy cows are irregular within a lactation period. Months in which the marginal net revenues from the present cow are lower than the corresponding opportunity cost occur before and during the dry period. This irregularity affects the determination of the optimum time for replacement when decisions at intervals shorter than a constant calving interval are considered. The comparison of marginal net revenues with the opportunity cost of postponed replacement no longer immediately yields the optimum time. In this case the time for planned replacement of the present cow and all subsequent cows have to be varied. The combination which results in the maximum present value of the net revenues, anticipated from the present and all subsequent cows, is optimum (Burt, 1965). The optimum time for replacement is not changed when a constant amount is subtracted from the marginal net revenues per period from the present and subsequent cows (Faris, 1960). This implies that the optimum time can be obtained by maximization of the present value of the differences between marginal net revenues from the present cow and the opportunity cost of postponed replacement.

For the calculation of the opportunity cost of postponed replacement it must be assumed that all subsequent replacement cows are identical with respect to net revenues for example. This assumption makes it impossible to account for a continuous genetic improvement. Problems also arise when seasonal differences in net revenues are taken into consideration. With these techniques it is not possible to account for the fact that subsequent cows will likely be replaced in different seasons.

Due to the irregular course of the net revenues of a cow, when periods shorter than one year are considered, the optimum time for replacement may differ among cows. The optimum time will depend on the age and the stage of lactation of the cow at the decision time. All replacement cows have the same optimum time because of the assumption that all subsequent replacement cows are identical.

Some characteristics of the marginal net revenue approach, when applied to dairy cattle replacement, are summarized in table 1. Zeddies (1972) demonstrated that the replacement principle can be used to rank animals on future profitability. This is equal to the sum of the differences between marginal net revenues and

Table 1. Characteristics of applications of the marginal net revenue approach to dairy cattle.

	Zeddies (1972)	Renkema and Stelwagen (1979)	Korver and Renkema (1979)	Dijkhuizen (1980)	Kuipers (1982)	Dijkhuizen (1983)
Decision time (days after calving)	365	365	30-365(245)[a]	205	b	25-525(225)[a]
Calving interval (days)	365	365	365	365	b	345-525(365)[a]
Variation in production[c]	yes	yes	yes	yes	yes	yes
Involuntary disposal	no	yes	yes	yes	yes	yes
Discounting	yes	no	no	no	no	yes
Genetic progress	yes	yes	no	no	---	yes

a) Variation in current lactation, fixed value for later lactations in parentheses.
b) No limitations.
c) No variation for replacement cows.

the opportunity cost of postponed replacement until the optimum time for replacement occurs. Renkema and Stelwagen (1979) extended the model proposed by Zeddies (1972) by including the age-associated probability of involuntary disposal. The model was used to quantify the economic consequences of changes in involuntary replacement rates. Dijkhuizen (1980) showed that the economic consequences were overestimated, as a result of the assumption that disposal of cows took place just prior to parturition. Korver and Renkema (1979) determined the production level below which replacement of cows at different times during the first lactation was optimum from an economic point of view. Dijkhuizen (1983) further extended the model of Korver and Renkema (1979) to determine production levels below which it was no longer profitable to inseminate cows, at different moments during the lactation period. In this case immediate replacement is no longer the appropriate alternative for keeping the cow. The economic consequences of keeping the cow, assuming that she conceives, have to be compared with replacement at the optimum time during the present lactation period (Dijkhuizen, 1983). It is therefore possible to indicate at an early stage of lactation whether or not replacement at a later stage is optimum.

Kuipers (1982) developed a culling guide based on the replacement principle described by Terborgh (1949). In the absence of discounting, an asset should be replaced when the average net revenues, calculated over the period which yields the maximum average value, are lower than the maximum average net revenues from a subsequent asset (Terborgh, 1949). It is obvious that this replacement principle results in the same optimum time for replacement as obtained by the earlier described replacement principles. This implies that this technique has the same limitations in applications to dairy cattle.

In calculating his culling guide, Kuipers (1982) considered the predicted monthly net revenues in the remaining part of the current lactation and for 6 months of the next lactation. For those cows having the lowest index values, it was recommended that replacement be considered. The index value, especially for younger animals, will be underestimated as a result of the short period over which net revenues are evaluated. The influence of net revenues in the next lactation period is also underestimated due to the fact that the probability of involuntary replacement is not properly incorporated in the index. Comparison of the future profitability of cows based on the maximum average net revenue (Kuipers, 1982) is not justified. The comparison of the future profitability of different alternatives, based on the average net revenues during a given period of time, is only valid when each alternative can be repeated over the same period of time (Van Hulst, 1973).

3.3. Dynamic programming

Dynamic programming (Bellman, 1957) is concerned with processes which involve a sequence of decisions over a given period of time, that being the planning horizon. This technique can be used to determine a replacement policy which maximizes (or minimizes) an objective function, for example the present value of net revenues. For a description of the technique and possible applications to agricultural problems reference is made to Burt and Allison (1963) and Throsby (1964).

The state of the process (cow) is specified by a set of parameters called state variables, such as age and production in case of dairy cattle. Each state variable consists of a finite number of distinct values.

Optimization generally starts at the end of the total planning horizon and moves backwards in time to the present stage. At each stage the optimum decision is determined for all combinations of the state variables. The combined effects of the current decision and the predetermined optimum sequence of decisions during the remainder of the planning horizon are considered. Mathematically this process can be represented by the recurrence relation (Bellman, 1957).

For each state one has to specify the possible states for the next stage. These transitions, which are controlled by the optimum decisions, may incorporate stochastic elements. This property enables the technique to account for involuntary culling and for variation in production, calving interval and other variables. Given the production level in the present stage, the distribution over the production levels in the next stage can be defined taking into account repeatability of production.

Dynamic programming has the advantage that it puts no restriction on the nature of the marginal net revenue curve or other functions used to specify the structure of the system (Throsby, 1964). Furthermore it is possible to alter the net revenue or other variables over time (Burt and Allison, 1963). This offers the opportunity of including the effect of continuous genetic improvement. The effect of season on variables like milk production and carcass value can be incorporated by defining a state variable representing month or season of calving.

In a number of cases dynamic programming has been used to determine optimum culling decisions for dairy cattle (table 2). Ben-Ari et al. (1983) also applied this technique, but that model was not explicitly described.

The number of state variables and the number of classes within each variable varies among the different dynamic programming models (table 2). The total number of states by which cows were represented in the models ranged from 9 to 15138. As stated earlier, the probabilities of transition of each state to other states in the next stage must be defined for all possible decisons. These transition probabilities can be dependent or independent of the state variables. Stewart et al. (1977; 1978) assumed that a cow remained in the same class for milk production and fat percentage during her entire life. The absolute production for each class was changed according to age. Based on the repeatabilities of lactation production, Smith (1971) predicted the production class in the next lactation based on the production in the last 2 lactations. The expected value was used without regard for the distribution around that expectation. All cows were compared to average replacement heifers with respect to production. Due to the constant regression of the expected production of the present cow and the comparison with average replacement heifers, the optimum sequence of decisions during the planning horizon mainly considers characteristics of animals at or near the average. States further from the average contribute little to the present value of the cash flows during the planning horizon and to the optimum decisions in that case. On the other hand Kristensen and Østergaard (1982) accounted for the distribution around the expected production for the present cow and the replacement heifer.

Table 2. Some characteristics of the dynamic programming models which have been applied to dairy cattle.

Characteristics	Jenkins and Halter (1963)	Smith (1971[e])	McArthur (1973)	Stewart et al. (1977)	Stewart et al. (1978)	Killen and Kearney (1978)	Kristensen and Østergaard (1982)
State variables[a]							
- age or lactation number	12	6	7	7	7	9	4
- stage of lactation							3
- calving interval		3					4
- milk production		29[d]	80	11	11		5[c]
- fat percentage				7	7		
- body weight				5	5		
Number of states	12	15138	560	2695	2695	9	176
Length of each stage (mo)	12	12[b]	12	12	12	12	3
Genetic improvement	no	yes	no	yes	yes	no	no
Length planning horizon (yr)	12	15	20	5;10	10	20	∞

a) The number represents the number of classes within each state variable; a blank indicates that the variable was not incorporated.
b) Length varies because of variation in calving interval.
c) In the 2nd and 3rd lactation 6 classes were distinguished.
d) For each of the last 2 lactations.
e) A short description is given by Smith (1973).

Stewart et al. (1978) showed that inclusion of variation in production and body weight of replacement heifers rather than average characteristics resulted in more intensive culling. They concluded that the specification of an average replacement heifer tended to underestimate the value of replacement. The fact that cows were assumed to remain in the same production and body weight class during their entire life, probably caused an overestimation of that effect.

The length of the total planning horizon varied among the dynamic programming models (table 2). Optimum decisions at the present stage changed when an initially short planning horizon was lengthened (Stewart et al., 1977; Kristensen and Østergaard, 1982). In general one would choose the length at which present decisions remain unchanged due to a further time increment. McArthur (1973) stated that in his case it usually took 15 years to reach stable solutions for the present stage. Kristensen and Østergaard (1982) determined the replacement policy which is optimum under a infinite planning horizon by the policy iteration algorithm. In this case the replacement policy is assumed equal for each stage. The policy iteration algorithm can only be applied if revenues and costs for each state are assumed to be stationairy over time (Wagner, 1969). This assumption makes it impossible to account for continuous genetic improvement. When not all elements of the model are stationairy over time the optimum policy can be determined by value iteration with a finite planning horizon.

In most dynamic programming models replacement decisions are taken at the beginning of a lactation period. Only in the model of Kristensen and Østergaard (1982) voluntary replacement at monthly intervals is possible (table 2). In this case decisions were taken at intervals of 3 months. In addition to the alternatives of keeping or immediately replacing a cow, replacement in 4 or 8 weeks was taken into consideration.

Smith (1971) compared the optimum replacement policy determined by dynamic programming when present value of net revenues or production was used as the objective function. Maximization of production resulted in more intensive culling during the first and second lactation and less intensive culling in later lactations. Stewart et al. (1978) compared the 10-year discounted net revenues obtained by dynamic programming for heifers of four dairy breeds. In this way the profitability of each breed was determined under the optimum replacement policy for the corresponding breed. For all breeds the effects of variation in milk yield, fat percentage and body weight on the discounted net revenues were determined.

Dynamic programming can also be used to determine the future profitability of cows (Smith, 1971; Kristensen and Østergaard, 1982). Future profitability equals the difference between maximum present value of future revenues obtained from the optimum decision and that of immediate replacement. Kristensen and Østergaard (1982) applied this principle to the cows belonging to one herd.

3.4. *Evaluation*

Differences among the techniques to determine the optimum time for replacement exist with respect to the characteristics of the replacement cows. In the marginal net revenue approach, it is necessary to assume that all subsequent replacement cows are identical. Thus it is impossible to account for seasonal variation and continuous genetic improvement. Extension of these methods, to overcome this limitation would result in dynamic programming in its simplest form. As stated by Burt (1965), the marginal net revenue approach is a special case of dynamic programming.

Dynamic programming also has the advantage that variation within traits can be included. In other instances decisions have to be based on the expected value of one or more variables. These expectations have to be based on a priori information about the levels of these variables below which replacement is optimum. The expected values of a trait should not include that part of the distribution of the trait for which replacement is optimum. A priori information is also necessary on the probabilities of disposal for voluntary reasons like low production and failure to conceive. Knowledge about the optimum level of these parameters is limited. Therefore further research is needed into the optimum replacement policy and how this is affected by changes in prices and other factors.

The number of variables for which variation can be included in dynamic programming is not unlimited. Especially when variables are correlated, which is often the case in dairy cattle, the calculation of the transition probabilities becomes a laborious task. A compromise has to be found between the accuracy with which animals are represented in the model on one hand and the complexity of the model on the other.

Dynamic programming is a very flexible tool for determining the optimum replacement policy. In some situations, however, application of the marginal net revenue approach may be justified, given its computational advantages. Awareness of the limitations of the technique is necessary in those cases. The application of an marginal net revenue approach to a situation with continuous genetic improvement will generally be less erroneous than application to a situation with seasonal variation.

The computing cost associated with an optimization technique is not the decisive factor in establishing general knowledge about the optimum replacement policy. This factor becomes more important in the comparison of culling guides for individual cows which are calculated in combination with a regular milk recording scheme. Dynamic programming is probably too expensive to be used as a culling guide itself. However this technique can be applied in the development of a culling guide. The opportunity cost of postponed replacement, taking into account seasonal variation and genetic improvement, can be calculated by dynamic programming. Methods of incorporating these results into a culling guide based on cash flows of individual cows should be investigated. As well, the results obtained by dynamic programming could serve as a reference for comparison of decisions and rankings based on alternative culling guides.

4. Profit equations

Profit equations or profit functions which reflect the realized profitability of cows (Andrus and McGilliard, 1975; Gill and Allaire, 1976; Lin and Allaire, 1977; Balaine et al., 1981; Norman et al., 1981) or sires (Bakker et al., 1980) have been developed. The profit equation includes revenues and costs during a specified period or the total herd life of the cow. In most cases they were used to determine the relative importance of different variables, such as herd life, to the profitability of cows. Furthermore profit equations have been used for the comparison of the relative efficiency of indexes for improving profitability. The results obtained with the earlier profit equations have been reviewed by Pearson and Miller (1981).

First of all profit equations which equal the profit until disposal from the herd or until the end of the defined period will be discussed. In all studies the opportunity cost of postponed replacement, which reflects the profit sacrificed by keeping the cow, has been omitted. It has therefore been assumed that a cow is not replaced after leaving the herd. The effect of herd life and associated variables such as stayability on profitability will therefore be overestimated.

In a number of profit equations (Andrus and McGilliard, 1975; Gill and Allaire, 1976; Balaine et al., 1981; Norman et al., 1981) profit has been expressed per day or per year of herd life. Comparison of the profitability of cows based on their average value is only allowed when identical replacement can be assumed (Van Hulst, 1973). This assumption does not hold in this case, given the fact that within a herd no systematic differences exist between the heifers available for replacement of different cows. The profit equations in which average values are applied therefore do not reflect the profitability in a correct manner. This is illustrated for a simplified situation (table 3) in which profitability was calculated by arbitrarily setting the opportunity cost of postponed replacement equal to 200.

Table 3. An illustration of the differences between total profit, average profit and real profitability.[a]

Cow	Profit in year 1	2	3	4	Total profit	Average profit	Real profitability[a]
A	100	200	300	200	800	200	0
B	150	250	---	---	400	200	0
C	200	300	---	---	500	250	100
D	200	250	300	250	1000	250	200

a) Opportunity cost of postponed replacement equal to 200.

It can be concluded that a profit equation should be equal to the profit until disposal of the cow and that it is necessary to take the opportunity cost of postponed replacement into account. The relation between this profit equation and an equation considering profitability to a fixed age should be investigated in order to judge whether or not a shorter period of time can be used.

5 Summary

Optimization techniques which have been applied to dairy cattle to determine the optimum time for replacement have been evaluated.

In the marginal net revenue approach the optimum time for replacement is determined by comparison of the marginal net revenues anticipated from the present cow with the opportunity cost of postponed replacement. The latter value equals the maximum average net revenue (or annuity in case discounting is applied) anticipated from replacement cows. In this approach it must be assumed that all subsequent replacement cows are identical. This assumption makes it impossible to account for continuous genetic improvement and for seasonal variation in revenues and costs. This limitation does not hold for the more general dynamic programming technique. Furthermore dynamic programming offers the opportunity to account for variation in traits.

The possibilities offered by the different techniques to rank cows within a herd based on future profitability have been considered. Future profitability is defined as the profit anticipated by keeping the cow until the optimum time for replacement instead of immediate replacement.

In the last section the impact of the replacement principles on profit equations is discussed.

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Chapter 2

A model to estimate the performance, revenues and costs of dairy cows under different production and price situations

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Summary

A model was constructed and validated to determine the course of performance, revenues and costs of dairy cows with different levels of milk production and of number of open days. For each month in lactation the revenues from milk production, which are dependent on the fat and protein content, were determined. The feed costs were calculated from consumption of roughage and concentrate, which were estimated from the energy requirements. Furthermore, the course of the carcass value, calf revenues, the probability of, and the financial loss associated with involuntary disposal were considered. Seasonal variation in production and prices was included in the model.

Parameters of, and prices in, the model were chosen to represent the Black and White cows in the Netherlands at the normalized price level of 1981-1982.

In the future the model will be used in studies on replacement policies in dairy cattle.

1. Introduction

Techniques to determine the optimum replacement policy for dairy cows were described and evaluated by Van Arendonk (1984). Dynamic programming was shown to be a very flexible technique which allows incorporation of seasonal variation, genetic improvement, repeatability of and variation in traits. To determine the optimum replacement policy, information about the expected revenues and costs during the productive life of present and replacement cows has to be provided. Furthermore knowledge is needed about the carcass value, the probability of and the financial loss associated with involuntary disposal.

Gartner (1981) constructed a model to evaluate the effect of different replacement rates on dairy farms where heifers compete with cows for grassland. The model estimated the profitability of the total herd rather than of individual cows. France et al. (1982) designed a model that estimated the monthly revenue from milk sales and concentrate requirements for use in on-farm advisory work. No allowances were made for the effect of season on milk production or for changes in calving interval. An economic index, based on the predicted monthly revenues from milk and calf sales and feed costs, has been developed by Kuipers (1982). The performance of cows was predicted for the remainder of the current lactation and for 6 months of the next lactation. To determine optimum replacement decisions, Dijkhuizen (1983) developed a model to predict revenues and costs taking into account among others the cow's production level and calving interval. Kuipers (1982) and Dijkhuizen (1983) did not incorporate the effect of season on, for example, milk production, feed costs and prices.

This paper reports on the construction and validation of a model to estimate the course of performance, revenues and costs of individual cows with different levels of milk production and of number of days open. The model should offer the opportunity to include seasonal variation in traits and prices. In subsequent papers the model will be used to determine the optimum replacement policy for various production and economic situations by dynamic programming.

2. General concepts

At most Dutch dairy farms, revenues originate from three interdependent activities: grassland exploitation, rearing young stock and managing dairy cows (Renkema and Stelwagen, 1979). In the model the rearing of young stock is isolated from the other activities as it is the idea to buy pregnant heifers through the market or from the farm's rearing enterprise.

It is assumed that the amount of fresh and conserved grass consumed by the dairy cows, is produced on the farm's area of grassland. Labour supplied by the farmer is not included in the calculation of the costs. The net revenues per cow originating from grassland exploitation and the dairy cow enterprise form therefore a compensation for the supplied labour and management.

The parameters of the model were chosen to represent the Black and White cattle population in The Netherlands. By changing some parameters the model can be adapted to the use in other production circumstances or cattle populations.

As far as possible prices were based on monthly reports during the years of 1978 to 1982. Prices were normalized, because of incidental price fluctuations, and corrected for trend. The final price level related to the normalized situation during the period of 1981 - 1982.

The performance, revenues and costs of cows are estimated for each month to allow replacement at regular intervals within the lactation period. Months were taken to be of 30.5 days.

The major components of the model are represented in the diagram shown in figure 1.

3. Production

3.1. Lactation production

The production of milk, fat and protein during the lactation period of a cow is influenced by the herd, the season of calving and the age at calving (Dommerholt, 1975; Danell, 1982; Funk, 1983). The production is furthermore influenced

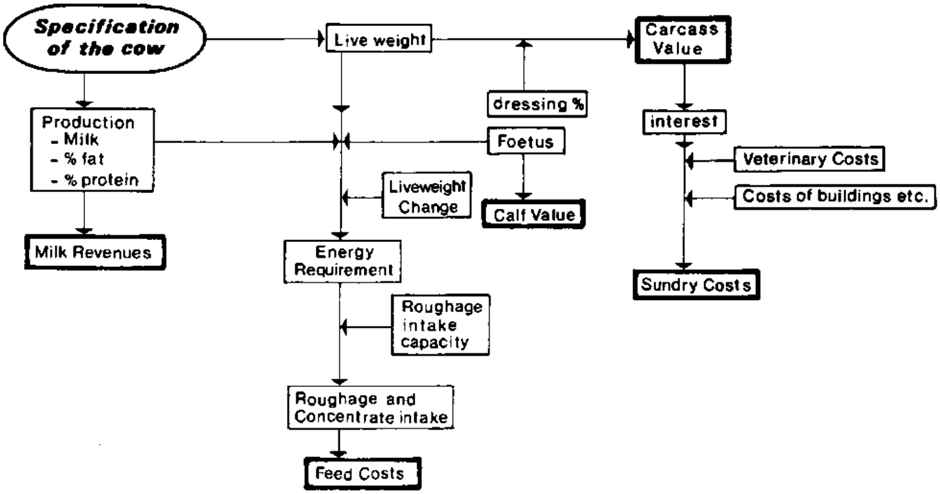

Fig. 1. Schematic representation of major components of the model.

by the number of days open in the present lactation (Bar-Anan and Soller, 1979; Oltenacu et al., 1980, Funk, 1983) and the previous lactation (Bar-Anan and Soller, 1979; Funk, 1983). Unless stated otherwise number of days open are related to the present lactation.

The expected lactation production of a cow at a constant calving interval can be represented by the following equation:

$$ylac_i = a_{i,j}\ s_{i,k}\ HA_i\ \hat{c}_i \qquad (1)$$

where $ylac_i$ = the expected lactation production expressed as kg milk (i=1), % fat (i=2) and % protein (i=3)

$a_{i,j}$ = the effect of j-th age at calving on trait i

$s_{i,k}$ = the effect of the k-th month of calving on trait i

HA_i = the average herd level for trait i at mature (8 years) age and average season

$\hat{c}_i$ = the relative superiority of the cow for trait i

The adjustment factors for age at calving (figure 2) and month of calving (table 1), calculated by Dommerholt et al. (1977[a]) were used. The adjustment factors for ages above 11 years were obtained by extrapolation.

At the same age milk production is higher for second parity cows than for heifers (Auran, 1973). The influence of season of calving on lactation production

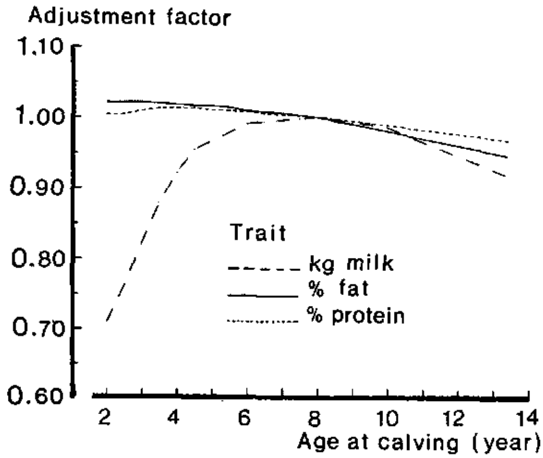

Fig. 2. Multiplicative adjustment factors for the effect of age at calving on milk production, fat and protein content during the lactation (305 days).

is caused partly by differences in feeding and management (Auran, 1973; Dommerholt, 1975). The adjustment factors for season might therefore depend on the type of herd, district and year. In the application of equation (1) awareness of these factors is needed.

The effect of the number of days open on the production of milk, fat and protein will be treated separately.

Table 1. Multiplicative adjustment factors for the effect of month of calving on milk production (kg), fat percentage and protein percentage (Dommerholt et al., 1977[a]).

	Month											
	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Kg milk	1.026	1.009	0.992	0.977	0.970	0.970	0.973	0.978	0.997	1.034	1.039	1.035
% Fat	0.992	0.985	0.987	0.996	0.999	1.005	1.008	1.009	1.014	1.003	1.003	0.999
% Protein	0.985	0.988	0.996	1.007	1.012	1.013	1.012	1.009	1.009	0.991	0.991	0.987

3.2. Production per month in lactation

3.2.1. Milk production

Milk production reaches its maximum during the second month of lactation and declines afterwards. The shape of the lactation curve is influenced by the age of the cow (Auran, 1973; Dommerholt et al. 1977[b]). Heifers show a flatter lactation curve than older cows. The distribution of milk production during the lactation hardly differs among third and later parity cows (Dommerholt et al., 1977[b]). The lactation curve is furthermore influenced by season (Dommerholt et al., 1977[b]; Wood, 1972), herd level (Dommerholt et al., 1977[b]) and gestation (Auran, 1974; Danell, 1982). Milk production, free of stage of lactation effects, shows a peak during May and June which gradually subsides to a trough in the winter. Wood (1972) showed that the seasonal differences in production were influenced by the feeding strategy of the cows. Dommerholt et al. (1977[b]) found an effect of the herd level on the shape of the lactation curve. The adjustment factors for the effect of season on monthly production will therefore refer to a more or less uniform group of herds. Gestation starts to influence production 3 to 4 months after conception (Auran, 1974; Danell, 1982).

Prediction of a cow's performance has to include the effect of the number of days open on monthly and lactation production. The production in the first part of the lactation needs to be independent of the number of days open. This restriction and the characteristics of the lactation curve have been combined into one equation (2). This equation was used to calculate the distribution of production during the lactation period and the adjustment factors for the effect of number of days open on the lactation production.

The model proposed by Cobby and Le Du (1978) gave better results than the model of Wood (1967) when those were fitted to monthly milk productions obtained from factors given by Dommerholt et al. (1977[b]) in absence of seasonal variation. Data of the first, second and third parity relating to high yielding herds (5300 kg) were used in this comparison. Extension of the model of Cobby and Le Du (1978) to include the effect of season and number of days open resulted in the following equation:

$$y_{t_l,i,DO} = (a - bt_l - 13e^{-ct_l})(1+(t_p/140)^2)^{-1} f_m g_i \qquad (2)$$

where $y_{t_l,i,DO}$ = the milk production (kg) at t_l days after calving for the i-th month of calving and DO days open

- a = level parameter
- b = the slope during the decline in production after the peak
- c = parameter describing the initial increase of production
- t_p = t_l-DO-122 when $t_l \geq$ DO+122 and t_p = 0 when $t_l <$ DO+122
- f_m = effect of the m-th calendar month on monthly production
- g_i = effect of the i-th month of calving on the level of production

Distinct values were used for parameter a and b during the first, second and third or higher parity. The values were equal to 22.0, 26.5 and 31.0 kg, respectively, for the level parameter (a) and 0.035, 0.050 and 0.065 kg per day for the de-

Table 2. Multiplicative adjustment factors for the effect of calendar month on monthly milk production (f_m) and the effect of month of calving on lactation production (g_i) in equation (2).

	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
							Month					
f_m	0.95	0.97	1.00	1.03	1.07	1.07	1.06	1.04	1.00	0.95	0.93	0.93
g_i	1.012	0.990	0.973	0.962	0.962	0.973	0.986	0.997	1.019	1.052	1.046	1.030

crease parameter (b). Parameter c was fixed at 0.125. The effect of pregnancy on production was based on the effect of number of days open on test day yields calculated by Danell (1982). The adjustment factors for the effect of season on monthly production (f_m) given in table 2 were based on Dommerholt et al. (1977[b]). The combination of these factors and the effect of month of calving on the level of lactation production (g_i; table 2) resulted in the differences in lactation production given in table 1 for cows with 88 days open.

Equation (2) results in a flatter lactation curve for heifers than for older cows as shown in table 3, where the effect of season on production is omitted and the number of days open equalled 88. These lactation curves agreed well with those based on Dommerholt et al. (1977[b]) except for the last 2 months in lactation. This is likely caused by an on average higher number of days open in their data (Dommerholt et al., 1977[b]). When equation (2) was applied to a calving interval of 13 months the differences in relative (%) monthly production compared to Dommerholt et al. (1977[b]) ranged from -.27% to .22% with an average of .11% in absolute terms.

Table 3. Relative production (%) in each month in lactation for different parities based on equation (2) for 88 days open excluding the effect of season.

Parity	1	2	3	4	5	6	7	8	9	10
					Month in lactation					
1	11.55	12.81	12.18	11.51	10.83	10.16	9.49	8.62	7.22	5.63
2	12.51	13.36	12.55	11.71	10.87	10.02	9.18	8.15	6.64	5.01
3	13.26	13.79	12.85	11.87	10.89	9.91	8.93	7.78	6.19	4.53

3.2.2. Fat and protein content

Milk protein content shows a smaller decrease in the beginning of the lactation period and reaches its minimum value at an earlier time during the lactation than fat content (Syrstad, 1975; Lindgren et al., 1980; Korver, 1982). Lindgren et al. (1980) concluded that the interaction between stage of lactation and lactation

Table 4. Additive adjustment factors for the effect of month in lactation on fat and protein content.

	Month in lactation												
Trait	1	2	3	4	5	6	7	8	9	10	11	12	≥13
Fat content (%)	0.00	-0.32	-0.40	-0.40	-0.32	-0.22	-0.12	0.00	0.12	0.22	0.30	0.36	0.40
Protein content (%)	0.00	-0.35	-0.27	-0.18	-0.09	0.00	0.09	0.18	0.26	0.33	0.37	0.39	0.40

number for fat and protein content was negligible. This implies that the same adjustment factors for the effect of stage of lactation can be applied to all parities.

The additive adjustment factors for fat content based on Syrstad (1975), Lindgren et al. (1980), Danell (1982) and Korver (1982) are given in table 4. The adjustment factors for protein content (table 4) are derived from Syrstad (1975), Lindgren et al. (1980), Korver (1982) and Ng-Kwai-Hang et al. (1982). The course of fat and protein content of milk derived from these factors is illustrated in figure 3.

It is assumed that there is no interaction between season and month in lactation on the composition of milk.

3.3. *The influence of the number of days open*

Oltenacu et al. (1980) found an increase in the number of days in milk ranging from 0.78 to 0.87 per additional day open. The number of days open ranged from 30 to 230. The quadratic component of the number of days open was not significant

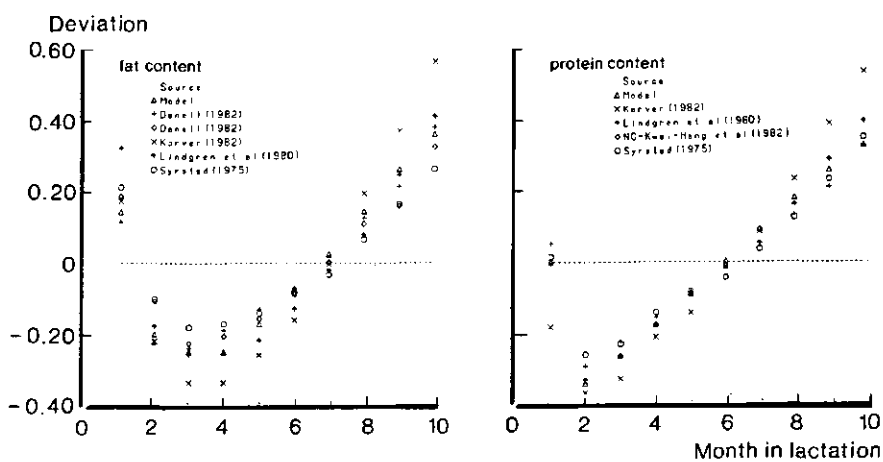

Fig 3. Estimates of fat and protein content, expressed as deviation from the mean, in relation to month in lactation.

in the prediction of the number of days in milk. Bar-Anan and Soller (1979) found an increase ranging from 0.81 to 0.96 in the days open range of 30 to 200.

In this study the following equation was used to calculate the number of days in milk (DIM) from the number of days open (DO), which was allowed to range from 30 to 240:

$$\text{DIM} = 234.6 + 0.8\ \text{DO} \tag{3}$$

From equation (2) and (3) the relative milk production for each number of days open can be calculated. In table 5 the effect of the number of days open on milk production is shown for a situation without seasonal variation. These coefficients were included in equation (1) to predict the lactation production for different numbers of days open.

Oltenacu et al. (1980) determined the effect of the number of days open on milk production up to 360 days in milk. After correction for the difference in production up to 210 days in milk, the production with 60, 120, 150 and 180 days open was on average 6% lower and 7%, 10% and 12% higher, respectively, than with 90 days open. Except for the last value, in which case the cows may not yet have finished the lactation period, these results are in agreement with table 5. Bar-Anan and Soller (1979) found an increase in production for heifers and for cows of, on average, 24% and 17%, respectively, when the number of days open increased from 85 to 180. In a preliminary analysis of data from Dutch Black and Whites, an increase in milk production of 21% for heifers and 19% for second parity cows was found when the number of days in milk increased from 305 to 400 (Van den Broek and De Jager, 1983).

Table 5. Adjustment factors for the effect of the number of days open (DO) on milkproduction (multiplicative) and composition (additive) of the milk during the total lactation period (excl. seasonal variation).

	Milk production			Fat content			Protein content		
Parity:	1	2	≥ 3	1	2	≥ 3	1	2	≥ 3
DO 57.5	0.933	0.940	0.945	-0.025	-0.023	-0.021	-0.024	-0.022	-0.020
88	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
118.5	1.061	1.054	1.048	0.026	0.023	0.020	0.023	0.020	0.019
149	1.118	1.101	1.087	0.050	0.043	0.038	0.039	0.038	0.034
179.5	1.168	1.141	1.120	0.071	0.062	0.053	0.060	0.052	0.046
210	1.214	1.175	1.145	0.090	0.077	0.065	0.074	0.064	0.055

The additive effect of days open on fat and protein content of the lactation production (table 5) was calculated from the additive adjustment factors for month in lactation (table 4) and the distribution of milk production based on equations (2) and (3). The increase in fat and protein content with the number of days open was bigger for heifers than for older cows due to the heifer's better persistency of production. For the effect of days open on the fat and protein content of the milk produced during the lactation period no estimates were found in the literature.

The application of the adjustment factors in table 5 resulted in a production and composition of milk which was independent of the number of days open. To keep this desired property intact the adjustment factors for the effect of days open on production were calculated for each month of calving seperately.

3.4. The influence of previous number of days open

Funk (1983) estimated the linear and quadratic effects of the number of days open and the number of days dry on the 305 day milk production in the following lactation. Furthermore in this analysis the effect of herd-year-season, parity and the number of days open in the present lactation were considered.

The effect of previous days open and days dry were combined, using equation (3) and a gestation length of 278 days, in the following equation:

$$f_{DO_p} = -429 + 6.9\ DO_p - .023\ DO_p^2 \qquad \text{if } DO_p \leq 95$$

$$\text{or} \quad f_{DO_p} = -201 + 2.7\ DO_p - .004\ DO_p^2 \qquad \text{if } DO_p > 95 \qquad (4)$$

where f_{DO_p} = the milk production (kg) as a deviation from the production at DO_p equal to 88

DO_p = number of days open in the previous lactation

Equation (4) was divided by the average production in that situation of 7400 kilogram to obtain multiplicative adjustment factors for the use in the model.

The adjustment factors for milk and milk fat production were equal (Funk, 1983). This suggests that the fat content of the milk was not influenced by the length of the previous calving interval. It is therefore assumed that the fat and also the protein content of the milk are not affected by that interval.

Bar-Anan and Soller (1979) found an increase in milk production ranging from 2.5% to 7% when the number of days open in the previous lactation increased from 85 to 180. The absence of correction for environmental effects and the fact that production during the total lactation, instead of 305 days, was used partly explains the bigger influence in comparison with the results of Funk (1983).

3.5. *Milk revenues*

In The Netherlands, milk price is based on fat and protein with a negative price for total milk volume. Regional price differences occur partly due to differences in proportion of the milk in fluid and manufacturing markets.

The price for fat and protein were 10.20 and 9.30 Dfl. per kilogram, respectively. These figures were based on prices paid by different dairy factories (Boerderij, 1980-1982). The base price of milk was on average equal to -0.056 Dfl. per kilogram. This reduction was dependent on season (table 6) which was not the case for the price of fat and protein.

Table 6. The average price and monthly deviations in price for milk quantity (Dfl.(100 kg)$^{-1}$), calves (Dfl. kg^{-1}) and carcass weight for a heifer 210 days in lactation (Dfl. kg^{-1}).

Trait	Average	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
		Monthly deviations in price											
Milk[1]	-5.60	0.50	-0.20	-0.60	-1.00	-1.00	-1.00	-1.00	-1.00	1.10	1.60	1.60	1.00
Carcass weight[2]	7.20	-0.12	-0.05	0.04	0.14	0.22	0.22	0.14	0.08	-0.06	-0.18	-0.24	-0.19
Calves[2) 3)]	10.85	-0.35	-1.35	-1.75	-1.75	-0.85	-0.05	0.55	1.35	1.45	1.25	0.95	0.55

1) Based on prices reported in Boerderij (1980-1982)
2) Based on prices reported by LEI (1977-1982)
3) Bull calves

4. Feed intake

The daily energy consumption was calculated from the daily energy requirement taking into account the effect of live weight changes. Daily feed costs were based on the intake of roughage and concentrate, respectively. The amount of energy was expressed in Dutch feed units for lactation (VEM); one VEM unit contains 6.904 kJ net energy (Van Es, 1978). The intake and energy content of feedstuffs are expressed on dry matter basis.

4.1. *Energy requirement*

The average daily energy requirement for maintenance and milk production (ER) during month i in lactation equals (Korver, 1982):

$$ER_i = (42.4\ \overline{W}_i^{\ 0.75} + 442\ FPCM_i)\ (0.9752+0.00165\ FPCM_i)\ (VEM\ d^{-1}) \qquad (5)$$

where $\overline{W}_i$ = the average live weight during month i (kg)

$FPCM_i$ = the average amount of fat and protein corrected milk during month i (kg d^{-1})

The FPCM in this equation was calculated from the formula:
FPCM = (0.349 + 0.107 milk fat % + 0.067 milk protein %) x milk yield (Korver, 1982). Fat and protein corrected milk was used since it predicted the energy milk output more accurately than fat corrected milk (Tyrrell and Reid, 1965; Korver, 1982).

When the dry period started during month i the energy requirement and feed costs were calculated for the lactating and dry part of that month separately.

The average live weight ($\overline{W}_i$) was determined as the average of the initial and final weight in the corresponding month of lactation calculated from the following function (Korver et al., 1985):

$$LW_{t_a t_p t_l} = f(\text{age}) + f(\text{lactation}) + f(\text{pregnancy})$$

$$= A\,[1-\{1-(y_o A^{-1})^{1/3}\}e^{-kt_a}]^3 + p_1 t_l p_2^{-1} e^{(1-t_l p_2^{-1})} + p_3^3 t_{pc}^{\ 3} \qquad (6)$$

where

$LW_{t_a t_l t_p}$ = live weight of a t_a days old cow at t_l days in lactation and t_p days pregnant

t_a = age (d)

t_l = number of days lactation

t_p = number of days after conception

A = mature live weight (kg)

y_o = birth weight (kg)

k = growth rate parameter

p_1 = maximum decrease of live weight during the lactation (kg)

p_2 = time during the lactation with the minimum live weight(d)

p_3 = pregnancy parameter

t_{pc} = t_p-50 when t_p-50 > 0; otherwise t_{pc} = 0

Bakker and Koops (1978) applied the von Bertalanffy function, f(age) in equation (6), to pure breed and cross-breed Dutch Black and White cows. Based on their results and the results obtained by Korver et al. (1985) the mature live weight (A), birth weight (y_o) and growth rate parameter (k) were set equal to 600 kg, 42 kg and 0.0028, respectively. Further, values of 50 kg, 75 days and 0.0187 were used for the parameters p_1, p_2 and p_3, respectively.

The average daily gain per month was calculated from equation (6) excluding the effect of pregnancy. The energy value of body tissue which is mobilised or restored was equal to 21 MJ kg^{-1} (Van Es, 1978). For a growing animal the energy content of live weight gain was lower (Van Es, 1978). Combining the requirement for growth and deposition of reserve tissue results in an additional energy requirement per kilogram live weight gain of 2700 VEM for heifers and 3000 VEM for older cows. During the dry period this process is less efficient and therefore a 10% higher requirement (Van Es, 1978) was used.

The daily energy requirement for pregnancy amounted to 2500 VEM during the last month of gestation, excluding the effect of pregnancy on maintenance requirement (Van Es, 1978). The energy requirement for pregnancy was assumed to be proportional to the monthly increase in live weight due to pregnancy. The latter was calculated from the function representing the effect of pregnancy on live weight in equation (6). This resulted, for example, in an average daily requirement for pregnancy of 815 VEM during the sixth month of gestation. The effect of pregnancy on the maintenance requirement was accounted for in equation (5).

The requirements of cows kept indoors differ little from those of grazing cows (Van Es, 1978). It was therefore assumed that the energy requirement is not affected by season in the strict sense.

The effect of the previous lactation length on the weight at calving was accounted for by setting that weight equal to the weight at the end of the previous lactation period excluding the effect of pregnancy. The weight at the end of the first month of lacation was not influenced. Therefore a shorter calving interval in the previous lactation only resulted in a reduction of the mobilisation of body tissue during the first month of lactation.

4.2. *Energy intake*

The amount of energy which has to be supplied by intake of feed was equal to the energy requirement minus the energy from mobilisation. Body tissue is converted into milk energy with an average efficiency of 85% (Van Es, 1978). The reduction of energy intake per kilogram mobilised body tissue was therefore 0.85 x 3000 = 2550 VEM. The daily body weight reduction was calculated from the monthly live weight change obtained from equation (6), taking into account the length of the previous calving interval.

It was assumed that the ration contained sufficient protein and "structural" material. The feed intake was therefore fully determined by the energy requirements of the cow.

4.2.1. Maximum roughage intake

A number of investigations have been made to predict the voluntary dry matter intake of cows (e.g. Brown et al., 1977; Vadiveloo and Holmes, 1979; Kuipers, 1982). The total intake of roughage and concentrate was predicted in those cases. These equations were hindered from application while the predicted additional intake of energy when production increased was lower than the corresponding additional requirements. Further, the equations were obtained in situations where cows received roughage ad libitum, which does not correspond with the situation on most Dutch farms.

Reitsma (1982) analysed the food supply of cows at 116 dairy farms in The Netherlands during 1978 and 1979. The farms showed an average stocking rate of 2.8 cows per hectare of grassland and an average production level of 5370 kilogram per cow. On average there was available per cow, 1915 kVEM of grass during the grazing period and 977 kVEM of own grassland products and 436 kVEM of supplementary roughage, mainly maize silage, during the indoor period.

In the Dutch Computerized Milk-Recording-Dairy-Cow Ration Program (Kuipers and De Jong, 1981) the roughage intake is calculated based on the quantities of roughages expected to be fed, the age and the stage of lactation of the cow. According to these equations, which are used in this model, the maximum daily roughage intake (kg DM) of a cow (MR), relative to the average intake of a mature cow (AR) amounts to:

$$MR_{t_l} = (0.9 + 0.0009\ t_l)\ AR \quad \text{if } t_l \leq 200 \quad \text{or}$$

$$MR_{t_l} = 1.08\ AR \qquad \text{if } t_l > 200 \tag{7}$$

for a cow t_l oays in lactation. For heifers less than 200 days in lactation equation (7) was multiplied by $(0.8 + 0.0004\ t_l)$. The maximum roughage intake equalled 0.95 AR for heifers in a later stage of lactation. In the last but one and the last month prior to calving the maximum roughage intake was reduced by 10 and 20%.

During the winter (Nov.-April) the average roughage intake (AR) was set equal to 9 kilogram, which corresponds with the situation reported by Reitsma (1982). The ration was assumed to contain 75% of grass silage and 25% of maize silage. This leads to an average energy content of 810 VEM per kilogram (Kuipers and De Jong, 1981).

The same formulas were applied to determine the maximum grass intake during the grazing period (May-Oct.). The average grass intake of a mature cow (AR) was equal to 13 (kg d^{-1}) (Reitsma, 1982) with an average energy content of

945 (VEM kg^{-1}) (Kuipers and De Jong, 1981). It was assumed that cows in October were on pasture for half a day, during which the average daily grass intake of a mature cow amounted to 8 kg. In that month all cows daily consumed 3 kg of silage by night, which equalled 2430 VEM.

If seasonal variation was excluded, the average roughage intake (AR) and the energy content were set equal to the overall average in case of seasonal variation, which amounted to 10.8 (kg d^{-1}) and 890 (VEM kg^{-1}), respectively.

4.2.2. Actual intake of roughages and concentrate

During the lactation period the minimum daily intake of concentrates (940 VEM kg^{-1}) equalled 1 (kg d^{-1}). If the energy demand was lower than the amount of energy obtained from the calculated maximum intake of roughages and the minimum intake of concentrate, the intake of roughages was reduced until the total intake met the cow's energy demand. Otherwise, the actual intake of roughages was set equal to the calculated maximum value. The intake of energy from concentrate met the energy demand which remained after the consumption of roughages.

4.3. Feed costs

For fresh grass and roughage no prices are reported. Therefore, these prices were calculated from the factors associated with grassland exploitation given by Wieling (1981), costs of silage making (Overvest, 1982) and the prices of fertilizer (L.E.I., 1977-1982). The losses during harvesting, conservation and feeding of silage and losses during grazing were accounted for in the price calculations. These figures therefore refer to consumed amounts of roughage. For fresh grass and grass silage a price of 0.22 and 0.42 Dfl. per kVEM, respectively, was obtained. Using a price of 0.48 Dfl. per kVEM of maize silage resulted in an average price for silage of 0.44 Dfl. per kVEM. The weighted average price of fresh grass and silage of 0.31 Dfl. was used when seasonal variation was excluded.

The price of concentrate was fixed at 0.54 Dfl. per kVEM based on monthly price reports (L.E.I., 1977-1982).

5. Carcass value

To determine the optimum time for replacement information is needed about the course of the carcass value of cows. Monthly changes in carcass value were not included in the net revenues since they are separately accounted for in determining the optimum time for replacement.

The carcass weight of a cow reached its maximum at 5-7 years of age (De

Boer, 1980; Wiemer et al., 1982) and decreased when age increased further. The price per kilogram carcass weight of a cow is influenced by age and stage of lactation (Wiemer et al., 1982; Van Arendonk et al., 1984). The effects of age and stage of lactation on dressing percentage have been quantified by Van Arendonk et al. (1984). The carcass value is furthermore influenced by the reason of disposal (Dijkhuizen, 1980; Wiemer et al., 1982; Van Arendonk et al., 1984). Cows culled because of low production or failure to conceive realised the highest price. In this model the carcass value for those cows was determined while the loss due to other reasons of disposal was accounted for separately.

The carcass value, based on live weight, dressing percentage and price per kilogram carcass weight, which depended on the season, is calculated from the following equation:

$$CV_{i,j} = LW_i \; D\%_i \; 100^{-1}(p_j + dp_i) - 100 \tag{8}$$

where $CV_{i,j}$ = the carcass value of cow i in month j including costs associated with the sale of the animal (Dfl.)

LW_i = live weight (kg)

$D\%_i$ = dressing percentage (%)

p_j = the average price per kilogram carcass weight in month j for a heifer 210 days in lactation (Dfl. kg^{-1})

dp_i = the price for cow i as a deviation from the average p_j(Dfl. kg^{-1})

The live weight of a cow was calculated from equation (6) excluding the effect of pregnancy. The effect of age at calving and stage of lactation on dressing percentage and the price per kilogram carcass weight is given in table 7. This price is expressed as a deviation from the price for a heifer's at 7 months in lactation (table 6).

Table 7. The effect of age at calving and stage of lactation on the dressing percentage (D%) and the deviation in price per kg carcass weight.

	Age at calving (yr)												
Trait	2	3	4	5	6	7	8	9	10	11	12	13	
D (%)	50.	49.8	49.6	49.4	49.3	49.2	49.1	49.0	48.9	48.7	48.5	48.2	
Price[1)] (Dfl.)	0.00	-0.05	-0.07	-0.10	-0.15	-0.20	-0.25	-0.30	-0.40	-0.50	-0.60	-0.70	
	Month in lactation[2)]												
Trait[3)]	1	2	3	4	5	6	7	8	9	10	≥11		Dry period
D (%)	-0.6	-0.6	-0.6	-0.6	-0.4	-0.2	-	+0.2	+0.4	+0.6	+0.6		+0.2
Price (Dfl.)	-0.20	-0.20	-0.20	-0.15	-0.10	-0.05	-	+0.05	+0.10	+0.10	+0.10		+0.05

1) As a deviation of the price for a heifer 210 days in lactation
2) The figures represent the value at the end of the month
3) As a deviation of the value at 210 days in lactation within 1 age class

The carcass value at the beginning of the lactation was set equal to that at one month in lactation to allow the calculation of interest during that month, as will be shown in a later section.

6. Calf value

Both heifer and bull calves were sold one week after they were born. Their average value was based on birth weight, survival rate and the price per kilogram.

Peijnenburg (1974), according to Politiek (1979), reported for the Dutch Red and White breed birth weights of 36.5 kg, 39.1 kg and 39.8 kg for heifers, second calvers and older cows, respectively. Politiek (1979) quotes still birth rates for Dutch Friesians of 10%, 3% and 2% for these categories, respectively. In a recent investigation (Meijering and Van Eldik, 1981) an average birth weight of 38.1 kg and an average still birthrate of 3.3% were found for second parity Dutch Friesian cows.

The calf value was based on an average birth weight of 36 kg, 38 kg and 39 kg and a survival rate, including the first week after birth, of 89%, 96% and 97% for the first, second and later calving, respectively. The average price per kilogram is only reported for bull calves (table 6). The value of heifer calves was assumed to be 60 Dfl. lower than the value of a bull calf with the same weight. To account for the costs to the farmer during the first week after birth, 15 Dfl. was substracted from the calculated calf value.

The calf value was assigned to the revenues during the first month in lactation.

7. Sundry costs

Interest was charged on the carcass value of the cow at the beginning of each month. The interest rate per month, corrected for the inflation of agricultural products, amounts to .41%, which corresponds with an interest of 5% per year.

Oldenbroek (1978) reported veterinary costs per cow per year equal to 90 Dfl. for Dutch Friesian cows. During the first month in lactation 30 Dfl. of veterinary cost were substracted. This amount reduced to 10 Dfl. per cow during the second and third month and to 5 Dfl. afterwards. Furthermore, 60 Dfl. of veterinary cost were assigned to the month in lactation during which the cow had to be disposed of because of health problems.

Costs of buildings, machinery etc., equal to 90 Dfl. per cow per month were charged in order to get a realistic level of the net revenues per cow. The cost of labour was not included in this item.

8. Involuntary disposal

The model will be applied to situations where culling for low production - and at a later stage, failure to conceive also - are incorporated in the decision making process of the dynamic programming model. Disposal of cows which is not subject to decision making in that model is referred to as involuntary. The calving interval is fixed at 12 months when failure to conceive is included in the involuntary disposal. The calving interval varies from 11 to 16 months otherwise. The probability and the distribution over reasons for disposal for each parity are obtained from Dijkhuizen (1980). The probabilities of involuntary disposal (appendix A.1) apply to a calving interval of one year. The probability of involuntary disposal for a cow in lactation i during month j (q_{ij}) is equal to:

$$q_{ij} = p_i m_j \left(\prod_{j'=1}^{j-1} (1-q_{ij'}) \right)^{-1} \tag{9}$$

where p_i = probability of involuntary disposal during lactation i (appendix A.1)
m_j = proportion of cow disposal during month j

The proportion of cows disposed of during each month (m_j) is given in (Appendix A.2) for the situation where failure to conceive is included and is excluded from involuntary disposal. As a result of these proportions the probability of involuntary disposal during a calving interval of 11, 13, 14, 15 and 16 months amounted to 93, 106, 111 115 and 119%, respectively, compared to the probability for a calving interval of 12 months.

Dijkhuizen (1980) quantified the financial loss associated with different reasons for disposal which results from a loss of production and veterinary treatment prior to disposal and reduced carcass value and idle production factors associated with disposal. Based on these results and the contribution of each reason to disposal at different times, the reduction in revenues from milk and the financial loss caused by the other factors are calculated (appendix A. 2). The partly reduced feed cost due to a lower production is accounted for. The financial loss due to idle production factors was set equal to 75 Dfl. per involuntary disposed of cow.

9. Model behaviour

Actual monthly records of revenues and costs of dairy cows on Dutch farms were not available. Therefore, the validation of the model was restricted to the comparison with results of other investigations. A number of components of the model have been validated in earlier sections. Some others will be treated in this section. First, results which were obtained in absence of seasonal variation in performance and prices are described. A mature equivalent herd level, HA_i in equation (1), of 7000 kg milk with 4.10% fat and 3.35% protein was used.

9.1. No seasonal variation

The net revenues during a one year calving interval are maximum for a 6-8 year old cow (table 8). The difference between a heifer and this maximum amounted to 963 Dfl. The latter was caused by a 1323 Dfl. and 60 Dfl. higher revenue from milk and calf sales, respectively, while feed and sundry costs were 410 Dfl. and 10 Dfl. lower for a heifer. The weighted average milk production amounted to 6144 kg (table 8). The weighting factors (table 8) were based on the probabilities of realization of each lactation which were derived from the marginal probabilities of disposal, including culling for low production, given by Dijkhuizen (1980).

The average feed costs amounted to 1871 Dfl. per cow. This resulted from a weighted average concentrate and roughage intake on a lactation basis of 1538 kVEM and 3355 kVEM, respectively. These intake figures were low compared to data from Reitsma (1982) who found an average energy intake of 4825 kVEM, of which 1497 kVEM originated from concentrate at a 774 kilogram lower milk production. A comparison of the energy intakes estimated in the model with results from two feed intake experiments, which were summarized by Korver (1984), indicated that the intake of energy was underestimated by, on average, 5.5%. To obtain a better correspondence with the observed energy intakes, all energy

Table 8. The revenues (Dfl.), costs (Dfl.) and production during the lactation period and the carcass value (Dfl.) at 7 months in lactation for cows with different ages at calving and a one year calving interval.

	Age at calving (yr)												Weighted
	2	3	4	5	6	7	8	9	10	11	12	13	average
Milk revenues	3398	3952	4418	4627	4715	4721	4716	4646	4572	4438	4306	4176	4182
Calf revenues	306	352	366	366	366	366	366	366	366	366	366	366	349
Feed costs	1645	1761	1934	2013	2050	2055	2056	2034	2012	1966	1920	1876	1871
Sundry costs	1255	1263	1266	1266	1266	1265	1264	1263	1262	1260	1258	1256	1262
Net revenues	805	1281	1585	1714	1766	1768	1762	1715	1665	1579	1494	1410	1398
Carcass value[1)]	1720	1862	1909	1914	1903	1888	1870	1852	1820	1784	1749	1709	1843
Lactation production													
- milk (kg)	4970	5761	6447	6769	6937	6962	7000	6951	6902	6762	6622	6482	6144
- fat %	4.186	4.140	4.174	4.166	4.137	4.125	4.100	4.063	4.022	3.981	3.940	3.899	4.154
- protein %	3.363	3.384	3.394	3.384	3.373	3.360	3.350	3.333	3.313	3.293	3.273	3.253	3.369
Weighting factor	.239	.192	.151	.118	.091	.068	.050	.035	.024	.016	.010	.006	

1) At 7 *months in lactation*

requirements in the model were increased by a safety margin of 5%. This resulted in an weighted average feed cost per cow of 2002 Dfl. and a concentrate consumption of 1771 kVEM.

The carcass value at 7 months in lactation was maximum for a 5 year old cow (table 8). The carcass value of a heifer was 194 Dfl. lower. Van Arendonk et al. (1984) found a 372 Dfl. higher carcass value for 5 year old cows compared to heifers. The bigger differences in live weight between these 2 age classes in the latter study was the main cause of the bigger difference in carcass value. Furthermore, the difference is influenced by the lower price per kilogram carcass weight in the model and the time during the lactation at which the carcass value was determined. The difference in carcass value increased to 277 Dfl. when the carcass value at 3 months in lactation was calculated from the model. Due to the greater growth, heifers showed a bigger increase in carcass value during the lactation compared with older cows.

In an analysis of data from 3007 Dutch Friesian cows, De Vries (1983) found a difference in carcass value of 290 Dfl. between heifers and 5 year old cows. When age increased further the carcass value decreased. The difference between 5 and 10 year old cows amounted to 96 Dfl. These results are in good agreement with the model.

The cow's relative level of milk production has a large influence on the average monthly net revenues during the lactation period (figure 4). The difference in

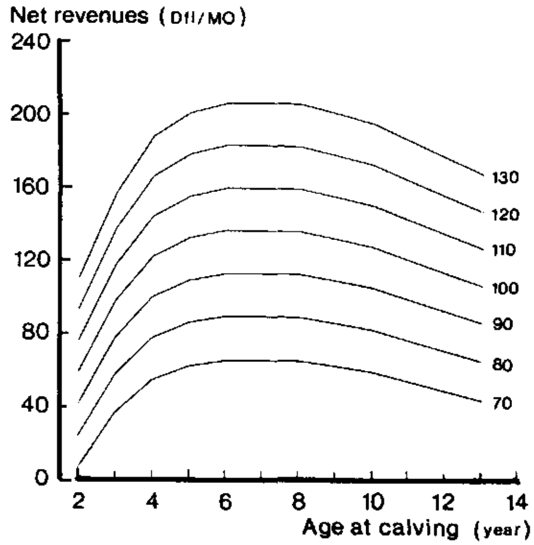

Fig. 4. Average monthly net revenues (Dfl.) during the calving interval (DO = 88) dependent on relative milk production capacity (%) and age at calving.

net revenues per month between the production level of 70 and 130% increased from 103 Dfl. for a heifer to 141 Dfl. for a 7 year old cow. The increment in feed costs per 100 Dfl. additional revenues from milk ranges from 37.5 to 41.6 Dfl. depending on the relative production level and, to a lesser extent, on the age of the cow. Changes in the herd level of production have the same influence on average monthly net revenues as changes in the relative production level of individual cows within the herd. However, the future profitability of cows (Van Arendonk, 1984), which have the same absolute production, is dependent on the production level of the herd.

A prolongation of the calving interval resulted in a decline of the average monthly net revenues during that period (figure 5). This is caused by a decline of the monthly revenues from calf and milk sales, which is partly compensated by a reduction of the feed costs. The sundry costs were hardly influenced by the length of the calving interval. The magnitude of the differences in monthly net revenues among different lengths of the calving interval were smaller for heifers than for older cows (figure 5). Due to their better persistency of milk production, the heifers show a smaller reduction in revenues from milk than older cows. These results are in agreement with the findings of Dijkhuizen (1983).

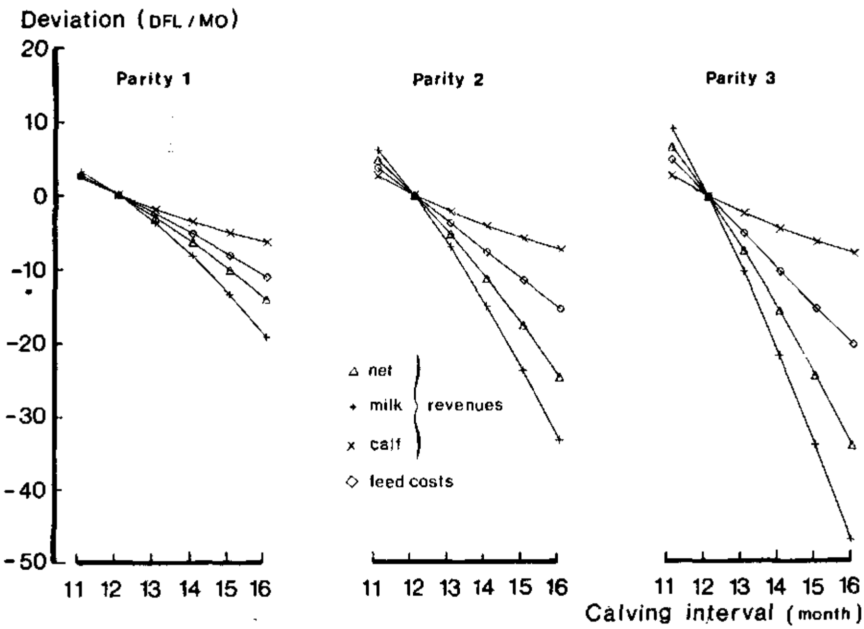

Fig. 5. Effect of changes in length of calving interval on monthly revenues and costs (Dfl.) during that period, expressed as deviation from a 1-year calving interval, dependent on the parity of the cow.

The net revenues of a cow with average production capacity and a one year calving interval were reduced by, on average, 42 Dfl. per year when the previous calving interval was 11, instead of 12, months long. The influence of an additional month open in the previous lactation declined when the length of the previous calving interval increased. The net revenues increased by 14 Dfl. when the previous calving interval increased from 15 to 16 months.

The financial loss of an additional day open is not linear. Reducing the calving interval from 12 to 11 months on average led to a 0.79 Dfl. higher daily net revenue when the influence on both the present and the next lactation was considered. The financial loss of lengthening the interval from 12 to 13 months amounted to 1.57 Dfl., while a lenghtening from 15 to 16 months resulted in a loss of 2.59 Dfl. per day. The literature differs with respect to the elements considered in determining the financial loss due to prolongation of the calving interval (Dijkhuizen, 1983). Losses ranging from 1.00 Dfl. to 5.00 Dfl. were reported.

9.2. *The effect of seasonal variation*

The weighted average net revenues were highest for cows calving in November and lowest for those calving in April (figure 6). The differences amounted to 216

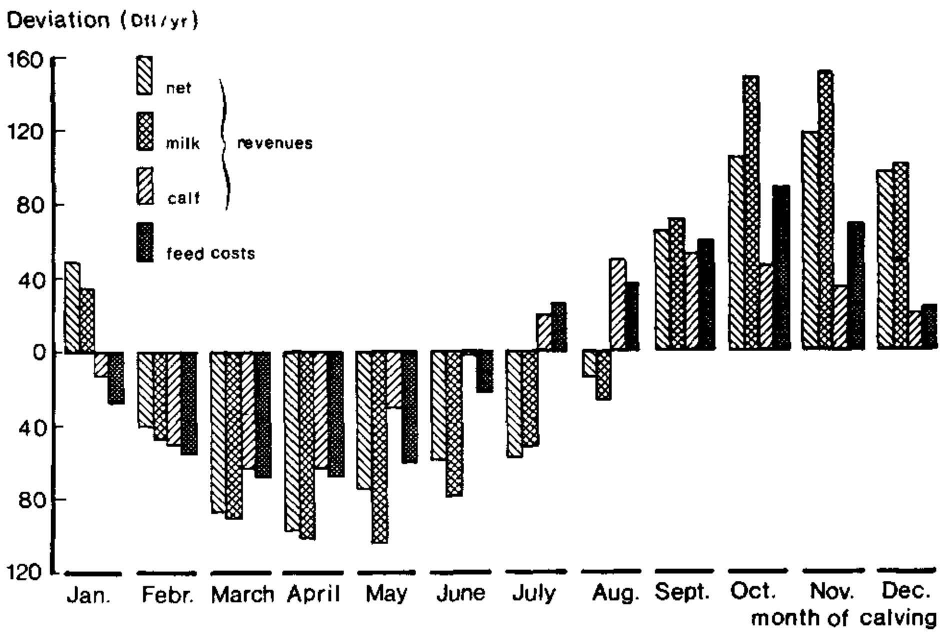

Fig. 6. Effect of month of calving on revenues and costs (Dfl.) during a 1-year calving interval, expressed as deviation from the overall mean.

Dfl. which resulted from 251 Dfl. higher milk revenues, 98 Dfl. higher revenues from calf sales and 134 Dfl. higher feed costs for cows calving in November. The difference in milk revenues were mainly caused by the effect of season on milk production and the composition of the milk. The seasonal differences in milk price hardly influenced the difference. De Boer (1977) and Korver (1977) also found that autumn calving cows raised the highest net revenues while the lowest net revenues were obtained from spring calving cows.

The effect of changes in calving interval on the average daily net revenues is bigger for winter calving cows than for cows during the grazing season. This corresponds with the results of James and Esslemont (1979).

Appendices

Appendix A. 1: The probability of and the average financial loss, due to a reduction in revenues from milk and other factors, associated with involuntary disposal, including and excluding failure to conceive, for all parities.

	Failure to conceive included			Failure to conceive excluded[2]		
	Probability	Financial loss		Probability	Financial loss	
Parity	of disposal	Milk (%)[1]	Others (Dfl.)[3]	of disposal	Milk (%)[1]	Others (Dfl.)[3]
1	0.14	30.	240.	0.12	35.	260.
2	0.15	30.	330.	0.13	37.	370.
3	0.18	30.	330.	0.14	38.	380.
4	0.20	30.	330.	0.15	39.	390.
5	0.23	30.	310.	0.17	41.	380.
6	0.25	30.	290.	0.17	43.	370.
7	0.27	30.	290.	0.18	45.	370.
8	0.29	30.	300.	0.19	47.	390.
9	0.32	30.	310.	0.21	47.	400.
10	0.35	30.	320.	0.23	47.	420.
11	0.38	30.	340.	0.25	47.	440
12	0.41	30.	360.	0.28	47.	470.

1) Expressed as a proportion of the revenues from milk in the month of disposal
2) Figures apply to a one year calving interval
3) Reduced carcass value, veterinary treatment and idle production factors

Appendix A. 2: *The proportion of cows disposed of during each month and the deviation from average financial loss, due to reduced revenues from milk and other factors, for each month in lactation associated with involuntary disposal, including and excluding failure to conceive.*

Month in	Failure to conceive included			Failure to conceive excluded		
	Proportion of	Financial loss		Proportion of	Financial loss	
lactation	disposal (%)	Milk (%)	Others (Dfl.)[2]	disposal (%)	Milk (%)	Others (Dfl.)[2]
1	15	14	+140	20	+2	+90
2	7	14	+ 70	8	+2	+20
3	6	12	+ 30	7	0	-10
4	7	6	0	7	-1	-20
5	8	0	- 20	8	-1	-30
6	10	-6	- 40	9	-1	-40
7	11	-9	- 60	9	-1	-40
8	11	-9	- 70	9	-1	-40
9	10	-9	- 70	8	-1	-40
10	9	-8	- 50	7	-1	-20
11				6	-1	-10
12				5	-1	0
≥13				4	-1	0
Dry period	3	-	+ 60	4	-	+10

1) Last 2 months prior to calving
2) Reduced carcass value, veterinary treatment and idle production factors

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Chapter 3

STUDIES ON THE REPLACEMENT POLICIES IN DAIRY CATTLE

II. Optimum policy and influence of changes in production and prices

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Abstract

A dynamic programming model was developed to determine the optimum replacement policy of dairy cows. In the model cows were described in terms of lactation number, stage of lactation and the level of milk production during the previous and present lactations.

The objective in determining the optimum replacement policy was to maximize the present value of net revenues from the present and subsequent replacement cows over a 20 year planning horizon. Milk and calf revenues, feed costs, carcass value, cost of replacement heifers and the probability of and financial loss associated with involuntary replacement were considered.

The optimum replacement decisions corresponded with an average herd life of 42.9 months. Voluntary replacement accounted for 26% of all replacements.

Changes in the price of a replacement heifer or the carcass price for culled cows had a considerable effect on the optimum replacement policy. A reduction in the difference between the carcass value of culled cows and the replacement costs resulted in a higher rate of voluntary replacement. Changes in the price of milk, calves or feed, the production level of the herd or the rate of genetic improvement did not greatly affect the optimum replacement policy.

The financial advantage of a reduction in involuntary disposal rates increased when voluntary replacement of cows according to the optimum policy took place. These changes in voluntary replacement rates however reduced the effect on the optimum average herd life of cows.

1. Introduction

On average 25-30% of the dairy cows are replaced each year (Stellingwerf, 1977; Gravert, 1980) but enormous variation is observed between herds (Young et al., 1983; Sol et al., 1984). A farmer's cow replacement policy influences herd profitability (Renkema and Stelwagen, 1979; Kuipers, 1982) but exerts a negligible effect on genetic improvement in the herd (Korver and Renkema, 1979; Allaire, 1981).

Low production and failure to conceive are the major reasons for disposal of cows (Stellingwerf, 1977; Gravert, 1980; Young et al., 1983). Decisions to replace cows for these and, to a lesser extent, other reasons are based mainly on economic rather than biological considerations. The farmer expects a higher profit when the cow is replaced. Knowledge of the optimum replacement policy and the influence of changes in production and prices on it may assist the farmer in taking day to day management decisions.

Under Dutch conditions annual income per cow increased by Dfl. 113 when, because of a reduction in involuntary disposal rates, average herd life increased from 3.3 to 4.3 years (Renkema and Stelwagen, 1979). In a later study (Dijkhuizen, 1980) it was shown that the financial advantage was overestimated by 30% due to the assumption that disposal took place just prior to parturition instead of after 205 days in lactation, that being the average time of disposal. In both studies an optimum average herd life of over 10 lactations was reported when no involuntary disposal took place and a constant level of voluntary replacements was maintained.

Korver and Renkema (1979) found that heifers with a milk production of less than 86% of the herd average, after correction for age and stage of lactation, should be replaced. This corresponds with results of Dijkhuizen (1983). He showed that the critical production level increased when the number of days open and, to a lesser extent, the lactation number increased.

The optimum replacement policy was greatly influenced by the replacement heifer price and the carcass value of culled cows (Allaire and Cunningham, 1980; Kristensen and Østergaard, 1982; Dijkhuizen, 1983). A smaller difference between the replacement heifer price and the carcass value of culled cows resulted in more voluntary replacement. Allaire and Cunningham (1980) found that the rate of involuntary replacement influenced the voluntary replacement rate at which economic returns were maximum. Price changes of milk, feed or calves or changes in production level of the herd scarcely affected the optimum replacement policy (Korver and Renkema, 1979; Kristensen and Østergaard, 1982; Dijkhuizen, 1983; Congleton and King, 1984).

Optimization techniques which have been applied to dairy cattle replacement were described and evaluated by Van Arendonk (1984). Dynamic programming, which was introduced by Bellman (1957), has the advantage among others that it offers the possibility of including variation in and repeatability of traits. Because of this information about optimum culling levels during each lactation is not needed (Van Arendonk, 1984).

Besides an optimization technique a model to estimate, among other things, revenues and costs of dairy cows is needed in determining the optimum replacement policy. The model used here was constructed and validated by Van Arendonk (1985). It represents Black and White cows in the Netherlands at the normalized price level of 1981-1982.

The objective of this study was to determine the optimum replacement policy of dairy cows taking into account the variation in milk production. To determine to what extent these results depended on the data used the effects of changes in production or prices were studied. The influence of variation in calving interval and month of calving will be treated in subsequent papers.

2. Material and methods

2.1. Dynamic programming model

Dynamic programming has been used to determine the replacement policy that maximized the expected value of the cash flow over a given planning horizon, that being the objective function. Optimization starts at the end of the planning horizon with setting the value of all cows equal to their carcass value. Using this information the maximum present value of cash flow anticipated from cows and the corresponding optimum decisions are determined at the start of the preceding stage. This process is continued backwards, stage by stage, until the present time is reached. At each stage the present value of the cash flow when keeping the cow until the end of that stage and following an optimum policy during the remainder of the planning horizon, is compared with the value when the cow is replaced immediately.

Cows were described by four state variables namely lactation number (j), stage of lactation (k), milk production level during previous (l) and present lactation (m). The maximum expected present value of the cash flow during the remainder of the planning horizon under an optimum replacement policy, $F_t(x_t)$, given the initial state of the cow at the beginning of stage t equals:

$$F_t(X_t) = \mathrm{Max}\ (\mathrm{Keep}_t(X_t), \mathrm{Repl}_t(X_t)) \qquad ; t=1, N-1 \tag{1}$$

where

$$\mathrm{Keep}_t(X_t) = \delta[R_t(X_t) + (1 - PI(X_t)) \ \Sigma^{15}_{m'=1} \ PT(X_t,m')F_{t+1} \ (X_{t+1}) + PI(X_t)(S(X_{t+1}) - L_t(X_t) + FH_{t+1})] \tag{2}$$

$$\mathrm{Repl}_t(X_t) = S(X_t) + FH_t \tag{3}$$

$$FH_t = -C + \delta\Sigma^{15}_{m=1} PH(m)[R_t(X_t) + (1 - PI(X_t))F_{t+1}(X_{t+1}) + PI(X_t)(S(X_{t+1}) - L_t(X_t) + FH_{t+1})] \tag{4}$$

where $\mathrm{Keep}_t(X_t)$ = expected present value of cash flow given the initial state of the cow, the decision to keep at stage t and an optimum policy during the remainder of the planning horizon;

$Repl_t(X_t)$	=	expected present value of cash flow given the initial state of the cow, the decision to replace at stage t and an optimum policy during the remainder of the planning horizon;
FH_t	=	expected present value of cash flow from stage t until N for a replacement heifer under an optimum policy;
X_t	=	vector representing the cow's state at stage t(see earlier);
$R_t(X_t)$	=	net revenues during stage t;
$S(X_t)$	=	carcass value at the beginning of stage t;
$PI(X_t)$	=	marginal probability of involuntary disposal at the end of stage t;
$L_t(X_t)$	=	financial loss associated with involuntary disposal of a cow during stage t;
$PT(X_t,m')$	=	probability of transition to production level m' at the next stage given the state of the cow;
$PH(m)$	=	probability of a replacement heifer with production level m;
C	=	price of a replacement heifer;
N	=	number of stages during the planning horizon;
δ	=	discount factor.

The future profitability of a cow ($FP(X_1)$, which is the expected profit by keeping the cow until replacement is optimum instead of immediately, was calculated from equation (1) and (3) as:

$$FP(X_1) = F_1(X_1) - Repl_1(X_1)$$

2.2. Elements of the model

The elements of the dynamic programming model that are influenced by each state variable are summarized in table 1.

2.2.1. State variables

The lactation number of a cow could lie between 1 and 12. Given that replacement heifers calved at an age of 2 years and given a calving interval of one year, the age of calving would vary from 2 to 13 years.

The state variable for stage of lactation was defined in such a way that it was possible to decide at monthly intervals during the lactation whether to replace a cow. For the production level, which is defined relative to the mature equivalent production in the absence of genetic improvement and voluntary replacement,

Table 1. Summary of the elements of the dynamic programming model that are influenced by lactation number (j), stage of lactation (k), milk production level during previous (l) and present lactation (m).

	State variable			
Element	j	k	l	m
Net revenues (R)	*	*		*
Carcass value (S)	*	*		
Price replacement heifer (C)				
Loss involuntary disposal (L)	*	*		*
Prob. involuntary disposal (PI)	*	*		
Transition probabilities (PT)	*	*1)	*	*

1) Changes in production level only occurred prior to parturition.

15 alternatives were used. For the limits and the calculation of the mean value for each alternative see appendix 1. Variation applied only to the production of milk; fat and protein content, except for the influence of age and stage of lactation, were held constant.

The four variables resulted in a total of 29880 possible states of a cow.

2.2.2. Net revenues

Monthly net revenues were calculated from milk revenues, calf revenues, feed costs and sundry costs which included veterinary costs and interest. The cost of labour supplied by the farmer was not included. Furthermore the revenues from culled cows and the replacement heifer costs were treated separately, as shown in equation (2), (3) and (4).

The model used to estimate these revenues and costs was described by Van Arendonk (1985). The results apply to a situation where genetic improvement is absent. To account for genetic improvement in milk production the monthly milk revenues at each period during the planning horizon were calculated as:

$$MR'_{t,jkm} = MR_{jkm} + tl_{t,jk}\, pr_{jk}\, r_{gl,j}\ \Delta G \qquad (5)$$

where $MR'_{t,jkm}$ = milk revenues for a cow in the j^{th} lactation, k^{th} stage of lactation with production level m at stage t of the planning horizon corrected for genetic improvement;

MR_{jkm} = milk revenues in the absence of genetic improvement;

$tl_{t,jk}$ = time lag in months between birth of the cow and the replacement heifer at stage 1 (t-(j-1)12-k);

pr_{jk} = age and stage of lactation correction factor;

$r_{g1,j}$ = genetic correlation between milk revenues in lactation 1 and j;

ΔG = monthly genetic improvement of heifers in milk revenues minus feed costs.

To account for the distribution of milk revenues during the lactation period and for the effect of age at calving on milk revenues the correction factor, pr_{jk}, was used in equation (5). These factors were calculated from the milk revenues of an average cow in the absence of genetic improvement. The genetic correlation between first and later lactations was set at 0.9.

An improvement in milk revenues is partly offset by higher feed costs. Based on results of Van Arendonk (1985) the increase in feed costs was put at 40% of the increase in milk revenues. The genetic improvement in milk revenues minus feed costs depended on the price of milk and concentrates which, in the base situation (table 2), were 0.67 and 0.54 Dfl., respectively. For other prices of milk or concentrates the genetic improvement was calculated from:

$$\Delta G = \Delta G_0 \frac{\text{milk price}}{0.67} \frac{1 - 0.4 \dfrac{\text{concentrate price}}{0.54}}{0.6} \tag{6}$$

ΔG_0, the original genetic improvement, was set at 20 Dfl. per year for heifers.

Table 2. Basic prices and other parameters used to determine the optimum replacement policy.

Prices (Dfl.):	
+ milk fat (kg)	10.20
+ milk protein (kg)	9.30
+ base price of milk (100 kg)	-5.60
+ calves (kg)	10.85
+ roughages (kVEM)[1)]	0.31
+ concentrate (kVEM)	0.54
+ carcass weight (kg)[2)]	7.20
+ price of replacement heifer	2500.
Mature equivalent (8yr) herd level:	
+ milk (kg)	6500.
+ fat content (%)	4.10
+ protein content (%)	3.35
Management:	
+ age at first calving (mo)	24.
+ calving interval (mo)	12.

1) Excluding the cost of labour supplied by the farmer.
2) Price per kilogram carcass weight for a heifer 7 months in lactation.

2.2.3. Probabilities

The marginal probabilities of involuntary disposal, dependent on age and stage of lactation, were taken from Van Arendonk (1985). Involuntary disposal, among others, consisted of removal for failure to conceive, udder and teat diseases and foot and leg problems

The production level of a cow remained the same during the lactation period. After 2 months of lactation a reasonable prediction of the lactation production can be made (Dommerholt, 1975; Van Arendonk and Fimland, 1983). Before then voluntary replacement of a cow was not considered. Transition to other production levels took place only at the end of the lactation period.

For heifers the expected production in the next lactation was predicted from the production in the present lactation while for second and higher parity cows the present and the previous lactations were used.

Based on Maijala and Hanna (1974), Rothschild and Henderson (1979) and Hansen et al. (1983) factors of 0.55 and 0.50 for the repeatability of lactation production at one and two year intervals, respectively, were used. For lactation production a variation coefficient of 12%, after correction for the effects of age and herd-year-season (Dommerholt, 1975), was used.

The probability of transition to each of the 15 production levels during the next lactation given the state of the cow, was calculated from the predicted value for the next lactation, the limits of each class and the residual variation in production. The calculation of the probabilities is described in appendix 1.

2.2.4. Other elements

The carcass value was calculated from live weight, dressing percentage and price per kilogram carcass weight (Van Arendonk, 1985). The values refer to cows disposed of voluntarily. The financial loss associated with involuntary disposal was incorporated to account for the loss in carcass value in such cases. The financial loss consisted additionally of loss of production, costs of veterinary treatment prior to disposal and idle production factors associated with disposal (Van Arendonk, 1985). The loss of production was expressed as a proportion of the milk revenues during the month prior to disposal. The loss was therefore influenced by the production level of the cow and genetic improvement in milk production.

To account for time preference of revenues the discount factor in the dynamic programming model was taken to be $0.96^{1/12}$ per month. The planning horizon was taken to be 20 years.

2.3. *Prices and production characteristics*

The prices and production characteristics used in the basic situation are given in table 2. The prices are related to the normalized situation during 1981-1982 (Van Arendonk, 1985). The optimum replacement policy was also determined for alternative price and production levels which are summarized in table 3. In each alternative only one component was changed.

Table 3. Alternative prices and production levels for which optimum replacement policy was determined.

Component	Low	High
Milk prices [1]	90%	110%
Feed prices	90%	110%
Carcass price	90%	110%
Calve price	90%	110%
Price of replacement heifer	90%	110%
Herd level (kg milk) [2]	6000	7000

1) Includes prices of fat and protein and the base price.
2) Mature equivalent in the absence of genetic improvement and voluntary replacement.

2.4. *Parameters describing the optimum situation*

The dynamic programming model yields optimum decisions for all possible states of a cow. To characterize the situation, which would result from applying these decisions, the probability of realisation of each state in the case under consideration was calculated. These probabilities depended on involuntary and voluntary replacement occuring since the cow freshened as a heifer. Replacement of cows which was subject to decision making in the dynamic programming model, was refered to as voluntary.

The probability of a heifer having a certain production level was taken from appendix 1. If replacement at the beginning of stage in lactation was optimum, the probability of realisation of that and the subsequent months of the lactation was set at zero. At the beginning of every subsequent lactation the frequency of production levels was calculated from the frequency of the production levels at the end of the foregoing lactation, taking into account voluntary replacement during that lactation, and the transition probabilities for production.

The probabilities of realisation were used to calculate the marginal probability of voluntary and involuntary replacement during each lactation, and the total proportion of cows which were disposed of voluntarily. In addition the average herd life of the cows was derived.

The average income per cow was calculated as the annuity of the expected present value of the cash flow of a replacement heifer during the planning horizon under the optimum replacement policy, FH_t in equation (4), as: $FH_1/(\Sigma_{t=1}^{N} \delta^t)$ where represents the discount factor.

3. Results

3.1. Basic situation

Heifers were replaced when their relative milk production was lower than 82%. This led to a voluntary replacement rate of 6.2% during the first lactation (table 4). The voluntary replacement rate was lower during the next three lactations but started to increase in lactation 5. The relative production level below which voluntary replacement was optimum is given in table 4 to illustrate the replacement of low producing cows. It represents the production level during both the present and previous lactation for older cows. For some cows, which had a higher production during the present lactation, replacement was optimum as a result of the low production in the previous lactation. Conversely it was sometimes advantageous to retain, rather than replace, cows that had a low production in the present lactation because of high production in the previous lactation.

The voluntary replacement rate of second parity cows was lower than that of heifers although the limit below which replacement was optimum was identical

Table 4. Marginal[1] probability (%) of voluntary and involuntary replacement, the production limit (%)[2] below which replacement is optimum and the proportion (%) and relative production (%) of voluntary replacements during each lactation.

Lactation	Marginal probability of replacement: Involuntary	Voluntary	Limit	Voluntary replacements: Proportion	Rel. production
1	13.6	6.2	82	23.6	76.6
2	14.9	2.7	82	8.2	75.7
3	17.9	2.6	82	6.6	76.5
4	19.8	3.7	86	7.3	78.1
5	22.7	5.9	86	9.1	80.9
6	24.5	9.3	90	10.1	84.4
7	25.9	17.6	98	12.7	89.1
8	27.3	26.8	102	11.0	93.9
9	29.0	43.9	110	8.2	100.5
10	31.0	51.6	118	2.6	106.2
11	32.6	60.4	126	0.5	112.4
12	34.5	65.5		0.1	118.0

1) Seen from the beginning of each lactation.
2) Production level applies to present and previous lactation.

in both cases (table 4). This was caused by the culling of low producing heifers. All cows which started the second lactation had a relative production of over 82% during the first lactation.

Heifers accounted for about one quarter of all voluntarily replaced cows in the optimum situation (table 4). The proportion of voluntary replacements not only depended on the culling level during that lactation but was clearly influenced by the probability of realisation of the lactation and by the effect of voluntary replacements during the foregoing lactations on the probability of any of the production levels occurring. The relative production level during the last lactation of voluntarily replaced cows remained fairly constant up to parity 5 but distinctly increased afterwards (table 4).

Voluntary replacement of cows occured, on average, 205 days after calving but the time ranged from 61 to 275 days depending on the production level and the parity of the cow. Heifers and second parity cows were voluntarily replaced on average at 135 and 205 days in lactation, respectively. Voluntary replacement took place on average 214 days and 244 days after calving for cows with production levels of 80% and 100%, respectively.

After calving a rapid decline in future profitability, as defined in section 2.1., of second and later parity cows occured because of the sale of the calf (figure 1). The future profitability reached its lowest value at 7 to 9 months after calving. At the end of the lactation period the expected revenues during the next lactation clearly caused an increase in future profitability. The course of the future profitability during the lactation is influenced by the age and production level of the cow (figure 1). Low producing cows had a flatter curve and reached the minimum earlier

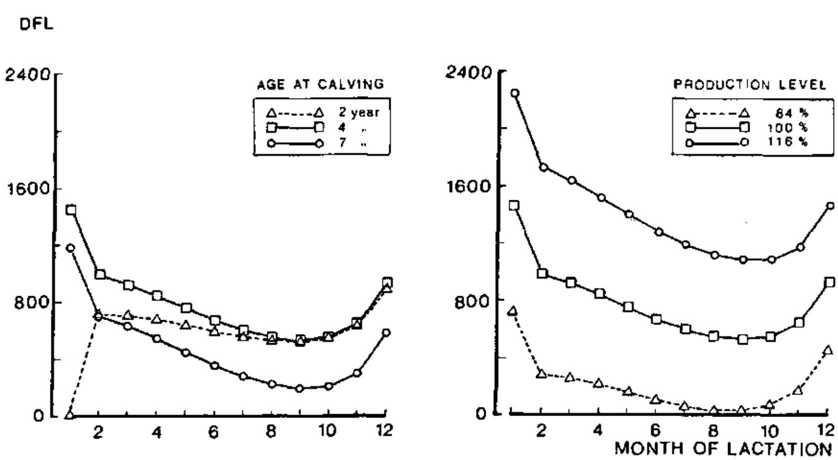

Figure 1. Course of future profitability (Dfl.) during the lactation period of cows with average production dependent on age at calving and of third parity cows dependent on production level.

than high producing cows. The future profitability of a heifer was, by definition, equal to zero before calving. Despite the sale of the calf the heifer's future profitability increased after calving as a result of the big difference (1056 Dfl.) between the price of a replacement heifer and the corresponding carcass value. When the replacement heifer has calved, the purchase price has been paid and therefore no longer affects the future profitability of that heifer.

Given the production capacity the future profitability of cows reached its maximum during the second lactation. These cows had completed the relatively unprofitable first lactation on the one hand and had not yet reached the lactation with maximum net revenues and the highest carcass value on the other. Furthermore their survival probabilities were relatively high. The carcass value and net revenues were at a maximum during parities 4 and 6, respectively.

Given the probabilities of involuntary disposal the average herd life in the optimum situation was 42.9 months which corresponded to an annual replacement rate of 28%. In total 26% of the replacements were voluntary, resulting in a voluntary replacement rate of 7.3%.

The average income during the planning horizon amounted to 85.8 Dfl. per month.

3.2. *Changes in prices or production level*

Changes in the price of a replacement heifer and the carcass price had a considerable effect on the optimum average herd life of cows (table 5). An increase in beef prices or a decrease in the price of a replacement heifer resulted in a shorter optimum herd life, corresponding to a higher replacement rate. Changes in the price of milk, calves or feed and the production level of the herd did not greatly affect the optimum average herd life.

A short average herd life in a given optimum situation was, as a matter of course, associated with a high proportion of voluntarily replaced cows (table 5). The higher proportion of voluntary replacement was caused mainly by higher re-

Table 5. The optimum average herd life of cows (mo) and the proportion (%) of cows for which replacement was voluntary for the alternatives in table 3.

	Average herd life		Voluntary replacement	
Component	Low	High	Low	High
Milk prices	44.9	40.5	22.4	30.6
Feed prices	40.9	43.3	29.8	25.5
Carcass price	46.0	36.1	19.4	39.3
Calf price	43.1	42.8	25.9	26.5
Price of replacement heifer	35.4	47.1	40.8	17.4
Herd level	43.2	40.9	25.6	29.7

placement rates for younger cows. The voluntary replacement rate of heifers amounted to 11.2% in the case of low feed prices, high milk prices or a high production level of the herd. High beef prices and a low price for a replacement heifer resulted in a voluntary replacement rate of 18.4% for heifers, which corresponded with a production level of 90% below which replacement is optimum. Low carcass prices and a high price of replacement heifers reduced the voluntary replacement rates during the first lactation to 3.2 and 1.5%, respectively.

For each alternative the average monthly income per cow was calculated from the expected present value of the cash flow during the planning horizon under the optimum replacement policy. The maximum average income was greatly affected by changes in milk prices and, to a lesser extent, by changes in feed prices and production level of the herd (table 6). The influence of changes in the price of calves, carcass weight or a replacement heifer was relatively small. The effect of price changes on the income per cow reflected the composition of the income in the basic situation where revenues originated mainly from milk (82%). The sale of cows and calves contributed 10% and 8%, respectively. Costs, as defined in the model, were determined to be 48%, 18%, 2% and 32% by feed, replacement heifers, loss associated with involuntary replacement and sundries, respectively.

In line with the results of Renkema and Stelwagen (1979) and Dijkhuizen (1983), the effect of price changes on income per cow did not correspond with the effect on the replacement policy (table 5).

Table 6. The average monthly income per cow (Dfl.) under the optimum replacement policy for the alternatives in table 3.

Component	Low	Medium	High
Milk prices	45.2	85.8	126.7
Feed prices	102.8	85.8	68.9
Carcass price	82.0	85.8	90.2
Calf price	82.0	85.8	89.6
Price of replacement heifer	93.6	85.8	79.1
Herd level	70.2	85.8	101.4

3.3. *Changes in involuntary disposal*

The consequences of a proportional decrease and increase of 20% in the marginal probabilities of involuntary disposal for the replacement policy and the annual income per cow were determined for the prices and production level given in table 2. Besides the situation where cows were replaced according to the optimum decisions, the effects were also studied in the absence of any voluntary replacement.

Table 7. The average herd life (mo) and the average annual income per cow (Dfl.) for a situation with and without voluntary disposal at different rates of involuntary disposal.

Involuntary disposal rate[1]	No voluntary disposal		With voluntary disposal	
	Herd life	Annual income	Herd life	Annual income
120 %	45.5	959 (-37)[2]	38.7	982 (-48)
100 %	52.4	996	42.9	1030
80 %	61.4	1028 (+32)	45.8	1078 (+ 48)

1) Relative to the basic situation
2) Between brackets the deviation from 100 %

If all cows were kept until they were replaced involuntarily the average herd life amounted to 52.4 months (table 7). A 20% increase in involuntary disposal rates resulted in a reduction in average herd life of 6.9 months. The average annual income per cow decreased by 37 Dfl. in that case while a 20% decrease of involuntary disposals led to a 32 Dfl. higher average (table 7).

If the voluntary replacement of cows according to the optimum replacement decisions obtained by dynamic programming was considered, the average herd life was shortened by 9.5 months given the original level of involuntary replacement (table 7). The application of the optimum replacement decisions resulted in an increase in the average annual income per cow from 996 Dfl. to 1030 Dfl.

The difference in average herd life, due to a 20% reduction of the involuntary disposal rates, was reduced from 9 to 2.9 months when voluntary replacement took place (table 7). This was caused by a higher voluntary replacement rate at the lower rate of involuntary replacement (9.5% vs 7.3%). The percentage voluntary replacement rates for heifers were 11.4, 6.2 and 6.0 for the low, medium and high involuntary disposal rates, respectively.

The effect of voluntary replacement on the income per cow increased when the level of involuntary disposals decreased. The annual income per cow increased by 50 and 23 Dfl. due to voluntary replacements at the low and high level of involuntary disposals, respectively (table 7).

3.4. Changes in genetic improvement

The effect of changes in genetic improvement in milk revenues minus feed costs on the average herd life of cows was relatively small (table 8). When the genetic improvement was raised from 20 to 40 Dfl. per year the average herd life in the optimum situation was shortened by 2.4 months. This reduction was caused by an increase of the production level below which voluntary replacement was optimum for older cows. The increase in genetic improvement caused the differences in

Table 8. The effect of genetic improvement (Dfl./year) on the average herd life (mo), the proportion (%) of cows for which replacement was voluntary and the average monthly income per cow (Dfl.) in the optimum situation.

	Genetic improvement		
	10	20	40
Average herd life	44.0	42.9	40.4
Voluntary replacement	23.2	26.3	32.4
Monthly income	79.8	85.8	98.1

net revenues among different age classes at a given time to be in favour of the younger cows.

It was also determined how the replacement policy was affected when only the expected genetic improvement of replacement heifers during the planning horizon was changed to 40 Dfl./year. The genetic improvement realised in the past, which influenced the differences in net revenues among age classes in the present herd, was held constant at 20 Dfl. per year. Voluntary replacement of older cows was reduced due to the greater improvement of replacement heifers. The marginal probability of voluntary replacement of 6^{th} parity cows was reduced from 9.3% to 6.4%. The profit in obtaining a better replacement heifer by keeping the present cow longer counterbalanced the lower revenues from the present cow in this case. The heifers available in one year's time would be expected to give 40 Dfl. instead of 20 Dfl. higher net revenues from milk production than the present replacement heifers in this case. As a result of the greater genetic improvement the longer term effect is a shorter optimum herd life, but this might not be apparent in the short term. The reduction in voluntary replacement rates of older cows in the present herd as a result of the increase in genetic improvement is therefore only a temporary effect. From these results it can be concluded that alterations to the optimum replacement policy during the change over of the herd may not appear immediately to be consistent with the new optimum policy.

5. Discussion

5.1. Dynamic programming model

The dynamic programming model accounted for the variation in milk production of present and replacement cows. In this way the production levels below which replacement at different ages is optimum, can be determined simultanously for the present and the replacement cows. Furthermore the risk that a high producing cow has a low future lactation production is accounted for.

If no variation in production of present and replacement cows was considered, the optimum average herd life and the monthly income equalled 48.5 months and 84.9 Dfl., respectively, at the given level of involuntary replacement. The average income was hardly influenced by the inclusion of variation in production (table 6). The average herd life, however, was reduced by 6 months. The shorter herd life when variation in production is considered was caused by the voluntary replacement of low producing cows occuring during all lactations (table 4). If only average cows were considered voluntary replacement only took place at 7 months of lactation 8. The effect on income of the higher average production per cow was, however, nearly completely counterbalanced by the costs associated with the higher replacement rate.

The effects of changes in the replacement heifer price on the optimum average herd life were much smaller in the absence of variation in production (table 9) than in the situation where variation in production was considered (table 5). The influences on the average income were not much different. It can be concluded that for a correct evaluation of the effects of changes in production or price situation on the optimum replacement policy, variation in production should be taken into account. The variation in production of present cows, for which replacement decisions are to be optimized, is particularly important.

Table 9. Optimum average herd life (mo) and monthly income (Dfl.), dependent on the replacement heifer price (Dfl.), without variation in production.

	Heifer price		
	2250	2500	2750
Herd life	48.5	48.5	50.1
Monthly income	91.3	84.9	78.7

In the dynamic programming, future lactation productions were predicted from production during the present and previous lactation. The accuracy of prediction scarcely increased when more than 2 lactations were considered (Bakker et al., 1979). If the prediction was based only on the present production of the cow the marginal probability of voluntary disposal decreased for cows up to 8 years of age. The greatest effect was observed for heifers, where the marginal probability decreased from 6.2% to 3.2%.

If future productions were predicted from the last lactation only, the expected differences in production between low and high producing cows decreased more rapidly. This is illustrated in figure 2 for two heifers with a relative production of 120% and 80%, respectively. The lower accuracy in predicting future lactations especially affected the replacement decisions for younger cows since they had

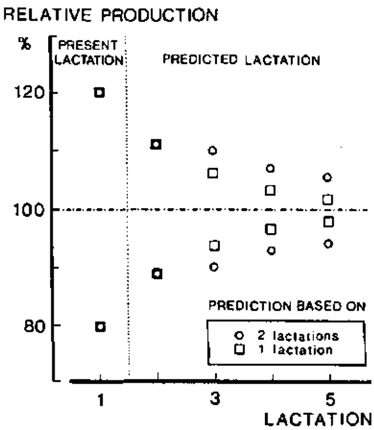

Figure 2. The relative production during future lactations predicted from the last and the last 2 lactations for a heifer with present production of 80% and 120%.

not yet reached their most profitable lactation and were less subject to involuntary disposal than older cows.

Transitions in production level did not occur before the end of the lactation in the dynamic programming model. This assumption does not greatly affect the decisions since the majority of the voluntary replacements took place after 180 days in lactation. By that time the total lactation production could be predicted with a reliability of 96% (Dommerholt, 1975). To incorporate changes in production level during the lactation, the number of state variables representing the production capacity in the model has to be increased in order to account for expected differences in production in future lactations. Due to the limited total number of states which can be handled, this extension of the model does not seem to be justified when weighed against the incorporation of variation in calving interval.

5.2. *Optimum replacement policy*

The optimum replacement policy was greatly affected by the magnitude of the difference between the price of a replacement heifer and the carcass value of culled cows while price changes of milk, feed or calves had a negligible effect (table 5). This is in agreement with results of Stewart et al. (1977), Allaire and Cunningham (1980), Kristensen and Østergaard (1982) and Dijkhuizen (1983). Stewart et al. (1977) found that changes in beef price hardly affected the optimum policy. However as beef price influenced both the carcass value of culled cows and the replacement heifer price only a limited effect was to be expected. It can therefore be concluded that attention should be paid mainly to the cost of replacement heifers and the carcass value of culled cows in any comparison of results reported in the literature or in an application of results to a given population or country.

The effects of a permanent change in prices or production level were quantified. However, whether these results also apply to a situation where cyclical changes occur due, for example, to seasonal variation, requires further study.

The calculated optimum average herd life at the given level of involuntary replacement lies close to the average observed in practice (Sol et al., 1984). However an exact comparison is difficult since variation in calving interval and month of calving were not considered in the model.

The production level of cows was defined relative to the mature equivalent production in the absence of genetic improvement. Due to genetic improvement, however, the mature equivalent productions of a heifer and an older cow, both with a production level of 100%, are no longer equal. Relative to the actual average mature equivalent production of the herd the production level of the heifer increases compared with that of the older cow. Furthermore the average production level of all cows, as defined in the model, increased from 100% to 101.8% due to the replacement of low producing cows.

The financial consequences of a change in involuntary replacement rates in the absence of voluntary replacement (table 7) agreed with results obtained by Dijkhuizen (1980). However, taking into account the variation in voluntary replacement of cows increased the financial advantage of a reduction of involuntary disposal rates but it reduced the effect on average herd life (table 7).

The increase in annual income per cow resulting from voluntary replacement varied from 23 to 50 Dfl. depending on the level of involuntary replacement. Optimization of the replacement policy improved the annual income per cow. The profit is expected to increase when variation in calving interval is considered. Furthermore it should be noted, that besides involuntary disposal, financial loss may occur in practice due to the replacement of cows at a time which is not optimum. Further research is needed to quantify the consequences of using different criteria in taking replacement decisions.

If it were assumed that no involuntary replacement occured before the end of the 12^{th} lactation the optimum average herd life, for the prices and production level given in table 2, was 5.6 years. The annual income averaged 1281 Dfl. per cow which was 251 Dfl. higher than at the original level of involuntary disposal (table 7). A higher profit from voluntary replacement accounted for 133 Dfl. of this difference. In conclusion, a reduction of involuntary disposal rates of cows allowed higher voluntary replacement rates. This increases the financial advantage but reduces the effect on average herd life. From an economic point of view management and breeding policies should, therefore, be directed towards a reduction of involuntary disposal rather than maximization of the average herd life of cows.

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Appendix 1: State variable production.

Symbols used:

y_m	= upper limit of production level m (see table A1);
x^u_m	= standardized upper limit of level m ($x \sim N(0.1)$);
x^l_m	= standardized lower limit of level m;
$z(x)$	= height of distribution ordinate at point x;
$p(x)$	= proportion of animals with production lower than x;
vc	= variation coefficient of lactation production (12%);
b	= correlation of production in consecutive lactations (0.55);
b_{23}, b_{13}	= regression factor of subsequent lactation production on present and previous lactation respectively;
av_m	= average production (%) for production level m.

$$x^u_m = (y_m - 100)/vc$$

$$x^l_m = x^u_{m-1} \text{ for } m > 2 \text{ and } -\infty \text{ for } m=1.$$

$$z(x_m) = \frac{1}{\sqrt{2\pi}} \, e^{(x^2_m/2)} \qquad \text{(Searle, 1971)}$$

$$p(x_m) = \int_{-\infty}^{x_m} z(t)dt \quad ; t \sim N(0.1)$$

The latter integral is computed by the MDNOR - routine of the IMSL Library (IMSL, 1982).

1. The average production for each level (av_m) was calculated from equation (1), which was derived from the wellknown formula for the intensity of selection:

$$av_m = 100 - vc\,(z(x^u_m) - z(x^l_m)) \,/\, (p(x^u_m) - p(x^l_m)) \tag{1}$$

Table A1. The limits[1)] and average production[1)] for each production level of the state variable production and the probability of replacement heifer in each level, PH.

Production level (m)	Limits (%)	Average (%)	PH (%)
1	74	69.74	1.51
2	74- 78	76.22	1.82
3	78- 82	80.18	3.34
4	82- 86	84.15	5.49
5	86- 90	88.11	8.07
6	90- 94	92.07	10.62
7	94- 98	96.04	12.53
8	98-102	100.00	13.24
9	102-106	103.96	12.53
10	106-110	107.93	10.62
11	110-114	111.89	8.07
12	114-118	115.85	5.49
13	118-122	119.82	3.34
14	122-126	123.78	1.82
15	126	130.26	1.51

1) Relative to the mature equivalent production in the absence of voluntary disposal and genetic improvement.

2. Probability of a replacement heifer in each production level (PH(m)):

$$PH(m) = \int_{x_m^l}^{x_m^u} z(t)dt = p(x_m^u) - p(x_m^l) \tag{2}$$

3. Transition probabilities for heifers.

For a heifer with production level m the probability of transition to production level m' during the next lactation is calculated from the following equations:

$$PT(X_t,m') = p(x_{m'}^{u'}) - p(x_{m'}^{l'}) \tag{3}$$

$$\hat{a}_m = b\ av_m \tag{4}$$

$$vc' = vc \sqrt{(1 - b^2)} = 10.02 \tag{5}$$

$$x_{m'}^{u'} = (y_{m'} - \hat{a}_m)/vc' \tag{6}$$

$$x_{m'}^{l'} = x_{m'-1}^{u'} \quad \text{for } m' > 2 \text{ and } = -\infty \text{ for } m'=1 \tag{7}$$

4. Transition probabilities for second and later parity cows.

In case of second and later parity cows the average production in the next lactation ($\hat{a}_m$) is predicted from the production level in the present and previous lactation:

$$\hat{a}_m = b_{23}\, av_m + b_{13} av_l \qquad (8)$$

The least squares solutions for b_{23} and b_{13} (0.394 and 0.283, respectively) are calculated from the repeatability of lactation production at a one and two year interval (0.55 and 0.50). This resulted in a reliability (R^2) of 0.36, which corresponded with a remaining variation coefficient of 9.61.

The probabilities can now be calculated from equation (3), (6) and (7).

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Chapter 4

STUDIES ON THE REPLACEMENT POLICIES IN DAIRY CATTLE

III. Influence of variation in reproduction and production

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Abstract

The optimum policy of insemination and replacement of dairy cows was determined by the dynamic programming technique. The model used in the previous study was extended to allow variation in time of conception. From 2 to 7 months after calving three alternatives were considered for an open cow namely (1) inseminating the cow, with a calculated probability of success (2) leaving her open, and (3) replacing her immediately. When it was profitable to leave a cow open, the optimum time for replacement during the lactation period was determined.

The minimum production level for insemination to be the optimum choice depended on the stage of lactation and the parity of the cow. In the optimum situation the average calving interval was 371 days, while 13% of the cows had an interval of 14 months or longer.

The optimum policy was greatly affected by changes in the replacement heifer price. Changes in the probability of conception and persistency of milk production had significant but smaller effects. In herds with a smaller decline in production after the peak, insemination should be continued for longer than in herds with a larger decline.

The relation between production and calving interval, which resulted from the optimum policy, was determined. When a measure of milk production was used which was not affected by gestation, the average correlation was 0.09. The correlation increased to 0.35 when the total 305-day production was used.

1. Introduction

The optimum length of the calving interval and losses due to sub-optimum intervals have recently received considerable attention (Olds et al., 1979[b]; Esslemont, 1982; Zeddies, 1982; Holmann et al., 1984; Dijkhuizen et al., 1985[a]). The economic consequences of sub-optimum fertility are determined not only by the length of the calving interval but also by the need to replace cows because of reproductive failure (Dijkhuizen et al., 1985[a]).

In deciding whether or not to re-inseminate a particular cow the two elements, mentioned above, should be weighted against each other rather than added. A cow should be inseminated as long as the anticipated loss from a longer calving interval is less than that from replacing the cow.

The stage of lactation at which insemination of a cow was no longer profitable, depended on the age and the production level of the cow (Dijkhuizen et al., 1985[b]). It appeared to be profitable to continue inseminating cows for a long time, especially young cows with an average or above average production level.

The production level, below which insemination of cows is no longer optimum, depended also on the cow's persistency of production (Dijkhuizen et al., 1985[b]). With better persistency of production the loss associated with a longer calving interval is reduced. Insemination should therefore be continued longer than for cows with poor persistency.

Repeatability of measures for fertility in consecutive lactations ranged from 0.03 to 0.13 (Hansen et al., 1983[a]). The optimum policy was scarcely influenced by an increase in the repeatability of calving interval from 0.0 to 0.2 (Dijkhuizen et al., 1985[b]). The optimum replacement policy was greatly affected by the size of the difference between the replacement heifer price and the carcass value of culled cows, while price changes for milk, feed or calves had a negligible effect (Stewart et al., 1977; Kristensen and Østergaard, 1982; Van Arendonk, d1985[b]; Dijkhuizen et al., 1985[b]).

In literature phenotypic correlations of calving interval with 120-day milk production were from 0.05 to 0.10, and with 305-day milk production were from 0.21 to 0.30 (Olds et al., 1979[a]; Hansen et al., 1983[b]; Schneeberger and Hagger, 1984). The increase in correlation with the length of the period over which production accumulated, was attributed to the influence of gestation on production. The 305-day production of a cow, with a given production capacity, increases when conception takes place at a later time. Genetic correlations of measures of fertility with production were summarized by Philipsson (1981). Although results were conflicting, an antagonistic relation prevailed. However, in designed selection experiments for milk production (Shanks et al., 1978; Hansen et al., 1979), no response on fertility traits was observed.

The influence of the farmer's policy of inseminating cows on the phenotypic and genetic correlations is unknown. For high producing cows insemination is generally continued longer than for low ones. Confounding of management decisions with biological effects might occur especially when the analysis was restricted to those cows which became pregnant and calved at the end of the lactation.

From an evaluation of optimization techniques which have been applied to dairy cattle replacement (Van Arendonk, 1984) it was concluded that dynamic programming has the advantage among other things of accounting for variation in, and repeatability of, traits. In the previous paper (Van Arendonk, 1985[b]) this technique was applied to determine the optimum replacement policy for dairy cows, taking into account the variation in milk production. In the present study the optimization is extended, allowing also for variation in time of conception. The relation between production and calving interval which resulted from the optimum policy is quantified.

2. Material and methods

2.1. Dynamic programming model

The objective in determining the optimum replacement policy was to maximize the expected present value of the cash flow of present and replacement cows over the project period.

In the period after calving it was decided whether a cow should be inseminated. This decision was made by comparing the expected present value of the cash flow when the cow was inseminated with that if it was kept open at the same time. An open cow was kept in the herd until the optimum time for replacement was reached. The time at which it was decided to replace a cow, by leaving her open, and the optimum time of voluntary replacement do not therefore necessarily coincide.

Up to 2 months after calving voluntary replacement or insemination of a cow was not considered. From 2 to 7 months after calving the optimum decision for an open cow was chosen from 3 alternatives. These were: 1) to inseminate the cow, with a calculated probability of success, (2) to leave her open or (3) to replace her immediately. For the remaining months of the current lactation of open and pregnant cows the alternatives to keep or to replace immediately were considered.

In the previous model (Van Arendonk, 1985[b]) cows were described in terms of lactation number, stage of lactation and milk production level during the previous and present lactations. To account for the variation in time of conception this variable was added.

Given the initial state of the cow, the optimum decision and the corresponding maximum expected value of the cash flow from stage t until the end of the planning horizon was calculated from one of the following equations:

- open cow during insemination period:

$$F_t(X_t) = \mathrm{Max}(\mathrm{Open}_t(X_t), \mathrm{Ins}_t(X_t), \mathrm{Repl}_t(X_t)) \quad t=1,..,N-1 \tag{1}$$

- pregnant or open cow after the insemination period:

$$F_t(X_t) = \mathrm{Max}(\mathrm{Keep}_t(X_t), \mathrm{Repl}_t(X_t)) \qquad t=1,..,N-1 \tag{2}$$

where

$$\mathrm{Open}_t(X_t) = \delta[R_t(X_t)+(1-\mathrm{PI}(X_t))F_{t+1}(X_{t+1})+\mathrm{PI}(X_t)(S(X_{t+1})-L_t(X_t)+FH_{t+1})] \tag{3}$$

$$Ins_t(X_t) = \delta PC(X_t)[R_t(X_t')+(1-PI(X_t'))F_{t+1}(X_{t+1}')+PI(X_t')(S(X_{t+1}) -L_t(X_t')+FH_{t+1})]+(1-PC(X_t))Open_t(X_t) \tag{4}$$

$$Keep_t(X_t)=\delta [R_t(X_t)+(1-PI(X_t))\Sigma_{m'=1}^{15}PT(X_t,m')(F_{t+1}(X_{t+1})+D(X_t)) +PI(X_t)(S(X_{t+1})-L_t(X_t)+FH_{t+1})] \tag{5}$$

$$Repl_t(X_t)=S(X_t)+FH_t \tag{6}$$

$$FH_t = -C+\delta\Sigma_{m=1}^{15}PH(m)[R_t(X_t)+(1-PI(X_t))F_{t+1}(X_{t+1})+PI(X_t)(S(X_{t+1}) -L_t(X_t)+FH_{t+1})] \tag{7}$$

where

$Open(X_t)$,$Ins(X_t)$,$Keep(X_t)$,$Repl(X_t)$ = expected present value of cash flow given the initial state of the cow, the decision to leave open, to inseminate, to keep or to replace at the beginning of stage t, respectively, and an optimum policy during the remainder of the planning horizon;

FH_t = expected present value of cash flow from stage t until N for a replacement heifer under an optimum policy;

X_t = vector representing the cow's state at stage t which consisted of lactation number (j), stage of lactation (k), milk production level during previous (l) and present lactation (m) and time of conception (n);

X_t' = state when cow conceived at the beginning of stage t;

$R_t(X_t)$ = net revenues during stage t;

$S(X_t)$ = carcass value at the beginning of stage t;

$L_t(X_t)$ = financial loss associated with involuntary disposal during stage t;

$PI(X_t)$ = marginal probability of involuntary disposal at the end of stage t;

$PC(X_t)$ = marginal probability of conception at the beginning of stage t;

$PT(X_t,m')$ = probability of transition to production level m' at the next stage given the state of the cow;

$PH(m)$ = probability of a replacement heifer with production level m;

C = price of a replacement heifer;

N = number of stages during the planning horizon;

δ = discount rate;

$D(X_t)$ = deviation in net revenues due to the length of the previous lactation.

The planning horizon was taken to be 15 years. Given a stage length of one month, this corresponds with 180 stages.

The future profitability of a cow $FP(X_1)$, which is the expected profit by inseminating and keeping the cow as long as this is optimum instead of immediate replacement, was calculated from equation (1) or (2) and (6) as:

$$FP(X_1) = F_1(X_1)-Repl_1(X_1) \tag{8}$$

2.2. Elements of the model

Insemination of a cow could occur at monthly intervals from 2 to 7 months after calving. A cow which remained open was allowed to stay in the herd up to a maximum of 16 months after calving. The variation in time of conception influenced the milk revenues, feed costs, the probability of, and the loss associated with, involuntary disposal.

The production of a cow was defined relative to its mature equivalent milk production during a one year calving interval in the absence of genetic improvement and voluntary replacement. The time of conception did not influence the production level of a cow. However, the 305-day or the total lactation production, which corresponded with a given production level, depended on the time of conception. The production levels and transition probabilities were identical with those used in the earlier study (Van Arendonk, 1985[b]).

The model described by Van Arendonk (1985[a]) was used to calculate the net revenues resulting from milk and calf revenues on the one hand and feed and sundry costs on the other in the absence of genetic improvement. Further, it was applied to calculate the carcass value, the marginal probability of, and the financial loss associated with, involuntary disposal which consisted partly of a loss of production. For a description of the influence on milk revenues and feeds costs of a continuous genetic improvement in milk production, set at 20 Dfl. per year for heifers, see Van Arendonk (1985[b]).

2.3 Probability of conception

The marginal probability of conception of an open cow (table 1) was calculated from the probability of first and/or later inseminations occurring and the probability that conception took place after insemination. For a detailed description see appendix 1.

The conception rate of cows was assumed to be independent of the production level and the length of the previous lactation of the cow.

Table 1. Marginal probability of conception of an open cow at different times of insemination dependent on lactation number.

	Time after calving (mo)					
Lactation	2[1)]	3	4	5	6	7
1	0.26	0.46	0.49	0.53	0.49	0.48
2	0.31	0.51	0.54	0.57	0.53	0.52
3	0.32	0.52	0.55	0.59	0.55	0.53
4	0.32	0.52	0.55	0.59	0.55	0.53
5	0.32	0.51	0.54	0.57	0.54	0.52
6	0.31	0.49	0.52	0.56	0.52	0.51
7	0.30	0.48	0.51	0.54	0.50	0.49
8	0.29	0.46	0.49	0.51	0.48	0.47
9	0.27	0.44	0.47	0.49	0.47	0.45
10	0.26	0.43	0.45	0.47	0.45	0.43
11	0.25	0.41	0.43	0.45	0.43	0.41

1) 61 days after calving.

2.4. *Financial consequences of length of calving interval*

The influence of the length of the previous and present calving interval on revenues and costs during the present lactation was taken from Van Arendonk (1985[a]).

The effect of the length of the previous calving interval on the net revenues during the present lactation was accounted for during the transition to the present lactation. The effect, variable $D(X_t)$ in equation (5), was equal to the net revenues during the present lactation, which was assumed to be 1 year long, expressed as a deviation from those for a previous calving interval of 1 year. For an average second lactation cow the deviation amounted to Dfl. -36 and Dfl. 63 for previous calving intervals of 11 and 16 months, respectively.

2.5. *Other elements*

The model used to estimate revenues and costs (Van Arendonk, 1985[a]) represented Black and White cows in The Netherlands at the normalized price level of 1981-1982. For information on some of the characteristics see table 2.

The discount rate in the dynamic programming model was set at $0.96^{1/12}$ per month.

2.6. *Parameters describing the optimum situation*

Some parameters were derived from the optimum decisions, for all possible states of a cow, to characterize the situation which would result from applying

Table 2. Base prices and other parameters used to determine the optimum replacement policy.

Prices (Dfl.):	
+ milk fat (kg)	10.20
+ milk protein (kg)	9.30
+ base price of milk (100 kg)	-5.60
+ calves (kg)	10.85
+ roughages (kVEM)[1)]	0.31
+ concentrate (kVEM)	0.54
+ carcass weight (kg)[2)]	7.20
+ price of replacement heifer	2500.
Mature equivalent (8yr) herd level:	
+ milk (kg)	6500.
+ fat content (%)	4.10
+ protein content (%)	3.35
Age at first calving (mo)	24.

1) Excluding the cost of labour supplied by the farmer
2) Price per kilogram carcass weight for a heifer 7 months in lactation
3) During a 1 year calving interval in the absence of genetic improvement and voluntary replacement.

these decisions. For example the optimum average herd life and the voluntary and involuntary replacement rates were determined. The principles of these calculations have been described by Van Arendonk (1985[b]).

Further information was obtained about the relation between production and calving interval, which resulted from the optimum replacement policy. At the end of the lactation the correlation between the length of the calving interval and the production level of the cow was calculated.

2.7. *Persistency of milk production*

Pieterse (1980) observed a residual variation coefficient of 37% for the decline in daily milk production of Dutch Friesian heifers. In the model (Van Arendonk, 1985[a]) a parameter (b), representing the decline in milk production after the peak, was used to calculate the distribution of production during the lactation period. The influence of the production level and the number of days open on the shape of the lactation curve were accounted for separately. The model was further used to calculate the effect of the length of the calving interval on the lactation production.

To study the effects of a flatter or a steeper lactation curve for all cows in the herd, a 20% lower or higher slope (b), respectively, was used. The milk, fat and protein production of a cow with a one-year calving interval was not affected by a change in slope. No differences in lactation length due to differences in persistency were used. The increase in production with the calving interval, however, was greater in the case of a flatter lactation curve.

3. Results

3.1. Basic situation

The relative production level above which insemination of heifers was optimum increased from 82% at 3 months after calving to 94% at 7 months (table 3). The critical production level was the same at the second and third month after calving. The same results were found for cows in the second and third lactation, whereas for older cows the critical production levels increased. Moreover the difference in critical production level (%) between 3 and 7 months after calving increased from 12 units the first three lactations to 16 units in later lactations. Most cows for which re-insemination was not optimum were replaced between the 7^{th} and 10^{th} month in lactation. The time depended mainly on the production of the cow.

In the first lactation a replacement rate of 23.4% was calculated, of which 47% was subject to decision making (table 3). The latter category, which resulted from the combination of the relative production and the reproduction status of the cow, is referred to as voluntary replacement. Replacement of cows which failed to conceive after re-insemination for up to 7 months after calving was

Table 3. Marginal probability (%) of voluntary and involuntary replacement and the production level (%)[1] above which insemination at different months after calving is optimum during each lactation.

Lactation	Marginal probability of replacement		Production level at insemination time[2)]		
	Involuntary	Voluntary	3	5	7
1	12.4	11.0	82	90	94
2	13.5	3.6	82	86	94
3	14.3	4.1	82	90	94
4	15.2	5.3	86	90	98
5	17.0	8.0	86	94	102
6	16.9	11.9	90	98	106
7	17.4	21.6	94	102	110
8	17.7	34.9	102	106	118
9	18.9	51.1	110	114	126
10	20.1	62.6	118	122	-
11	21.5	73.5	126	-	-
12	24.1	75.9	-	-	-

1) The production level applies to present and previous lactation
2) Months after calving.

regarded as involuntary. This category differed from other involuntary replacements since the optimum time for replacement during the remainder of the lactation period was determined. This concerned almost 1% of all heifers. The proportion of second parity cows which were replaced voluntarily, was 3.6%. Due to the replacement of low producing heifers this proportion was lower than for heifers, although the critical production levels for insemination to be profitable hardly differed. In later lactations the marginal probability of voluntary replacement clearly increased. The probabilities of voluntary and involuntary replacement led to an average herd life of 44.0 months in the optimum situation corresponding with an annual replacement rate of 27%. Voluntary replacement accounted for 40% of all replacements, while 2% was due to failure to conceive during the insemination period.

The average calving interval of the herd in the optimum situation, given the marginal probabilities of conception, was 371 days (table 4). On average 13% of the cows had a calving interval of 14 months or longer. The average calving interval and the proportion of cows with a long calving interval decreased with the age of the cow.

For cows which completed a lactation, the weighted average correlation between the length of the calving interval and the production level during that lactation was 0.09 after correction for differences between lactations. The measure used for production of cows in that case was, by definition, independent of the time of conception. The correlation therefore resulted from the fact that it is profitable to continue insemination for a longer time for high, rather than low, producing cows. The correlation between production and the length of the calving interval clearly differed between lactations (table 4) and was higher in lactations with a higher proportion of voluntary replacement.

Table 4. Frequency (%) distribution and average calving interval and the correlation between calving interval and production level of cows which completed the lactation period dependent on parity.

	Calving interval (mo)						Average	
Lactation	11	12	13	14	15	16	interval(d)	Correlation
1	28.1	36.5	19.6	9.8	4.2	1.8	375	0.10
2	32.5	36.2	18.3	8.5	3.2	1.3	371	0.05
4	34.0	36.5	17.8	8.0	2.7	1.0	370	0.08
6	34.6	36.0	18.0	7.9	2.6	0.9	369	0.14
8	36.5	38.3	16.1	6.5	1.6	0.4	366	0.24
10	34.2	46.0	14.8	4.6	0.4	0.0	363	0.25
Average	32.4	36.4	18.3	8.5	3.2	1.2	371	0.09

The course of the future profitability, as defined in equation (8), during the lactation was clearly influenced by the time of conception. This is illustrated in figure 1 for a third parity cow with relative productions of 100 and 124%, respectively. After calving a decline in future profitability occurred for all cows as a result of a decrease in marginal net revenues and an increase in carcass value with the stage of lactation. At the different times of conception the future profitability is given of a cow which was inseminated with the probability of conception shown in table 1. At the later times of conception the probability of remaining open and the loss associated with it clearly influenced the expected profitability. Conception started to influence the future profitability one month after the cow was inseminated. Due to the shorter interval until the next calving, cows which conceived early had a higher future profitability at a given stage of lactation and reached their minimum earlier than cows which conceived later. At one month before the next calving however, the future profitability was slightly higher for cows with a longer calving interval. This is because of the influence of a prolonged calving interval on the net revenues anticipated during the next lactation. The loss during the present lactation due to a prolonged calving interval has already been sustained and no longer affects the expected profit as calving intervals in consecutive lactations are assumed to be unrelated.

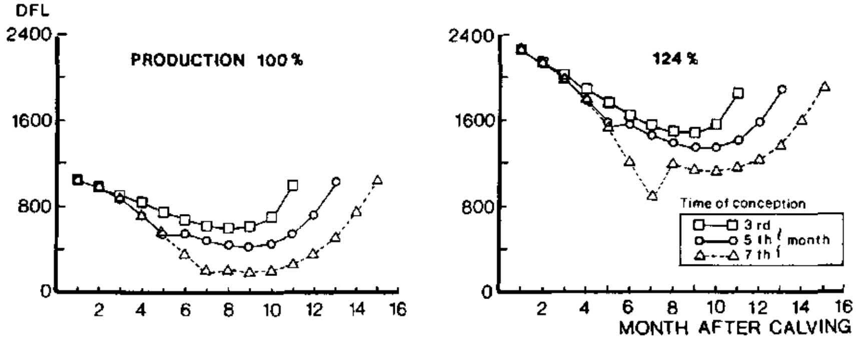

Figure 1. Course of future profitability (Dfl.) during the lactation period of a third parity cow with a production level of 100% and 124% dependent on time of conception.

3.2. Sensitivity analysis

A proportional increase in the marginal probabilities of conception of 20%, resulted in an average 6 days shorter calving interval while a reduction of 20% led to an increase of 8 days (table 5). The level of the conception rates slightly increased the production level above which insemination was optimum for old cows. However, a reduction in the probabilities of conception increased the proportion of cows for which re-insemination was no longer profitable. Further the

Table 5. *The average value of parameters describing the optimum replacement policy for some alternatives[1].*

	Basic situation	Probability of conception[2]		Heifer price (Dfl.)		Persistency	
		80%	120%	2250	2750	80%[3]	120%
Income (Dfl./mo)	81.6	79.1	83.2	89.3	75.1	81.8	81.6
Herd life (mo)	44.0	41.3	45.5	34.3	50.0	45.6	41.9
Voluntary replacement (%)[4]	40.2	39.7	39.2	54.5	30.7	37.4	42.9
Calving interval (d)	371	379	365	370	372	376	370
Calving interval ≥14 mo (%)	12.9	19.8	7.6	11.7	13.6	15.3	11.5

1) Only one component was changed at a time.
2) Relative to probabilities in table 2.
3) Smaller decline in production; flatter lactation curve.
4) As a proportion of all replacements.

percentage proportion of cows which failed to conceive, although insemination at 7 months after calving was still optimum, amounted to 0.4 and 6.8 for 20% higher and 20% lower probabilities of conception respectively. The average annual income was 30 Dfl. lower after a 20% reduction of the conception probabilities while a 20% increase led to a 19 Dfl. higher income. The changes resulted from changes in the calving interval and in replacement due to failure to conceive.

The replacement heifer price greatly affected the optimum average herd life of cows but had hardly any influence on the average calving interval (table 5). The minimum production for insemination to be optimum depended on the heifer price. Differences between parities and times of conception did not change systematically.

The persistency of production had a negligible effect on the production level above which cows at 3 months should be inseminated from an economic point of view. However, the increase in the critical production level from 3 to 7 months in lactation was 8 and 19 units, on average, in a herd with a good (80%) and poor (120%) persistency, respectively. Furthermore high producing cows in their second or later lactation should not be inseminated before 3 months after calving in case of good persistency of production. This resulted in a proportion of cows with a 11 months interval of 25% compared with 33% in case of poor persistency. The differences in optimum policy resulted in a 6 day difference in average calving interval (table 5). The average herd life increased slightly when the persistency improved.

3.3. *Changes in insemination period*

In the dynamic programming model insemination of cows was stopped after the 7^{th} month in lactation. The consequences of a shorter insemination period were determined for the replacement policy and the income per cow. The other elements of the dynamic programming model were kept equal to those in the basic situation. In all cases insemination started at the second month after calving.

The average calving interval was shortened by 4 days when cows were no longer inseminated at the 6^{th} and 7^{th} month in lactation (table 6). The average herd life of cows was reduced by 4 months in that case. The 2 months shorter insemination period reduced only slightly the average income per cow. However, the financial loss was considerable when especially high producing cows had to be replaced when they failed to conceive.

When cows were only inseminated at the second and third month after calving the calving interval was reduced to 352 days on average (table 6). This reduction, however, was associated with about 145 Dfl. lower average annual income per cow compared with the other situations. The benefit of shorter calving intervals in no way compensated for the greater loss due to the increased replacement rate. It can therefore be concluded that the farmer's insemination policy should not be directed solely towards shorter calving intervals.

Table 6. Influence of the length of the insemination period on the average monthly income (Dfl.), calving interval (d) and herd life (mo).

	Last time of insemination[1]		
	3	5	7
Monthly income	69.1	80.2	81.2
Calving interval	352	367	371
Herd life	22.4	39.9	44.0

1) Month after calving.

4. Discussion

In the present study a 15-years planning horizon was used to save computation time. The optimum replacement policy in the absence of variation in time of conception (Van Arendonk, 1985[b]) was not influenced by a reduction of the planning horizon from 20 to 15 years. As a result of the continuous genetic improvement and the moderate discount rate of 4% the average monthly income per cow was 4.60 Dfl. lower for 15 than for 20 years. The differences in future profitability among parities or relative productions of a cow were not affected by the reduction of the planning horizon. No changes as a result of a shorter planning horizon were therefore expected in the influence of alternative prices or production parameters on income or the optimum replacement policy.

The production levels below which cows should be kept open at 3 months after calving (table 3) are identical to the critical production levels when a constant calving interval of 1 year and previously determined probabilities of failure to conceive were used (Van Arendonk, 1985[b]). In the latter case the marginal probability of disposal was lower for heifers and higher for cows in lactations 3 to 7 compared with that in the present study (table 3). These differences resulted in a minor reduction in the annual replacement rate from 28.0 to 27.3%. The average monthly income per cow, taking into account the effect of the shorter planning horizon, was not affected by the inclusion of variation in time of conception. This also holds for the effect of changes in the replacement heifer price on income (table 5). The difference in average herd life between a low and high heifer price increased from 11.7 (Van Arendonk, 1985[b]) to 15.7 months (table 5). It can be concluded that when, in addition to production, the reproduction status of a cow was considered in optimizing the replacement policy, differences in average herd life, or annual replacement rate, as a result of changes in heifer price, for example, increased. The differences in income were not affected.

The minimum production level for insemination to be optimum increased with the stage of lactation (table 4). Nevertheless insemination should be continued for a long time for cows with an average or higher production. The production level of a cow did not change during the lactation period which means that a correlation of 1 between the partial and total lactation was assumed. Due to the lower actual correlation (Dommerholt, 1975) the deviations in cumulative yield relative to the average for insemination to be optimum, are slightly underestimated in table 4. For example 90 days in lactation a heifer should have a relative cumulative production of about 78% to get a predicted lactation production of 82%. The critical productions for insemination to be profitable (table 4) were generally in good agreement with the results of Dijkhuizen et al. (1985[b]). The critical productions were closer to the average (100%) in that study. This was caused by the greater effect of the cow's present production on the production in future lactations.

A change in the probability of conception in an individual case does not influence the decision whether or not to inseminate a cow when no costs have to be paid. A cow should be inseminated, irrespective of the probability of success, if the maximum profit anticipated after conception is higher than that of an open cow. However, another situation arises when because of the reason for the difficulty to conceive a recurrence of the problem in future lactations is expected. As a result of the lower future conception rates the future profitability after conception is reduced. Insemination of that cow should be stopped earlier (Dijkhuizen et al., 1985[b]). In this study, probabilities of conception were changed for all cows (table 5). Besides the expected profit from cows presently in the herd, the level of the conception rates also influenced the expected income from a replacement heifer. When cows become older, the influence of the conception rate during the next lactation on the expected profit decreases due to the reduction in survival probability. The higher expectation from a replacement heifer when conception rates improved, slightly increased the minimum production for insemination to be optimum for older cows. The increase in expected profit during future lactations for young cows in that situation counterbalanced the increased revenues in case of replacement.

In agreement with earlier findings (Dijkhuizen et al., 1985[b]) insemination was optimum for a longer time when the persistency of production improved. Furthermore it was profitable to postpone the first insemination of high producing older cows. This was not observed for first and second parity cows due to the relatively low revenues, especially with heifers. No effect of persistency of production of all cows in the herd was found on the average income per cow. However, the influence of an improved energy balance during the first part of the lactation and of a shorter dry period as a result of improved persistency were not accounted for.

The optimum policy of insemination and replacement of cows resulted in a correlation between the length of the calving interval and the milk production level of 0.09, on average (table 4). The correlation was 0.13 and 0.06 when the price of a replacement heifer was Dfl. 2250 and Dfl. 2750, respectively. The extent to which farmers replace cows voluntarily clearly influences the correlation. The measure of production in these calculations was not affected by gestation. When, however, the 305-day production was used the correlation increased to 0.35 in the basic situation. The correlations between production and calving interval closely agree with the estimates of Olds et al. (1979[a]), Hansen et al. (1983[b]) and Schneeberger and Hagger (1984). If farmers inseminate cows according to the optimum policy this would explain to a great extent the phenotypic correlation between production and calving interval.

Appendix 1: Calculation of marginal probabilities of conception.

In the dynamic programming model conception could take place at distinct points in time. To account for conception of cows which remained open after earlier inseminations, however, monthly periods were used to calculate the probability of conception. For example, the period of 45.75 to 76.25 days after calving was used to calculate the marginal probability of conception at 2 months. These periods are referred to as month of insemination.

The probability of conception during the i^{th} month of insemination, p_i, was calculated from the following equation:

$$p_i = fl_i cr_i + \left(\sum_{k=2}^{i} \sum_{j=1}^{m} f_{ijk}\, q_{ijk} \right) d\, cr_i$$

where fl_i = proportion of first insemination in month of insemination i (table A1);

cr_i = conception rate after insemination;

f_{ijk} = proportion of empty cows which were inseminated for the first time during month k and had their j^{th} oestrus during insemination month i;

q_{ijk} = probability of a cow, inseminated for the first time in month i, failed to conceive until the j^{th} oestrus;

d = heat detection rate (70%);

m = maximum number of oestri considered after first insemination (8).

The conception rate after insemination during month i, cr_i, was equal to:

$cr_i = \overline{cr}\, l_i$

where $\overline{cr}$ = average conception rate after insemination (table A2);

l_i = relative conception rate during the i^{th} month of insemination (table A1).

Table A1. The proportion (%) of first inseminations for heifers and older cows (fl_i)[1] and the relative[2] conception rate for different months of insemination (l_i)[3].

	Month of insemination					
	2[4]	3	4	5	6	7
Proportion of 1° inseminations						
- heifers	44	41	11	4	0	0
- cows	49	38	10	3	0	0
Relative conception rate	0.97	1.02	1.02	1.00	0.97	0.92

1) Based on Jansen (Pers. com., 1984)
2) Relative to the average conception rate (see table a2)
3) Based on De Kruif (1975)
4) 46-76 days after calving

Table A2. The average conception rate after insemination ($\overline{cr}$) dependent on lactation number[1].

	Lactation number										
	1	2	3	4	5	6	7	8	9	10	11
$\overline{cr}$	0.56	0.61	0.63	0.63	0.61	0.59	0.57	0.55	0.52	0.50	0.47

1) Based on De Kruif (1975)

It was assumed that first inseminations were distributed equally over a month of insemination. Furthermore a constant cycle length of 21 days was used for cows which did not conceive.

The marginal probability of conception at i months after calving, pc_i, was calculated as:

$$pc_i = p_i \qquad \text{for } i = 2$$

and

$$pc_i = p_i/(1 - \sum_{j=2}^{i-1} p_j) \qquad \text{for } 3 \leq i \leq 7$$

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Chapter 5

STUDIES ON THE REPLACEMENT POLICIES IN DAIRY CATTLE

IV. Influence of seasonal variation in performance and prices

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Abstract

The optimum policy for inseminating and replacing cows, taking into account seasonal variation in traits and prices, was determined by the dynamic programming technique. The decision to inseminate a cow was based on comparing the expected income when the cow conceived with that when the cow was left open and replaced at the optimum time in the remainder of the lactation period. In the model cows were characterised by their lactation number, stage of lactation, time of conception, milk production level and month of calving. The month of calving influenced the production of milk, fat and protein, the probability of conception, feed costs and the price of milk, calves, replacement heifers and culled cows.

Heifers calving from September to November yielded the highest income while those calving in May or June gave the lowest. The difference in expected income between October and June was 277 Dfl.

The minimum production for insemination to be optimum was largely dependent on the time of year. Lowest production was found when insemination took place from February to April. The consequences of the differences in the optimum policy in months of calving for the average length of the calving interval and the probability of replacement during the first lactation, and for the expected herd life of heifers were quantified.

Seasonal differences in production, feed costs and calf prices were the main sources of the differences in the expected income from heifers. The optimum policy for inseminating and replacing cows was greatly affected by the seasonal variation in production and to a much smaller extent, in calf prices and feed costs.

1. Introduction

It is well recognized that seasonal differences exist for a number of traits and prices. Under Dutch conditions cows calving in autumn produce the highest revenues from milk and calves during a 1-year calving interval (De Boer, 1977; Van Arendonk, 1985[a]). Besides the influence on performance in a lactation, season also affects the course of revenues and costs during the lactation. The consequences of seasonal changes in performance and prices for the optimum replacement policy for dairy cows have not been investigated thoroughly up to now.

James and Esslemont (1979) showed that the influence of changes in the length of the calving interval on the margin of milk revenues over concentrate costs depended on the month of calving. The decision whether or not to inseminate a cow is, however, determined not only by the loss due to a prolonged calving interval but also by the loss in case of replacement (Dijkhuizen et al., 1985; Van Arendonk and Dijkhuizen, 1985).

Optimization of the decision to replace or inseminate a cow is based essentially on a comparison of the expected net revenues from a cow presently in the herd with those in case of its replacement (Van Arendonk, 1984). In determining the expected net revenues from replacement cows, difficulties arise when seasonal varation has to be accounted for. As a result of replacement's occuring at different times after calving, subsequent replacement cows are not necessarily identical. The dynamic programming technique offers the opportunity to account for the fact that replacements are not identical because of seasonal variation (Van Arendonk, 1984). In a previous paper (Van Arendonk and Dijkhuizen, 1985) this technique was applied to determine the influence of variation in milk production and reproduction on the optimum replacement policy. In the present study the effects of seasonal variation in performance and prices are incorporated in this optimization. In addition the contributions of the seasonal differences in separate variables or prices are quantified.

2. Materials and methods

2.1. Dynamic programming model

To account for seasonal variation in production and prices a state variable, related to month of calving was added, to the dynamic programming model used by Van Arendonk and Dijkhuizen (1985). In that model the milk production in a subsequent lactation was predicted from the production level during the present and previous lactations. The large number of possible states of a cow made it necessary to omit the previous lactation's production level as a variable in the model. The more rapid decline of the differences in projected production among cows, resulting from this omission affected especially the replacement decisions for younger cows (Van Arendonk, 1985[b]). A lower level of production was needed for replacement to be optimum in that case. This was partly compensated for by a higher repeatability of lactation milk production for second and later parity cows (0.60).

Cows were therefore described in terms of lactation number, stage of lactation, milk production level during the present lactation, time of conception and month of calving. The influence of these variables on the elements of the dynamic programming model are summarized in table 1. For a detailed description of the model and its parameters reference is made to Van Arendonk and Dijkhuizen (1985).

Table 1. Summary of elements of the dynamic programming model which are influenced by lactation number (j), stage of lactation (k), milkproduction level (m), time of conception (n) and month of calving (p)[1].

Element	State variable				
	j	k	m	n	p
Net Revenues (R)	*	*	*	*	*
Carcass value (S)	*	*			*
Price replacement heifer (C)					*
Effect previous calving interval (D)	*		*		
Loss involuntary disposal (L)	*	*	*	*	
Probability of involuntary disposal (PI)	*	*			
Probability of conception (PC)	*	*			*
Transition probabilities (PT)	*	*	*[2]		

1) For description of the elements see Van Arendonk and Dijkhuizen (1985)
2) Changes in production level only occured prior to calving.

2.2. The influence of season

Since some variables are related to a point in time and others to a period of time, replacement and calving were defined as taking place at the beginning of a calendar month. This implies that the carcass price, for example, refers to that point in time. The milk price on the other hand is related to the period of one month.

The effect of season on the monthly milk production and the total lactation production of milk, fat and protein (table 2) was based on a recent analysis of data from Dutch Friesians (Wilmink, 1985). The model for calculating the monthly milk production, taking these factors into account, is described by Van Arendonk (1985[a]).

In relation to the conception rate after first insemination, De Kruif (1975) found the best results for cows inseminated in June while the poorest results occurred in January and February. In more recent material, Jansen (pers. comm., 1985) observed smaller differences between months but the pattern was very similar. The influence of months of insemination on the marginal probability of conception (table 2) were derived from these data.

The replacement heifer price (table 2) was calculated from monthly reports (L.E.I., 1978-1982). In the Netherlands the milk price is based on the fat and protein content with a (negative) base price for total milk volume. The base price of milk was dependent on season (table 2), but that of fat and protein was not (Van Arendonk, 1985[a]). The price for calves and carcass weight at the beginning of each month were calculated from Van Arendonk (1985[a]). The price of roughage and the maximum intake differed for the indoor (November - April)

Table 2. The effect of calendar month on prices, monthly milk production and marginal probability of conception and the effect of month of calving on lactation production[1].

	Month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
						Prices (Dfl.)						
Base price milk (100 kg)	-5.10	-5.80	-6.20	-6.60	-6.60	-6.60	-6.60	-6.60	-4.50	-4.00	-4.00	-4.60
Calves (kg)	10.95	10.00	9.30	9.10	9.55	10.40	11.10	11.80	12.25	12.20	11.95	11.60
Carcass weight (kg)[2]	7.04	7.12	7.20	7.29	7.38	7.42	7.38	7.31	7.21	7.08	6.99	6.98
Replacement heifer	2505	2445	2440	2450	2475	2500	2510	2515	2525	2535	2550	2550
						Multiplicative adjustment factors						
Lactation production:												
- milk (kg)	1.032[3]	1.021	1.009	0.998	0.988	0.972	0.960	0.964	0.983	1.009	1.029	1.035
- fat (%)	0.992	0.990	0.987	0.988	0.990	0.997	1.004	1.011	1.016	1.015	1.010	1.000
- protein (%)	0.989	0.993	0.996	1.001	1.005	1.008	1.009	1.010	1.007	1.001	0.993	0.988
Monthly milk production	0.95	0.97	1.00	1.03	1.05	1.07	1.06	1.03	1.00	0.96	0.94	0.94
Conception rate	0.96	0.95	0.97	0.99	1.02	1.04	1.04	1.02	1.02	1.01	1.00	0.98

1) For source see text
2) For a heifer 210 days in lactation.
3) Milk production is 3.2% higher than average.

and the grazing period (Van Arendonk, 1985[a]). For fresh grass and silage prices of 0.22 and 0.44 Dfl. per energy unit (kVEM), respectively, were used.

The probability of involuntary disposal and the financial loss associated with it, were assumed to be independent of the time of year. The loss in milk revenues prior to disposal, which formed part of the financial loss, were therefore calculated in the absence of seasonal variation in yield and milk price.

Parameters not mentioned above, were assumed to be independent of season.

3. Results

3.1. Basic situation

The highest income was obtained from heifers calving from September to November whereas those calving in May and June yielded the lowest (table 3). The profitability of different months was calculated from the present value of the cash flow from a heifer calving in a particular month and its replacements

Table 3. The expected present value (Dfl.) of the cash flow from heifers calving in different months and its replacements during the planning horizon.

	Month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Income[1]	50.9	15.8	-65.7	-116.3	-131.3	-134.4	-87.3	13.1	104.4	142.2	127.4	81.6

1) Deviation from the average (10871 Dfl.)

under an optimum replacement policy during the 15-year planning horizon. The month of calving of the heifer in subsequent lactations and that of its replacements during the planning horizon varied due to the variation in the length of the calving interval and replacement occurring at monthly intervals. As a result of this, the initial difference in time of calving faded away during the planning horizon and differences in income, therefore, resulted mainly from the first years of the projected period.

The differences in expected income between second parity cows calving in different months (figure 1) were greater than those for heifers. These cows have completed the relatively unprofitable first lactation and have not yet reached the lactation with maximum net revenues. When the age of the cows increased further the difference in expected income between the months of calving decreased. This was because of the reduction in the remaining life expected.

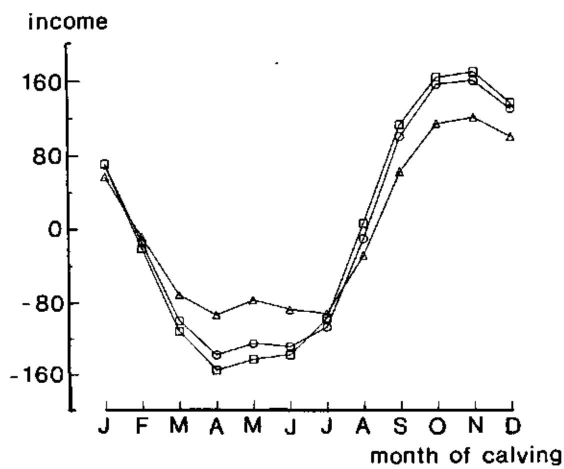

Fig. 1. Expected differences (relative to unweighted average) in income (Dfl.) between different months of calving for second (□), fourth (O) and sixth (Δ) parity cows.

The production level of cows above which insemination was optimum depended clearly on the time of the year when a cow was to be inseminated (table 4). The lowest production levels for insemination to be optimum were found for February to April. After conception the cows were expected to calve during the more profitable months. Further those cows had a relatively high milk production and low feed costs during the gestation period. On the other hand cows were expected to calve in relatively unprofitable months when insemination took place from July to November. However, the alternative of leaving the cow open and replacing her during autumn or winter was relatively profitable. The differences between the carcass value and the replacement heifer prices were big but high revenues were expected from the replacement heifers. There-

Table 4. The production level (%) [1] above which insemination at different number of months in lactation is optimum dependent on month of insemination and parity.

	Parity 1			Parity 3			Parity 6		
	3[3]	5	7	3	5	7	3	5	7
January	78	86	94	74	82	94	82	90	102
February	74	82	90	74	78	90	82	86	102
March	74	78	86	74	78	86	86	86	94
April	78	82	86	74	82	86	86	90	98
May	82	86	94	82	86	90	90	98	102
June	86	94	98	86	90	98	94	102	110
July	90	98	102	86	94	102	94	106	114
August	90	98	106	86	94	106	94	106	114
September	90	98	106	86	98	106	94	106	118
October	-[2]	98	106	86	94	106	94	106	118
November	86	94	102	82	90	102	90	102	114
December	78	90	98	78	86	98	86	98	110

1) Upper limit of classes of 4% (see Van Arendonk, 1985[b])
2) Insemination should be postponed for all cows.
3) Months in lactation.

fore higher production levels were needed in July to November for insemination to be the optimum choice.

The pattern over the year of the minimum production for insemination to be optimum was, except for the level, not very different between parities (table 4). The increase in critical production with the stage of lactation was slightly greater for older cows.

During autumn it was profitable to postpone the first insemination of cows to 3 and, to a lesser extent, 4 months in lactation. The loss during the lactation period due to the prolonged calving interval was compensated for by the higher net revenues after the next calving. The proportions (%) of heifers 2 months in lactation for which it was profitable to postpone the first insemination were 64, 100, 100 and 45 during September, October, November and December, respectively. For third parity cows, assuming a normal distribution of production, these proportions were 47, 94, 100 and 72, respectively. For postponent of insemination at 3 months in lactation to be optimum, a generally higher production was needed. Postponent was optimum for 4, 100, 79 and 0% of the heifers at 3 months in lactation which were to be inseminated during September, October, November and December, respectively.

To quantify the consequences of the seasonal differences in the optimum policy for inseminating and replacing cows, the weighted average calving interval and probability of replacement during the first lactation, and the expected herd life of heifers calving at different months were calculated. When the seasonal differences in the optimum policy were taken into account, the average calving interval, weighted for the probability of each milk production levels occurring, for heifers calving in March, was 44 days shorter than the interval for those calving in August (table 5). For March calving heifers the critical production level for insemination increased from 78% at 2 months in lactation to 106% at 7. For most August calving heifers first insemination should be postponed until December and insemination was optimum until the 7th month in lactation for heifers with a production of over 86%. Similar differences in calving intervals were found for later parities.

The proportion of heifers replaced during the first lactation, involuntarily or as a result of the optimum policy, was highest for heifers calving during the spring and summer (table 5). The differences in the average herd life between heifers entering the herd at different times of the year (table 5), however, were smaller compared with the proportions of replacement during the first lactation. Due to the variation in length of the calving interval, subsequent calvings occur also in other months; consequently the effects on herd life of month of calving in the first lactation are reduced.

Table 5. Averages for calving interval (d) and probability of replacement (%) during the first lactation and herd life (mo) of heifers dependent on month of calving.

	Month of calving											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Calving interval	372	370	369	370	371	378	409	413	394	385	377	375
Prob. replacement	24.3	27.5	31.1	35.5	34.9	34.2	33.6	28.9	21.9	19.1	18.5	20.0
Herd life	41.2	38.6	36.0	33.7	34.0	35.4	39.0	42.3	45.4	46.2	45.9	44.2

3.2. Sources of seasonal differences

In determining the sources of the seasonal differences in expected income and the optimum policy for inseminating and replacing cows, the seasonal variation in separate traits or prices was omitted in turn. The optimum policy and the corresponding expected income were determined for 7 alternatives where the variation was excluded successively for one trait but taking into account the variation in the remaining traits.

At first the differences in expected income from heifers calving in October and May amounted to 274 Dfl. (table 3). The difference reduced to 9 Dfl. when the seasonal variation in the production of milk, fat and protein was excluded (table 6). The difference in production therefore resulted in a 265 Dfl. higher expected income from heifers calving in October compared with May.

Table 6. Expected differences in income (Dfl.) from heifers calving in different months after exclusion of seasonal variation in different traits or prices.

	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Basic situation	51	16	- 66	-116	-131	-134	- 87	13	104	142	127	82
Variation excluded in:												
Production[1)]	6	33	7	- 11	- 9	- 8	1	16	21	0	- 29	- 28
Milk price	88	48	- 45	-111	-144	-161	-124	- 21	75	137	142	114
Feed costs[2)]	-52	-100	-168	-189	-147	- 67	30	131	201	208	133	21
Carcass price	81	38	- 54	-113	-141	-157	-120	- 18	86	140	146	112
Heifer price	49	- 41	-122	-158	-146	-126	- 75	27	127	172	169	122
Calf price	87	111	66	14	- 44	-119	-151	-103	- 25	41	60	63
Conception rate	44	6	- 76	-123	-134	-131	- 78	24	112	148	130	80

1) Milk, fat and protein production
2) Roughage intake and price.

Seasonal differences in milk production, feed costs and calf price contributed considerably to the differences in expected income from heifers freshening at different months (table 6). After exclusion of the seasonal variation in the production of milk, fat and protein only minor differences in income remained. The effects of the differences in the other traits compensated each other in this case. In the absence of seasonal differences in calf values the period with the highest income shifted from September-December towards November-March. Calvings from January to March benefit most from the higher intake and the lower price of roughage during the grazing period.

The influence of the replacement heifer price on the seasonal differences in expected income from heifers (table 6) almost equalled the differences in price which had to be paid for those heifers (table 2). This indicates that the differences in future replacement costs have minimal influence on the expected differences in income. The seasonal fluctuations in conception rate had only a very small effect on the expected income (table 6).

To quantify the influence of seasonal variation in a trait or price on the optimum policy for inseminating and replacing cows, the average herd life of heifers, resulting from the optimum policy and involuntary disposals, was calculated. The differences between months in average herd life disappeared if the influence of season on production was neglected (table 7). This was a result of a lengthening of the herd life of spring and summer calving heifers. The influence on the optimum average herd life of seasonal variation in feed costs was much smaller than that of production. The decisions to inseminate or replace a cow were based essentially on the comparison of the expected net revenues from that cow with those of a replacement heifer. Both the present cow and the replacement heifer benefit from the lower feed costs during the grazing

Table 7. Expected average herd life (mo) of heifers, when seasonal differences in different traits or prices were ommitted, dependent on month of calving.

	Month of calving											
Trait	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Production[1)]	44	44	44	44	44	44	44	45	45	45	45	45
Milk price	43	39	36	33	32	32	37	42	44	47	46	45
Feed costs[2)]	36	32	30	31	35	39	43	45	46	46	44	40
Carcass price	41	38	35	33	33	34	38	42	44	45	45	44
Heifer price	41	38	34	31	30	32	37	42	42	45	45	43
Calf price	46	45	43	41	39	36	36	39	43	46	47	47
Conception rate	41	38	35	33	34	35	39	43	45	46	46	44

1) Milk, fat and protein production
2) Roughage intake and price.

period. This is usually not the case for differences in production or calf value which are associated with the time of calving. Consequently a smaller effect on the optimum decisions, and thus on the average herd life, was observed for seasonal differences in feed costs than in production although they both had a big influence on income (table 6). This is illustrated in figure 2 by the minimum production level for insemination to be optimum for heifers at 3 and 7 months in lactation. The minimum production which depended on the time of insemination was hardly affected by the seasonal differences in feed costs. Ignoring the seasonal variation in production resulted in almost identical limits during the year. The profit from replacing low producing cows therefore contributed to the differences in income between heifers calving at different times of the year.

The influence of the seasonal variation in production and in calf value on the differences in expected income were comparable in size (table 6). The influence on the expected herd life, however, was smaller for the differences in

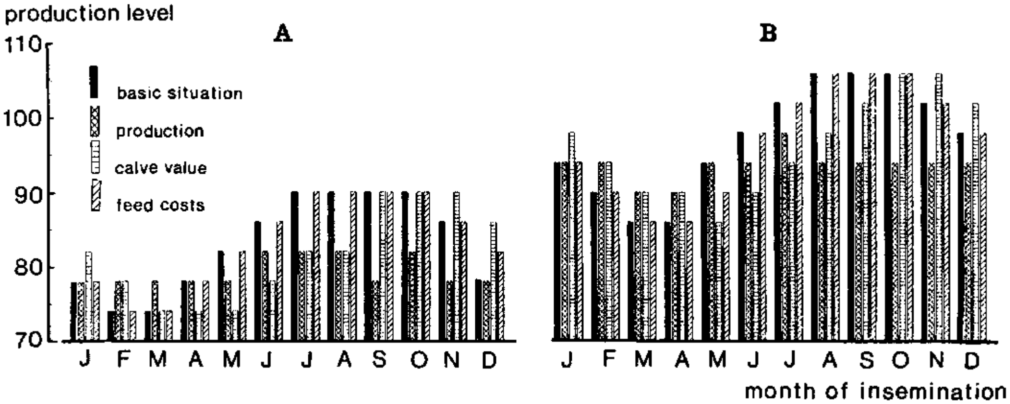

Fig. 2. The relative productions (%) for which insemination of heifers at 3 (A) and 7 months in lactation (B) is no longer optimum dependent on the month of insemination for the basic situation and after omission of seasonal variation in milk production, calf value and feed costs, respectively.

calf value (table 7). The seasonal differences in replacement of low producing cows reduced the differences in expected milk revenues during future lactations among cows calving at different times. These differences in replacement caused the differences in expected herd life. The seasonal differences in expected calf revenues during future lactations, however, were not influenced by the replacement during previous lactations.

4. Discussion

Heifers calving in October had a 274 Dfl. higher expected income, on average, than May calving heifers (table 3). The expected net revenues from the present heifer during the first and subsequent lactations and of its replacement contributed to this difference. The proportion of heifers for which replacement during the first lactation was optimum, was higher for May calving heifers than for those calving in October (table 5). The low producing heifers, which had calved in May, were replaced during the relatively profitable autumn months. The initial time of calving further faded away due to variation in the length of the calving interval. An October calving heifer, for example, calved for the second time during the period from September to February. Because of the differences in replacement and variation in the length of the calving interval, the initial difference of 274 Dfl. in the expected present value of the cash flow starting with a heifer calving in October and May reduced to 190 Dfl. after one year. The one year shorter projected period did not influence the difference. The difference in expected income further reduced to 94 and 12 Dfl. after 3 and 5 year, respectively. The first years of the planning horizon therefore contributed mainly to the differences in expected income from heifers calving at different months.

Korver (1977) found that heifers with a one year calving interval and a production of 81 and 104% relative to the corresponding mature equivalent production, should be replaced during the first lactation when they freshened in March and October, respectively. In the marginal net revenue approach, which was used to calculate these limits, it was necessary to assume that the replacement heifer will be replaced in the same month in future (Van Arendonk, 1984). This leads to a bigger difference in the expected revenues from replacement at different times of the year and therefore in the production below which replacement is optimum.

In the absence of seasonal variation, changes in the production level of the herd had a considerable influence on the annual income per cow but did not greatly affect the optimum policy for inseminating and replacing cows (Dijkhuizen, 1983; Van Arendonk, 1985[b]). Optimum decisions were hardly influenced since the change in production affected the expected net revenues of both the cow presently in the herd and the replacement heifer. This is no longer true if changes in production are associated with the time of calving. In the present study the seasonal differences in production had a considerable influence on both income (table 6) and the optimum policy (table 7). It can be concluded that the influence of changes in parameters on the optimum policy in the absence of seasonal variation does not necessarily correspond with that of seasonal differences.

The optimum policy for insemination and replacing cows was greatly affected by seasonal differences in production and, to a lesser extent, in calf price and feed costs. The seasonal differences in production are dependent on feeding and management (Auran, 1973; Dommerholt, 1975). The calving time with maximum income and the differences between months are therefore not necessarily the same for all herds. The price differences during the year for calves, culled cows and milk are partly related to the supply pattern of these products. Changes in the calving pattern in a country will therefore affect the price differences. The differences in production and feed costs are not affected by a change in calving pattern.

Changes in the calving pattern in a herd may result from differences in the length of the calving interval among cows and from the replacement of cows. Application of the optimum policy for inseminating cows (table 4) would result in a shift towards the profitable months. This was illustrated by the differences in the length of the calving interval among heifers calving at different times (table 5). Changing the calving pattern through replacement of cows at the relatively profitable times of the year will take longer in a herd where heifers are home reared instead of purchased from the market. The number of heifers available at different months is dependent on the calving pattern of all cows in the herd during previous years and the selection of the heifer calves to be reared for replacement.

The expected loss in case of a non-optimum decision can be used to support the farmer in taking decisions when only a limited number of replacement heifers are available at a given time. He can replace only those cows for which the greatest loss is expected and inseminate or postpone replacement for others. Further the loss when keeping a cow when replacement is optimum, equals the extra amount of money the farmer could afford to spend for a replacement heifer.

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Chapter 6

CONTRIBUTION OF VARIABLES TO THE OPTIMUM POLICY

1. Introduction

The revenues from dairy cows originate from the sale of milk, calves and cows while the costs are associated mainly with feeding, housing and rearing of young stock. These factors were accounted for in determining the optimum replacement policy (Stewart et al., 1977; Renkema and Stelwagen, 1979; Kristensen and Østergaard, 1982; Dijkhuizen et al., 1985; Van Arendonk, 1985[b]). However, the contribution of the variation occuring in these variables to the optimum replacement policy has not been studied so far. In developing management guides for individual cows, it is important to know which variables influence the optimum decisions for insemination and replacement.

The optimum replacement policy is not changed when a constant amount is subtracted from the monthly net revenues from present and replacement cows (Faris, 1960). For example the monthly costs of housing, which are equal for all cows in the herd, will have no effect on optimum decisions for insemination or replacement. It explains also the relatively small influence of changes in the average milk production of the herd on the optimum replacement policy (Stewart et al., 1977; Kristensen and Østergaard, 1982; Dijkhuizen et al., 1985; Van Arendonk, 1985[b]). The influence of a trait on the optimum replacement policy will therefore depend on the variation in monthly revenues or costs associated with it.

In previous papers (Van Arendonk, 1985[b]; Van Arendonk and Dijkhuizen, 1985; Van Arendonk, 1985[c]), the objective in determining the optimum replacement policy was maximization of the expected present value of the cash flow from present and replacement cows. The calculation of the expected cash flow from cows could be simplified by excluding variation in different traits. In this study the consequences of excluding variation in a number of traits for the optimum replacement policy are quantified. In addition the average performance is determined for cows when applying the optimum policies resulting from the different alternatives.

2. Material and methods

2.1. Optimization

The dynamic programming model described by Van Arendonk and Dijkhuizen (1985) was used to determine the optimum policy for inseminating and replacing cows. In the model cows were characterized by their lactation number, stage of lactation, time of conception and milk production levels during the present and previous lactation.

In addition to the basic situation, the optimum replacement policy was determined for three alternatives. In all cases optimization was directed towards maximizing the present value of the cash flow from present and replacement cows during the planning horizon. However the variables which entered the cash flow were different. In the basic situation, as described by Van Arendonk and Dijkhuizen (1985), the cash flow consisted of revenues from the sale of milk, calves and cows while costs were from feeding, replacement heifers, loss associated with involuntary replacement and sundries.

In the first alternative (I) the variation in carcass value between cows, which resulted from age, stage of lactation and reason for replacement, was excluded from the cash flow. In all cases the weighted average carcass value of cows which were disposed of voluntarily or involuntarily in the basic situation was used.

In the second alternative feed costs were excluded from the cash flow. The use of a constant monthly feed cost for all cows would not have influenced the results (Faris, 1960), and was therefore neglected.

Finally (alternative III) optimization was directed solely towards maximization of the milk revenues from present and replacement cows during the projected period, taking into account the difference between the replacement heifer price and the weighted average carcass value of disposed of cows as found in the basic situation.

Besides the four optimum policies, determined by the dynamic programming technique, a situation was studied where all cows were inseminated and kept in the herd if they conceived (alternative IV). Cows which failed to conceive from 2 to 7 months in lactation and cows which were in the 12th lactation were replaced 8 months after calving.

2.2. Simulation

In the previous studies the average income of cows, corresponding with the optimum replacement policy, was calculated from the present value of the cash flow expected during the planning horizon. However, due to the reduction in the number of variables entering the cash flow the expected income could not be calculated from the present values in this study. A simulation model was constructed, therefore, to determine the average monthly performance of cows corresponding with the optimum policy for the insemination and replacement of cows. The latter was dependent on the objective function used. Simulation also offered the opportunity of calculating variation in traits, which made it possible to assess the calculated differences.

The dynamic programming model was taken as the basis for the simulation model. Cows were characterized by the same state variables. The costs, revenues and production for all possible states were calculated as described by Van Arendonk (1985[a]). The influence of genetic progress was accounted for as described by Van Arendonk (1985[b]). In the simulation model, survival, conception and lactation production were treated as stochastic variables.

Survival to the end of the current month was calculated from its probability and a random number drawn from the uniform distribution between 0 and 1. The cow was disposed of involuntarily from the herd when the random number was greater than the probability of survival. In the dynamic programming model, however, survival and involuntary disposal were weighted for the probability of the event's occuring.

It was determined at the beginning of each month whether a cow, given its actual state, should be replaced voluntarily. The optimum decision was made on the basis of the dynamic programming results.

Insemination could take place from 2 to 7 months after calving (Van Arendonk and Dijkhuizen, 1985). This allowed the calving interval to vary from 11 to 16 months. First it was determined whether insemination was optimum according to the optimum policy. If this was the case, conception took place when the random number was smaller than the probability of conception.

The production level of a heifer was determined from the probabilities of each production level occuring and a random number. The cow kept the same production level during the entire lactation. Production during the next lactation was determined stochastically from the probabilities of transition to each of the 15 production levels. These probabilities depended on the cow's production level during the present and, in case of older cows, the previous lactation (Van Arendonk, 1985[b]).

All random numbers were obtained from the uniform random generator GGUBS of the IMSL-library (IMSL, 1982). They were distributed uniformly between 0 and 1.

The income, milk revenues, calf revenues, feed costs, sundry costs, carcass value and milk production during the entire herd life of each cow were calculated.

Further the length of the calving interval of each completed lactation and the time and reason for disposal were registered. The average value per month for a trait was calculated as the ratio of the average lifetime performance to the average herd life of the cows. The variance of the ratio was approximated by the method according to Sharma et al. (1982), described by Pearson (1897) as:

$$\mathrm{Var}\left(\frac{x}{y}\right) = \frac{\mu_x^2}{\mu_y^2}\left[\frac{\sigma_x^2}{\mu_x^2} + \frac{\sigma_y^2}{\mu_y^2} - 2r_{xy}\frac{\sigma_x\sigma_y}{\mu_x\mu_y}\right]$$

where μ_x and μ_y are the means for variables x and y,
σ_x^2 and σ_y^2 are their variances, and
r_{xy} is the correlation between the two variables.

For each alternative the results for 10000 cows were simulated.

3. Results

3.1. Replacement policy

In the basic situation the weighted average carcass value of cows which were disposed of was 1699 Dfl. This included the loss when disposal was involuntary. In optimizing the replacement policy for alternatives I and III, 800 Dfl. were charged as costs in the case of either voluntary or involuntary replacement. For an extensive description of the optimum policy for insemination and replacement of cows in the basic situation see Van Arendonk and Dijkhuizen (1985).

The minimum production for insemination of heifers at 3 months in lactation to be optimum increased from 82% in the basic situation (table 1) to 90% when the variation in carcass value was excluded in determining the optimum policy (alternative II). Since the relatively low carcass value when replacement took

Table 1. The production level (%) [1] above which insemination at 3 and 7 months after calving was optimum dependent on parity for the different policies[2].

	3 Months in lactation				7 Months in lactation			
Parity	Basic	Alt. I	Alt. II	Alt. III	Basic	Alt. I	Alt. II	Alt. III
1	82	90	90	90	94	94	102	98
2	82	82	86	86	94	90	98	94
4	86	82	86	82	98	90	98	94
6	90	86	94	90	106	98	106	98
8	102	94	102	98	118	110	118	110
10	118	106	114	110	-[3]	126	-[3]	122

1) Production level applies to present and previous lactation.
2) I = no variation in carcass value, II = no variation in feed costs, III = maximization of milk revenues.
3) All cows should be left open.

place during the first lactation was not taken into account in this alternative, a higher production level was needed to justify inseminating the heifer rather than to replace her. When age increased further, the increase in production level for insemination to be optimum was much smaller in alternative I than in the basic situation. The reduction in carcass value and the increase in the loss associated with involuntary disposal did not affect the optimum decision in this alternative. The increase in production level with the time in lactation at which a cow had to be inseminated, was smaller in alternative I (table 1) because the carcass value did not increase during the lactation period.

When variation in feed costs was not considered (alternative II), higher production levels were needed for insemination of heifers and, to a lesser extent, second parity cows to be optimum (table 1). The increase in critical production with stage of lactation remained the same.

When optimization was directed towards maximizing the expected milk revenues taking into account the costs of replacement of 800 Dfl. (alternative III), higher production levels were needed to justify the insemination of younger cows at 3 months in lactation. Conversely minimum productions were lower for old cows (table 1). The loss associated with a prolonged calving interval was reduced since calf revenues were not taken into account. Further, the constant carcass value reduced the expected revenues when a cow was left open and replaced during one of the remaining months of the lactation. This resulted in a smaller increase with time in lactation in the minimum production required for insemination to be the optimum decision.

3.2. Consequences of different policies

The optimum policy for insemination and replacement of cows in the basic situation, taking into account the probabilities of involuntary replacement and conception, resulted in an average herd life of 43.9 months (table 2). The average herd life decreased to 36.0 months when variation in feed costs was ignored in determining the optimum policy. The biggest differences in the optimum policy appeared during the first lactation (table 1). These differences resulted in an average replacement rate (%) of heifers of 24, 34, 36 and 36 in the basic situation and alternatives I,II and III, respectively. Cows were kept in the herd for 5 years on average when no voluntary replacement took place (alternative IV). In this situation the proportion of heifers which were replaced amounted to 14%. The different replacement policies hardly affected the average length of the calving interval and the proportion of cows with a calving interval of at least 14 months (table 2). Replacement of cows took place 49 days earlier, on average, in alterna-

Table 2. Average herd life (mo), length of calving interval (d), time of replacement (days in lactation) and proportion(%) of cows with a calving interval of 14 months or longer for different policies for insemination and replacement of cows.

	Alternative				
	Basic	I	II	III	IV[1)]
Herd life	43.9	39.9	36.0	38.4	59.5
Calving interval	371	372	370	372	374
Calving interval $\geq$14 mo	12.9	13.5	12.3	14.0	15.3
Time of replacement	196	147	178	158	179

1) Only involuntary replacement.

tive I compared with the basic situation (table 2). In the other alternatives cows were also replaced earlier. The increase in carcass value and, to a lesser extent, the reduction in feed costs during the lactation led to the postponement of voluntary replacement.

The average annual income per cow decreased by 19 and 11 Dfl. when variation in carcass value and feed costs, respectively, were neglected in optimizing the replacement policy (table 3). When milk revenues determined the optimum policy (III), the annual income per cow was 13 Dfl. lower than in the basic situation. In particular the milk revenues and carcass value of culled cows were influenced by the replacement policy. The influence of the carcass value on the annual income depended on the annual replacement rate. In alternatives II and III, about 50 Dfl. higher milk revenues were found compared with the basic situation. The average carcass value of replaced cows was reduced by nearly 100 Dfl. when variation in carcass value was ignored. The higher replacement rates in alternatives I, II and III resulted in higher calf revenues and higher annual replacement costs.

The standard deviation in annual income ranged from 305 Dfl. in alternative IV to 425 Dfl. in the second alternative (table 3). The differences in standard deviation were caused mainly by the differences in replacement during the first

Table 3. The mean of standard deviation (in brackets) of income, milk revenues, calf revenues, feed costs and milk production per cow per year and the carcass value of replaced cows for different policies.

	Alternative				
	Basic	I	II	III	IV
Income (Dfl.)	958 (363)	939 (400)	947 (425)	945 (406)	912 (305)
Milk revenues (Dfl.)	3969 (406)	3999 (410)	4023 (413)	4014 (399)	3851 (416)
Calf revenues (Dfl.)	389 (42)	405 (62)	402 (57)	404 (64)	382 (33)
Feed costs (Dfl.)	1894 (162)	1907 (166)	1913 (166)	1911 (160)	1854 (164)
Carcass value (Dfl.)	1699 (196)	1602 (168)	1669 (178)	1620 (179)	1611 (159)
Milk production (kg)	5825 (612)	5878 (626)	5911 (624)	5899 (607)	5672 (622)

lactation. When cows replaced during the first lactation were excluded from the analysis, the standard deviations in expected annual income (Dfl.) were 285, 269, 279, 264 and 273 in the basic situation and alternatives I, II, III and IV, respectively.

The optimum policy in the basic situation resulted in a 46 Dfl. higher average income per cow per year than in the situation where no cow was left open and replaced voluntarily (alternative IV). The annual revenues from milk, calves and culled cows increased by 118 Dfl., 7 Dfl. and 139 Dfl., respectively, when the optimum policy for insemination and replacement was applied. The replacement and feed costs increased by 179 Dfl. and 40 Dfl., respectively.

The optimum decisions for insemination or leaving cows open and replacing them during the remainder of the lactation, which resulted from dynamic programming in the different situations, were compared with those in the basic situation. Each possible state where insemination was considered was weighted for the probability occuring in the basic situation, calculated as described by Van Arendonk and Dijkhuizen (1985). In 10.9, 14.4 and 12.0% of the cases heifers were left open in alternatives I, II and III, respectively, while insemination was optimum in the basic situation (table 4). In the second and later lactations the weighted proportion (%) of cows for which decisions in the basic situation did not correspond with those in alternatives I, II and III were 6.1, 3.8 and 3.8, respectively.

Tabel 4. Comparison of the weighted proportion of open cows for which insemination or leaving open was optimum, respectively, in the basic situation with the decisions in the alternative situations for cows during their first and later lactation.

Decision		Heifers			Older cows		
Basic	Alternative	I	II	III	I	II	III
Inseminate	Inseminate	77.2	73.7	76.1	81.1	77.7	80.4
Inseminate	Open	10.9	14.4	12.0	0.1	3.5	0.8
Open	Inseminate	0.0	0.0	0.0	6.0	0.3	3.0
Open	Open	11.9	11.9	11.9	12.8	18.5	15.8

4. Discussion

The greatest differences between the alternatives in the minimum production for insemination to be optimum were found for the heifers (table 1). In comparing the expected income from heifers and older cows, it is therefore necessary to account for the differences in carcass value and feed costs. The calf revenues at the start of a lactation and the increase in carcass value during the lactation influenced the change in the minimum production for insemination to be optimum during the lactation.

The average loss in annual income per cow when the number of variables influencing the cash flow was reduced, varied from 11 Dfl. for alternative II to 19 Dfl. for alternative I (table 3). The loss in income resulted from differences in the minimum production for insemination to be the optimum choice and in the optimum time for voluntary replacement. The proportion of the open heifers for which leaving open and replacing during the remainder of the lactation was optimum was about twice as large in the alternative situations as in the basic one (table 4). Differences were smaller at greater ages. The average loss in annual income was therefore a result of the wrong decisions for a relatively small number of cows.

To obtain the optimum decisions, as in the basic situation, no additional information has to be gathered than for the alternatives studied. It can therefore be concluded, that it is not justified to reduce the variation in the expected cash flow, as was done in the 3 alternatives, in determining the optimum replacement policy.

In this study, variation in carcass value was due only to the effects of parity, stage of lactation and reason for disposal. Individual differences in carcass value were ignored. For carcass value a residual variation coefficient of 14% was observed (Van Arendonk et al., 1984) which resulted mainly from variation in live weight. The influence of the differences between cows on the optimum policy will depend greatly on its consistency over lactations and, to a lesser extent, its influence on feed costs. The decision to replace cows immediately will clearly be affected when the carcass value of a cow deviates from its expectation only at the time of the decision and not in the future. A higher carcass value, for example, increases the expected revenues when the cow is replaced immediately, while the alternative of keeping the cow is not affected. On the other hand, replacement decisions are scarcely affected when the differences in carcass value remain over time. In this case the expected revenues for both alternatives, immediate replacement and keeping the cow, are affected by the deviation in carcass value. Andela (1983) found correlations of live weights in successive lactations, ranging from 0.6 to 0.8. The individual differences in carcass value will therefore have only a limited effect on the replacement decisions.

The calf value was assumed to be independent of the expected production ability of the calf. The breeding value for production of the cow or the sire will affect mainly the expected calf revenues for cows with an average or above average production. Only calves from these cows will be kept for replacement. The differences in calf value will have no influence on the insemination decisions for the cows.

The seasonal variation in traits and prices greatly affected the expected income and the optimum policy for inseminating and replacing cows (Van Arendonk, 1985[c]). Heifers calving in October had a 277 Dfl. higher expected income and a 11 months longer herd life on average than heifers calving in June. The contribution of the seasonal variation in separate traits and prices to the differences in income and optimum policy was determined in that study. The differences in the optimum policy were mainly caused by the seasonal variation in the milk production characteristics. The influence of the different variables on the optimum policy for insemination and replacement, which were found in the present study, are expected also to apply to a situation with seasonal variation.

Kuipers (1982) found a U.S. $ 56 higher average annual income when the Maximum Average Monthly Return (MaxAMR) index was used compared to a situation where cows were randomly culled in a dairy herd simulation model. The annual income per cow increased by U.S. $ 1, on average, when the MaxAMR index was used as a culling guide instead of the estimated producing ability with a restriction on the actual yield. The number of cows for which replacement was optimum, was not addressed by any of the culling guides and was therefore determined entirely by the number of freshening heifers. In the present study the annual income per cow when using an optimum policy for insemination and replacement was 27 Dfl. to 46 Dfl. higher with involuntary replacement only (table 3). The latter alternative benefitted from a lower annual replacement rate. This explains the lower benefit from applying any of the 4 culling criteria compared with the results of Kuipers (1982) where the annual replacement rate was fixed. The increase in income when decisions were based on expected income instead of milk revenues was greater in the present study.

Simulation can be a valuable tool in comparing the consequences of different management criteria. The opportunity of changing the annual replacement rate, due to differences in the number of cows for which replacement is optimum, is of great importance. In calculating the expected profit of using a culling criterion, the alternative situation should be chosen carefully.

A restriction of the amount of milk a farmer is allowed to produce on his farm has reduced the benefits from higher milk production per cow. A number of investigations indicated that it is still worthwhile even then to produce the quota of milk with the minimum number of cows per farm (Köhne, 1984; Wieling et al., 1984; Van Arendonk et al., 1985). Van Arendonk et al. (1985) found that the revenue from higher milk production per cow was reduced by an average of 28%. The reduction ranged from 6 to 66%, depending on the herd and the possible cost savings. The difference in income between the alternatives studied will therefore change when a quota is used, according to the effects they have on the average milk production.

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Chapter 7

MANAGEMENT GUIDES TO SUPPORT REPLACEMENT DECISIONS FOR INDIVIDUAL COWS

1. Introduction

Decisions to replace a cow immediately, or at a later stage in lactation are generally based on economic considerations, rather than because a cow is no longer able to produce (Dijkhuizen, 1983). The decisions should be based on a comparison between the anticipated income from the present and that of replacement cows. In a number of studies techniques based essentially on this comparison have been used to obtain general guidelines for decisions on insemination or replacement of cows (see Van Arendonk, 1984 for a review). Little attention has been paid so far to the development of culling guides for individual cows. Kuipers (1982) developed an index which indicated the cows for which immediate replacement should be considered. Kristensen and Østergaard (1982) used the dynamic programming technique to determine whether a cow should be kept, replaced immediately or in 2 months time and to calculate the anticipated profit by keeping the cow. Neither of these studies considered the insemination decisions nor the influence of seasonal variation.

In this chapter the possibilities are discussed of supporting the farmer in making decisions to replace cows immediately or at a later stage in lactation. First the different categories of decisions, which involve replacement of the cow as one of the alternatives, will be described. The information that can be derived from an economic evaluation of the expected performance will be discussed for each of the categories. Thereafter, methods of calculating the information for individual cows will be discussed.

2. Economic information to support decision making

Stellingwerf (1977) observed that, on average, 70% of the cows which were disposed of after 3 months in lactation were not pregnant, 9% were declared pregnant and for 21% the pregnancy status was unknown. For the majority of the cows which were disposed of, the farmer had decided at an earlier stage of the lactation to leave the cow open. The health status and production of the cow play a major role in the decisions. The alternative of replacing a cow is also involved in deciding whether to seek veterinary treatment for a cow. Therefore three categories of decisions, which all include replacement of the cow as one of the alternatives can be distinguished, namely immediate replacement, veterinary treatment and insemination. Information to support the farmer in making optimum decisions can in all cases be obtained from comparing the expected cash flow from the cow presently in the herd with that of replacement heifers entering the herd at different times. The alternatives however, differ for each category. In all cases the alternative resulting in the highest expected income should be considered as optimum, given the information available for predicting cash flows. In addition to the optimum decision the loss anticipated by taking a non-optimum decision can be derived from comparing the expected cash flows.

A cow should be replaced immediately when the expected present value of the cash flow is higher when replacing the cow than when keeping the cow and replacing it at the optimum time later. The profit anticipated by keeping the cow until the optimum time for replacement instead of immediately, taking into account the risk of involuntary disposal, can be calculated from the present values. This is referred to as the future profitability (Van Arendonk, 1984). When immediate replacement is optimum the future profitability is zero. The expected loss by keeping the cow can be calculated by setting an alternative time at which replacement would be considered. Kristensen and Østergaard (1982), for example, calculated the expected loss when replacement would take place in 4 and 8 weeks time. It is therefore possible, to indicate the expected loss if non-optimum decisions are made.

When a cow has to be treated because of a health problem, the expected loss when the cow is treated must be weighed against the expected loss in the case of replacement (Renkema, 1980). The latter is equal to the future profitability of the cow and the possible reduction in carcass value due to the disease. It indicates the veterinary costs and the expected loss after the treatment, as a result of a permanent effect of the disease on production, which can be incurred. The use of the future profitability was illustrated by Breukink and Dijkhuizen (1982) in the decision to treat cattle with left-side abomasal displacement. The farmer can afford to pay more or accept a lower probability of recovery for a cow with a high than with a low future profitability.

Immediate replacement is generally not the appropriate alternative in deciding whether or not to inseminate a cow, due to the relatively high revenues at the time of the decision (Dijkhuizen, 1983; Van Arendonk and Dijkhuizen, 1985). When a cow is kept open, she will remain in the herd until the optimum time for replacement is reached. To determine if it is optimum to inseminate a cow rather than to keep her open, the expected present value of the cash flow after insemination should be compared with the value when the cow is kept open and replaced at the optimum time. The optimization can be extended to indicate cows for which postponement of insemination would be optimum. To do so, the effects of inseminations at later stages in lactation have to be taken into account if the cow was left open. This means that conception at later stages in lactation and replacement at the optimum time are weighed for the probability of occurence, as the alternative to immediate insemination of the cow.

Besides the optimum decision, the profit anticipated after insemination or conception of the cow can be calculated. The expected value might refer to the situation where conception has taken place or that of the cow's being inseminated with a given probability of success. The probability of conception of an individual cow does not influence the optimum decision whether or not to inseminate a cow when no costs have to be paid (Van Arendonk and Dijkhuizen, 1985). The 2 alternatives when leaving the cow open have been discussed already. The expected profit when the cow conceived rather than when it was kept open and replaced at the optimum during the lactation is likely to be the most informative choice from the alternatives. The expected profit in case the cow conceived and the probability of conception should be weighed against the costs of insemination to determine from an economic point of view, whether a cow should be inseminated. To calculate the expected loss when the cow conceived, after being inseminated with the aim of retention although replacement at a later stage in lactation would have been optimum, it has to be assumed that the pregnant cow is not diposed of voluntarily before the next calving.

In conclusion, two management guides must be given to the farmer to help him in making decisions concerning replacement of individual cows. In the first place, the future profitability should be calculated to support the decisions on immediate replacement and veterinary treatment of cows. This should include the expected loss by keeping the cow when immediate replacement is optimum. Secondly, the expected profit in case conception of a cow takes place should be given to help the farmer in deciding whether or not to inseminate a cow.

In figure 1 the course of the management guides over time is illustrated for two cows with an age adjusted lactation production of 92% and 108%, respectively, relative to the mature equivalent herd level. The cows were assumed to conceive at 3 months after calving.

The management guides can also be interpreted as the loss anticipated when taking a non optimum decision. This expectation can be used to weight additional information about the cow or the herd. For instance the farmer might want to incorporate the udder characteristics of the cow in his decision. Further, it allows

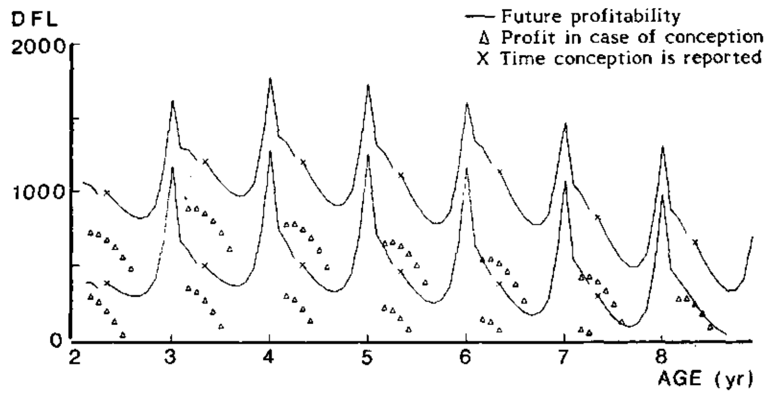

Fig. 1: The course of the future profitability (Dfl.) and the expected profit in case of conception (Dfl.) of a cow with a lactation production of 92% and 108% relative to the mature equivalent herd level.

a ranking of cows for which replacement is optimum when only a limited number of heifers is available on the farm. Based on the expected loss when a cow is kept rather than replaced, a farmer can decide whether to buy a heifer or to postpone replacement.

3. Calculation of information for individual cows

Techniques which were used to support decision making based on the anticipated performance of cows, were evaluated by Van Arendonk (1984). The application of the marginal net revenue approach is restricted, since subsequent replacement cows have to be assumed to be identical. This makes it impossible to account for seasonal variation in revenues and costs, and for continuous genetic improvement. The level of the genetic improvement hardly affected the optimum replacement policy (Van Arendonk, 1985[a]). Seasonal variation, however, was shown to have a great impact on the optimum policy for insemination and replacement of cows under Dutch conditions (Van Arendonk, 1985[b]).

Seasonal variation and genetic improvement can be accounted for by dynamic programming. The technique offers further the opportunity to account for variation in traits. Inclusion of the variation in production and reproduction reduced the differences in expected income between replacement heifers calving at different times of the year. The variation allowed the minimum production for insemination to be justified and the length of the calving interval to differ between seasons. For cows at present in the herd the variation in future performance and the smaller differences in income from replacement heifers calving at different months affected the optimum decisions, the future profitability and the profit after conception. It can be concluded that in calculating the future profitability and the expected profit of conception, seasonal variation and variation in production and reproduction of present and replacement cows should be taken into account.

The management guides are based on the anticipated performance of cows within a herd. Besides information on the cows, the expected herd situation needs to be characterized to predict future performances. The average production level of the herd is the main herd variable affecting the expected revenues of the cows. In the absence of seasonal variation, the average production has only a limited influence on the optimum policy for insemation and replacement of cows (Kristensen and Østergaard, 1982; Dijkhuizen, 1983; Van Arendonk, 1985[a]). However, due to its influence on the variation in revenues it will exert a considerable influence on the future profitability. The seasonal differences realized in production are not the same for all herds. The possibility of predicting these diferences deserves further research.

For the calculcation of the management guides information is needed on the age, the month of calving, the stage in lactation, the production and the reproduction status of a cow. Except for the reproduction status, the data in the Netherlands are recorded, for 73% of the cows, by the Dairy Herd Improvement organization (N.R.S., 1984). In addition the artifical inseminations performed by the A.I.-organization are registered. However, based on these data no distinction can be made between cows which conceived and those which were left open after one or more unsuccessful inseminations. Stellingwerf (1977) found that of all cows which were disposed of after 3 months in lactation, about 60% had been inseminated at least once. The future profitability of a cow would be greatly overestimated if she were wrongly assumed to be pregnant. Therefore cows left open after one or more successful inseminations should be registered for the calculation of the future profitability.

It is of very questionable value to use dynamic programming as a routine to calculate the management guides for individual farms. The expectations regarding the price and production circumstances, which are used in the calculations, are unlikely to change in the short run. Changes in the dynamic programming results are, therefore, expected to occur only occasionally. Management guides should therefore be calculated for all possible states of a cow for a group of similar farms rather than for each farmer at regular intervals. The guides for a particular cow can then be derived from these results after characterising the cow in terms of the state variables. In this way the costs of computation can be reduced considerably while keeping the desirable properties of the dynamic programming technique.

A dynamic programming model including seasonal variation has been described by Van Arendonk (1985[b]). The prediction of future productions in this model can be improved by including not only the production during the present lactation but also that during the previous lactation. A planning horizon of 15 years was used in order for the solutions to be unaffected by a further increase in the length of the period. By adding previously determined future profitability to the carcass value of each state when starting the optimization, the length of the planning horizon can be shortened considerably.

In the method described above for calculating the management guides, the cash flows from both the present and the replacement cows are predicted by the dynamic programming model. As an alternative, the use of dynamic programming can be limited to the calculation of the expected income from replacement at different times in the future. To determine the management guides for individual cows in a herd first the future cash flow needs to be predicted from the data available on the cow. Secondly, the maximum expected income from that and subsequent replacement cows can be determined by considering the expected income from replacement at different times in the future. The future profitability can be calculated as the difference between that maximum and the expected revenues from immediate replacement. For the calculation of the profit after conception, the cash flow when the cow conceived and that when she was kept open need to be predicted.

The latter approach has the advantage that in addition to the data collected from the cows, which need to be stored anyway, the amount of information necessary for the calculation of the management guides is reduced considerably. Only the expected income after replacement at different times is needed, instead of the management guides for all possible states of the cow. Further it allows more variables of the cows in the herd to be included in predicting the cash flow from cows in the herd. That number of variables no longer affects the size of the dynamic programming model. In the second approach it is, however, too cumbersome to account for the variation in the future performance of the cows at present in the herd. In addition more time is needed for calculating the management guides. When using a micro computer on the farm, the time needed for the calculations is of less importance than when calculations are made by the dairy herd improvement organisation. Summarizing, it can be concluded that the second approach is more suitable for use on micro computers on the farm.

4. Concluding remarks

Most dairy herd improvement organizations rank cows on their realized production capacity. The dairy farmer uses the information among others, to make decisions on immediate replacement, veterinary treatment and insemination of cows. It is shown to be possible to calculate two management guides based on the predicted future performance of cows to assist the farmer more specifically in making these decisions. The only additional information which needs to be recorded for the calculation of the management guides is the identity of the cows which are kept open after one or more unsuccessful inseminations.

The financial advantage of using the management guides cannot be determined exactly. An indication of it was obtained from the comparison of the annual income when the decisions for insemination and replacement were based on the expected income instead of on the expected milk revenues. Although decisions differed for only a small number of cows, the annual income per cow increased by 13 Dfl., on average (chapter 6). The management guides not only indicate the optimum decisions relating to a cow, but also allow the farmer to weigh additional information on the cow or the herd. Further they support the farmer in deciding on veterinary treatment and in optimizing the calving pattern during the year.

It can be concluded that future profitability and profit in case of conception may contribute to an improvement of the farmer's income.

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SUMMARY

In The Netherlands dairy farmers replace on average 25-30% of their cows each year. The decision to replace instead of to keep a cow is based mainly on economic considerations rather than because a cow is no longer able to produce.

The investigations described in this thesis were directed towards the economic optimization of the policy for replacement and insemination of dairy cows. The following three items were treated:

1. The evaluation of techniques to determine the optimum policy of inseminating and replacing dairy cows.
2. The consequences for the optimum policy of variation between cows in milk production, time of conception and season of calving.
3. The development of a management guide for individual cows to support the farmer in making decisions concerning replacement.

In the first chapter the optimization techniques which have been applied to dairy cattle replacement were described and evaluated. The optimum decision in all methods was derived essentially from the comparison of the expected revenues from the cow presently in the herd with those from her replacement at different times in the future. The latter revenues can be interpreted as the opportunity costs of keeping a cow. In the marginal net revenues approach it has to be assumed that subsequent heifers are identical. This assumption makes it impossible to account for seasonal variation in traits or prices. This limitation does not hold for the more general dynamic programming technique. Further, the technique allows the variation in, and the repeatability of, the performance of present and replacement cows to be accounted for. Most techniques offer the opportunity to rank cows according to their future profitability. Future profitability was defined as the profit expected by keeping the cow until the optimum time for replacement instead of replacing it immediately.

A model was constructed for estimating the performance, revenues and costs of individual cows on a monthly basis (chapter 2). The revenues came from milk, which depended on the fat and protein content, and the sale of calves; while costs originated from feeding and sundries. In addition, the course of the carcass value and the probability of, and the financial loss associated with, involuntary disposal were considered. The parameters and prices in the model were chosen as representing the Black and White cows in The Netherlands at the normalized price level of 1981-1982. The influence on the model's results of variation in age, stage of lactation, milk production, number of days open and season of calving between cows was validated.

The optimum policy for replacement of cows, taking into account the variation in milk production, was determined by dynamic programming (chapter 3). The objective in determining the optimum decision was the maximization of the expected present value of the cash flow from the present and subsequent replacement cows. In the optimization, cows were characterized by their lactation number, stage of lactation and the level of milk production during the previous and present lactations. Given the probabilities of involuntary replacement, the optimum replacement decisions corresponded with an optimum average herd life of 43 months. The optimum average herd life was greatly affected by the difference between the replacement heifer price and the carcass value of culled cows. A reduction of this difference resulted in a higher rate of voluntary replacement. The optimum replacement policy was not very dependent on the price of milk, calves or feed, the production level of the herd or the rate of genetic improvement. The financial advantage of a proportional decrease in the involuntary replacement rate of 20% increased from 32 Dfl. to 48 Dfl. per cow per year if the variation in milk production was taken into account. This was due to an increase in the voluntary replacement rate of cows which, however, reduced the lengthening of the optimum average herd life. When no involuntary replacement occurred, the optimum average herd life of cows was 5.6 years and the average annual income per cow was 251 Dfl. higher compared to the basic situation. The increase in profit from voluntary replacement accounted for 133 Dfl. of this difference. It was concluded that variation in production should be included for a correct evaluation of the consequences of changes in the production or price situation for the optimum replacement policy.

In chapter 4 the optimization was extended by taking into account also variation in the length of the calving interval. Between 2 and 7 months in lactation it was determined whether a cow should be inseminated, with a calculated probability of conception, or kept open and replaced at the optimum time during the lactation. Insemination was optimum as long as the expected loss from a prolonged calving interval was less than the loss from replacing the cow.

The minimum production level for insemination to be the optimum choice increased with the time in lactation and, to a lesser extent, the age of the cow. The optimum policy resulted in an average calving interval of 371 days, while 13% of the cows had an interval of 14 months or longer. Changes in the persistence of milk production and the level of the conception rates of all cows had a significant influence on the optimum policy. Insemination of cows according to the optimum policy gave a correlation of 0.09 between the production of the cow, corrected for the influence of gestation, and the length of the calving interval. The correlation increased to 0.35 when the total 305-day production was used. The correlations agreed closely with estimates from data analysis reported in the literature. Therefore the farmer's policy to inseminate cows could explain to a great extent the reported phenotypic correlations between production and calving interval.

Seasonal variation in performance and prices was found to have a great impact on the expected income and the optimum policy for inseminating and replacing cows (chapter 5). Heifers calving in October were expected to produce a 277 Dfl. higher income than those calving in June. The minimum productions for insemination to be optimum were the lowest when insemination took place from February to April. After conception the cows were expected to calve during the relatively profitable autumn months. The optimum policy resulted in an average 44 day longer calving interval for August calving heifers compared with heifers calving in March. Further it corresponded with an optimum average herd life of 37 and 46 months for heifers calving in April and October, respectively.

The seasonal differences in production, feed costs and calf prices were the main sources of the differences in the expected income from heifers. The optimum policy for replacing and inseminating cows was greatly affected by the seasonal variation in production.

Three alternatives to simplify the calculation of the expected cash flows, by excluding the variation in traits, were studied (chapter 6). A simulation model was constructed to determine the average performance of cows corresponding to the optimum policy resulting from each of the alternatives. The average annual income per cow was reduced by 19 Dfl. and 11 Dfl. per cow when a fixed carcass value or fixed feed costs, respectively, was used for all cows. When insemination and replacement decisions were based on the expected milk revenues, instead of on the expected income, the annual income per cow was reduced by an average of 13 Dfl. The alternatives did not affect the amount of information which has to be registered for each cow to arrive at the optimum decisions. It was therefore concluded that it is not justified to make any of the simplifications.

Two management guides should be given to the farmer to help him in making decisions concerning the replacement of individual cows (chapter 7). In the first place, the future profitability should be calculated to support the decisions on immediate replacement and veterinary treatment of cows. Secondly, the expected profit in case conception of a cow takes place should be given to support the farmer in deciding whether or not to inseminate a cow. These management guides indicate the loss anticipated when taking a non-optimum decision. This expectation can be used by the farmer to weigh additional information about the cow or the herd.

Two methods to calculate the management guides for individual cows were described. For the calculations information is needed on the production and reproduction status of the cows and on the expected herd situation. It was concluded that the future profitability and the expected profit in case of conception may lead to an inprovement of the farmer's income.

SAMENVATTING

In Nederland wordt jaarlijks gemiddeld 25 tot 30% van de melkkoeien vervangen. In het merendeel van de gevallen is sprake van een economische beslissing van de veehouder: de betreffende koe wordt niet vervangen, omdat ze niet meer zou kunnen produceren, maar omdat van een vervangend dier meer wordt verwacht.

Het onderzoek beschreven in dit proefschrift richtte zich op de economische optimalisatie van het beleid ten aanzien van inseminatie en vervanging van melkkoeien. De volgende 3 onderdelen werden hierbij onderscheiden:

1) De evaluatie van methoden voor het vaststellen van het optimale beleid voor inseminatie en vervanging van melkkoeien.
2) Het bestuderen van de invloed van variatie in melkproduktie, tussenkalftijd en seizoen van afkalven op het optimale beleid.
3) De mogelijkheden voor de berekening van een kengetal voor individuele dieren ter ondersteuning van de door de melkveehouder te nemen beslissingen met betrekking tot inseminatie en vervanging.

Evaluatie van optimaliseringstechnieken

In het eerste hoofdstuk zijn de optimaliseringstechnieken beschreven en geëvalueerd die in de literatuur zijn gehanteerd voor de vervanging van melkkoeien. De optimale beslissing werd in alle methode bepaald door de in de toekomst te verwachten opbrengsten van de aanwezige koe te vergelijken met de toekomstverwachting van een vervangende vaars. Het laatst genoemde dier vormt immers het alternatief dat wordt uitgesloten zolang de aanwezige koe wordt aangehouden. De verwachte inkomsten van de vervangende vaars moeten dan ook worden aangemerkt als de ontgane opbrengst bij aanhouden van een koe.

Bij de marginale arbeidsopbrengstmethode werd impliciet verondersteld dat de dieren die nu en in de toekomst zullen worden gebruikt voor vervanging, volledig identiek zijn. Deze veronderstelling maakt het onmogelijk rekening te houden met onder andere seizoensvariatie in produktie en prijzen. Deze beperking geldt niet voor de meer algemeen toepasbare techniek van dynamische programmering. Deze benadering heeft tevens als voordeel dat rekening gehouden kan worden met de variatie in, en de herhaalbaarheid, van kenmerken zoals melkproduktie. Naast het bepalen van de optimale beslissing kunnen de meeste technieken eveneens worden gebruikt om dieren binnen een bedrijf te rangschikken op basis van de toekomstige winstgevendheid. Onder toekomstige winstgevendheid werd verstaan de verwachte winst door het aanhouden van een koe tot het optimale tijdstip voor vervanging in plaats van onmiddellijke vervanging.

Uitgangspunten

In hoofdstuk 2 wordt het model beschreven wat in het vervolg van het onderzoek is gehanteerd voor de berekening van de arbeidsopbrengst van individuele koeien. Er wordt ingegaan op de berekening van de opbrengsten, bestaande uit de melkopbrengst, de slachtwaarde en de kalveropbrengst, en van de kosten bestaande uit voerkosten en overige kosten (zoals kosten voor gebouwen en de dierenarts). Daarnaast wordt aandacht besteed aan de kans op gedwongen afvoer en de daarmee samenhangende schade. In het model werden 12 laktaties onderscheiden. De lengte van de tussenkalftijd kon variëren van 11 tot 16 maanden. Om maandelijkse beslissingen ten aanzien van inseminatie en vervanging mogelijk te maken, werd een tijdseenheid van een maand gebruikt. De bij de berekeningen gehanteerde uitgangspunten hadden betrekking op Nederlandse zwartbonten, terwijl de gehanteerde prijzen betrekking hadden op de periode 1981-1982. De invloed van variatie in leeftijd, laktatiestadium, melkproduktie, tussenkalftijd en seizoen van afkalven op de met het model verkregen resultaten zijn geanalyseerd.

Het optimale beleid afhankelijk van de variatie in kenmerken

In hoofdstuk 3 wordt ingegaan op het optimale beleid voor vervanging van melkkoeien. Voor de bepaling ervan werd gebruik gemaakt van dynamische programmering. Het doel bij het bepalen van de optimale beslissing was het maximaliseren van de contante arbeidsopbrengst (kapitaalwaarde) van de aanwezige koe en de opeenvolgende vervangende vaarzen gedurende een periode van 20 jaar. Naast verschillen in leeftijd en laktatiestadium, werd rekening gehouden met de variatie in melkproduktie bij zowel aanwezige als vervangende dieren. Dit betekende bijvoorbeeld dat niet werd uitgegaan van een vervangende vaars met een gemiddelde melkproduktie maar dat laag-, gemiddeld- en hoogproduktieve vaarzen werden ingewogen met de kans op voorkomen. Hierdoor kon bij het bepalen van de te verwachten arbeidsopbrengst van een vaars rekening gehouden worden met de vervanging van vaarzen met een tegenvallende produktie. Het produktieniveau van dieren werd steeds uitgedrukt in procenten van het bedrijfsgemiddelde, na correctie voor leeftijd en laktatiestadium. Hierbij had het bedrijfsgemiddelde betrekking op de uitgangssituatie waarbij geen rekening gehouden werd met genetische vooruitgang en vervanging van laagproduktieve koeien. Bij de berekeningen werd uitgegaan van een tussenkalftijd van 12 maanden en afwezigheid van seizoensverschillen in produktie-omstandigheden. De invloed van variatie in de lengte van de tussenkalftijd en in seizoen komt in de volgende hoofdstukken aan de orde.

Het optimale beleid voor de vervanging van melkkoeien resulteerde, rekening houdend met de kansen op gedwongen afvoer, in een optimale gemiddelde gebruiksduur van 43 maanden. De optimale gemiddelde gebruiksduur was duidelijk afhankelijk van het verschil tussen de gemiddelde slachtwaarde van de afgevoerde koeien en de opfok - dan wel aankoopkosten van een vervangende vaars. Een afname van dit verschil leidde tot een verkorting van de optimale gemiddelde gebruiksduur. Dit was een gevolg van een verhoging van de produktiegrenzen waar beneden tot vrijwillige vervanging moet worden overgegaan. Zo nam bij vaarzen de produktiegrens toe van 82% tot 90% bij een verlaging van de kosten van een vaars met 10%. Veranderingen in de prijs van melk, kalveren en voer, in het produktieniveau van het bedrijf en in de hoogte van de genetische vooruitgang hadden nauwelijks effect op het optimale vervangingsbeleid.

Het financieel voordeel van een proportionele verlaging van 20% van de kansen op gedwongen afvoer nam toe van *f* 32,- tot *f* 48,- gemiddeld per koe per jaar wanneer rekening werd gehouden met het optreden van variatie in produktie. Deze toename is een gevolg van het feit dat bij een lager niveau van gedwongen afvoer de mogelijkheden en de opbrengsten van vrijwillige vervanging toenemen. Door de toename in vrijwillige vervanging nam echter de verlenging van de gemiddelde gebruiksduur af. Dit werd nog duidelijker geïllustreerd in een situatie waarin totaal geen gedwongen afvoer optrad. Bij afwezigheid van ook vrijwillige vervanging hadden alle dieren een gebruiksduur van 12 jaar. Indien echter rekening werd gehouden met vrijwillige vervanging van laag-produktieve koeien bedroeg de gemiddelde gebruiksduur 5,6 jaar. De gemiddelde arbeidsopbrengst per koe per jaar was in dit geval *f* 251,- hoger dan in de uitgangssituatie. Van deze toename kon *f* 133,- worden toegeschreven aan de vrijwillige vervanging van laagproduktieve koeien.

In hoofdstuk 4 is de optimalisatie uitgebreid, door naast de beslissingen tot vervanging ook de inseminatiebeslissingen in beschouwing te nemen. Het beslissingscriterium op het moment van insemineren kwam, afgezien van de gevallen waarbij uitstel van eerste inseminatie optimaal was, neer op de vergelijking van de verwachte arbeidsopbrengst bij verkregen dracht met de opbrengst bij vervanging op het optimale moment tijdens de lopende laktatie. Onmiddellijke vervanging komt meestal nog niet in aanmerking aangezien koeien worden geïnsemineerd in het deel van de laktatie met een relatief hoge produktie. De kans op het drachtig worden na inseminatie was afhankelijk van de leeftijd en het laktatiestadium van de koe. Er werd geen verband verondersteld tussen de produktie en de drachtigheidskansen.

In de berekeningen werd van 2 tot 7 maanden na afkalven nagegaan welk produktieniveau minimaal noodzakelijk was om tot insemineren te besluiten. Bij vaarzen nam dit minimum produktieniveau toe van 82% op 3 maanden tot 94% op 7 maanden. Voor een 8-jarige koe bedroegen deze grenzen respectievelijk 90% en 106%.

Het optimale beleid voor inseminatie en vervanging resulteerde in een gemiddelde tussenkalftijd van 371 dagen, waarbij voor 13% van de koeien de tussenkalftijd minimaal 14 maanden bedroeg. Toepassing van het optimale beleid in modelberekeningen leidde tot een correlatie van 0,09 tussen de lengte van de tussenkalftijd en de voor de invloed van dracht gecorrigeerde melkproduktie. Dit weerspiegelt dat bij koeien met een hoge produktie langer werd doorgegaan met insemineren dan bij laagproduktie koeien. De correlatie was 0,35 wanneer de gerealiseerde 305 dagen produktie werd gebruikt. Deze produktiemaat werd, in tegenstelling tot de eerste, beïnvloed door de dracht. De berekende correlaties stemden goed overeen met de in de literatuur gerapporteerde schattingen op basis van praktijkmateriaal. Er kan dus worden geconcludeerd dat het door de veehouders gevolgde beleid bij het insemineren voor een belangrijk deel de gerapporteerde fenotypische correlaties tussen produktie en tussenkalftijd kan verklaren.

In hoofdstuk 5 is het optimale beleid voor inseminatie en vervanging van melkkoeien bepaald, rekening houdend met seizoensvariatie. In de berekeningen was het seizoen van invloed op de produktie van melk, vet en eiwit, de drachtigheidskansen, de voerkosten en de prijs van melk, vlees, kalveren en hoogdrachtige vaarzen.

Het verwachte inkomen van vaarzen die afkalven in oktober was, gerekend over de periode van een aantal jaren, gemiddeld *f* 277,- hoger dan van in mei afkalvende vaarzen. De produktiegrenzen, waarboven inseminatie van koeien optimaal was, werd sterk beïnvloed door de maand van inseminatie. Voor vaarzen 3 maanden in laktatie nam de produktiegrens toe van 74% bij inseminatie in februari of maart tot 90% bij inseminatie in juli tot oktober. Deze seizoensverschillen bleven nagenoeg constant bij het toenemen van de leeftijd of het laktatiestadium. De koeien die drachtig worden in februari of maart kalven af in het relatief gunstige najaar, waardoor bij een lager produktieniveau tot inseminatie kan worden overgegaan dan bij dieren die in het voorjaar zullen afkalven. Het optimale beleid correspondeerde met een gemiddeld 44 dagen langere tussenkalftijd voor augustus afkalvende vaarzen in vergelijking met die in maart afkalven. Ook de gemiddelde optimale gebruiksduur werd sterk beïnvloed door het seizoen. Zo bedroeg de optimale gemiddelde gebruiksduur 37 en 46 maanden voor vaarzen die afkalven in respectievelijk april en oktober.

De bijdrage van de seizoensvariatie in de afzonderlijke variabelen aan de seizoensverschillen in inkomen en het optimale vervangingsbeleid werd bestudeerd.

De seizoensverschillen in het niveau van de melkproduktiekenmerken en, in mindere mate, in de voerkosten en de kalverprijs waren de belangrijkste bronnen voor de verschillen in inkomen. De seizoensvariatie in voerkosten had echter nauwelijks invloed op de optimale vervangings- en inseminatiebeslissingen. Dit is een gevolg van de compensatie die optreedt doordat de veehouder onafhankelijk van zijn beslissing te maken krijgt met een periode met hoge of lage voerkosten. Zo profiteert bij een beslissing tot onmiddellijke vervanging in mei, zowel de aanwezige koe als de vervangende vaars van de relatief lage voerkosten gedurende de weideperiode. De verschillen in melkproduktie en kalveropbrengst daarentegen hangen samen met de maand van afkalven en hebben daarom een grotere invloed op de optimale beslissingen. Met name de seizoensverschillen in produktie hadden een grote invloed. Wanneer deze verschillen buiten beschouwing werden gelaten, was de optimale gebruiksduur van vaarzen nagenoeg gelijk voor alle afkalfmaanden.

Drie alternatieven zijn bestudeerd, door het weglaten van de variatie in een aantal kenmerken, om de berekening van de te verwachten arbeidsopbrengst te vereenvoudigen (hoofdstuk 6). Voor het kwantificeren van de consequenties van het beleid voor elk van de alternatieven werd een stochastisch simulatiemodel gebruikt. De gemiddelde arbeidsopbrengst kon niet langer worden afgeleid van de resultaten verkregen met dynamische programmering, aangezien daarbij de variatie in aantal kenmerken achterwege werd gelaten.

Wanneer bij de optimalisatie werd uitgegaan van een constante slachtwaarde en van gelijke voerkosten voor alle koeien nam de gemiddelde arbeidsopbrengst per koe per jaar met respectievelijk *f* 19,- en *f* 11,- af. Wanneer tenslotte de beslissingen werden gebaseerd op de verwachte melkopbrengst, in plaats van de verwachte arbeidsopbrengst, nam de gemiddelde jaarlijkse arbeidsopbrengst met *f* 13,- per koe af. De lagere opbrengsten bij de verschillende alternatieven waren hoofdzakelijk een gevolg van het hogere vervangingspercentage bij vaarzen en de vervanging op een eerder moment tijdens de laktatieperiode. De hoeveelheid informatie van individuele dieren, die noodzakelijk was voor de berekeningen, was niet verschillend voor de alternatieven. Het lijkt daarom niet verantwoord om bij het bepalen van de optimale beslissingen geen aandacht te schenken aan de verschillen in voerkosten of de verschillen, als gevolg van leeftijd, laktatiestadium, seizoen en reden van afvoer, in slachtwaarde. De individuele verschillen in slachtwaarde hebben, wanneer ze een grote herhaalbaarheid over laktaties vertonen, nauwelijks invloed op de optimale beslissingen. Evenmin lijkt het verantwoord om uitsluitend aandacht te besteden aan de verschillen tussen dieren in de te verwachten melkopbrengst.

Kengetallen ter ondersteuning van de veehouder

In hoofdstuk 7 wordt ingegaan op de mogelijkheden om de veehouder te ondersteunen bij het nemen van beslissingen voor individuele koeien. Er werden 3 categorieën van beslissingen onderscheiden, namelijk: onmiddellijke vervanging, veterinaire behandeling en inseminatie. Voor de ondersteuning van de veehouder bij het nemen van deze beslissingen zouden voor elke koe twee kengetallen berekend moeten worden.

Op de eerste plaats kan de toekomstige winstgevendheid van een koe worden gehanteerd als hulpmiddel voor beslissingen tot onmiddellijke vervanging en veterinaire behandeling bij het optreden van een gezondheidsstoornis. De toekomstige winstgevendheid vormt een schatting van de te verwachten extra arbeidsopbrengst, wanneer een koe wordt aangehouden tot het optimale moment in plaats van onmiddellijke vervanging. Wanneer dit bedrag negatief is, komt de koe in aanmerking voor onmiddellijke vervanging. Bij de beslissing tot veterinaire behandeling moet een afweging gemaakt worden van de kosten van de behandeling en het effect van de gezondheidsstoornis op de toekomstige prestatie van de koe enerzijds en de schade bij vervanging anderzijds. De toekomstige winstgevendheid vormt een schatting voor het gemist toekomstig inkomen bij vervanging, uitgaande van het verwachte produktieverloop na volledig herstel. Dit kengetal is een belangrijk hulpmiddel bij het besluiten tot veterinaire behandeling.

Op de tweede plaats kan de verwachte winst, bij het op dat moment drachtig worden van de koe, worden toegepast als hulpmiddel bij het nemen van inseminatiebeslissingen. De verwachte winst bij drachtig worden van een koe kan worden berekend, door het vergelijken van de dan verwachte arbeidsopbrengst met de opbrengst wanneer het dier wordt gust gelaten en afgevoerd op het optimale moment tijdens de lopende laktatie. Deze winstverwachting moet samen met de verwachte kans op conceptie worden afgewogen tegen de kosten van inseminatie.

Beide kengetallen geven de naar verwachting optredende schade wanneer een niet-optimale beslissing genomen wordt. Dit geeft de veehouder de mogelijkheid om aanvullende informatie van het dier of het bedrijf in te wegen. Zo kan, ondanks een positieve winst bij verkregen dracht, besloten worden het dier gust te laten vanwege een slecht uier of slechte benen.

Twee methoden voor de berekening van de beide kengetallen worden beschreven. In ieder van de gevallen wordt gebruik gemaakt van de met dynamische programmering verkregen resultaten. Bij de berekening van de kengetallen is informatie noodzakelijk over de produktie en drachtigheidsstatus van de koeien. Voor de produktie kan gebruikt gemaakt worden van de gegevens die verzameld worden bij de melkcontrole. Voor het vaststellen van de drachtigheidsstatus moet, naast de gegevens omtrent de inseminatie van dieren, geregistreerd worden welke dieren na één of meerdere niet geslaagde inseminaties worden gust gelaten.

Er is geconcludeerd, dat het gebruik van de toekomstige winstgevendheid en de winst bij verkregen dracht kan bijdragen aan een verbetering van het inkomen van de melkveehouder.

Curriculum vitae

Johan A.M. van Arendonk werd op 13 september 1958 geboren te Bavel (Noord-Brabant), waar hij ook opgroeide. Na het behalen van het Atheneum-diploma aan de Newman-IJpelaar Scholengemeenschap te Breda in 1976 begon hij in september van dat jaar met zijn studie aan de Landbouwhogeschool te Wageningen. Het doctoraalexamen in de Zoötechniek, met als verzwaard hoofdvak de Veeteelt en als hoofdvak de Gezondheids- en Ziekteleer der Huisdieren, werd cum laude afgelegd in februari 1982. Na zijn afstuderen werd hij voor een periode van 3 jaar aangesteld als promotie-assistent bij de vakgroepen Veefokkerij en Agrarische Bedrijfseconomie van de Landbouwhogeschool. Sinds 1 februari 1985 is hij als universitair docent verbonden aan de vakgroep Veefokkerij van de Landbouwhogeschool.