GENETIC CHANGES IN A

NEW ZEALAND

PEDIGREE JERSEY HERD.

by

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INTRODUCTION.

The majority of sires used in New Zealand herds are obtained from pedigree breeders and in consequence, the genetic merit of the national herd depends largely upon the quality of the pedigree section of the cattle breeding industry. The continued use of pedigree sires by many commercial farms has probably resulted in a narrowing of the genetic margin between registered and non-registered dairy cattle. Upon this genetic margin the present elite status of pedigree cattle depends and if it were possible to demonstrate that this margin was negligible then the present rigid distinction between pedigree and non-pedigree stock would not be justified. This would have far reaching implications the most important of which would be that there would be little justification in restricting sires used in the industry to those bred in pedigree herds. On the other hand if it were possible to demonstrate that pedigree herds were improving genetically and preserving a genetic margin over commercial herds then the present policy of attempting to effect national herd improvement through the pedigree section of the industry would be vindicated.

This pedigree section consists of many more or less independent herds of varying size and duration. Many of these herds, because of the limitations imposed by small herd size and short herd duration must contribute little to breed improvement. The advances made by one will be largely counterbalanced by the losses of another. However, the vast majority of pedigree herds are not genetically isolated from each other due to the high transfer rate of both male and female stock from one herd to another. It has been demonstrated that pedigree herds in New Zealand belong to various strata according to the herds to which they supply sires. The top stratum herds, of which there are about a hundred, obtain their sires from within their own herds or from herds in the same stratum but not from herds in lower strata. They supply to herds in all strata. The second stratum herds obtain their sires from the top stratum herds and supply to herds in the lower strata. Thus the lower stratum herds are being continually graded up to the top stratum herds. It is clear that if genetic progress is to be made these top stratum herds must be making continued improvements because the remainder of the pedigree breed is ultimately dependent upon them for genetic gains.

Overseas workers have reported the gains possible in single herds and have estimated the gains actually made in some instances. To date, however, no such work has been reported in New Zealand and to this end the records of one of the top-stratum herds have been studied to determine firstly whether genetic gains during a twenty-year period have been made, and secondly to ascertain the breeding practises by which such improvement, if any, were effected.

SOURCE OF DATA.

The Herd Recording Council of the New Zealand Dairy Board has published the progeny test details of all pedigree bulls for which information was available since 1943 (N.Z. Dairy Board, 1943). One of the pedigree Jersey herds which has been conspicuous as a source of meritorious sires has been that of Mr. C.B. Lepper, Lepperton, Taranaki. Not only have the sires bred in this herd performed well in the industry's herds in which they were used but Mr. Lepper's herd has been outstanding insofar as per cow production is concerned. The herd has averaged at least four hundred pounds of butterfat per cow for many years in an environment which though favourable appears no better than that obtaining on a large number of dairy farms. Despite this the production of Mr. Lepper's "Maori" herd has been considerably in excess of the vast majority of herds maintained under comparable conditions.

An additional point of interest concerning the "Maori" herd is apparent from a study of the stratification of the Jersey breed during 1948 (Fahimuddin, 1952). This herd was numbered among the 112 herds comprising the top stratum of the breed, that is herds which supply sires to herds in the various strata but do not draw bulls from herds in strata other than their own. The herd is thus a unit of the nucleus upon which the remainder of the breed is largely dependent for genetic improvement and to which the whole breed is being graded. Further, among these nucleus herds, the "Maori" herd is one of the most important as judged by the total number of pedigree heifers sired by animals bred in the "Maori" herd.

For these reasons a study of the methods of selection practised in the "Maori" herd and an attempt to assess the proportion of the improvement in productive herds due to genetic causes should be of interest to both the animal husbandryman and the geneticist. The herd is admirably suited for such a study for the following reasons:-

(1) All animals in the herd have been continuously recorded since the beginning of the 1930-31 season, thus providing twenty-one years records.

(2) During this twenty-one year period the herd has numbered approximately 100 animals in milk each year, a total of 357 cows with 1892 lactations of at least 100 days duration being available for study.

(3) The herd has been closed since 1942. The last purchased bull sired progeny between 1937 and 1942, and since 1930 no purchased dams have entered the

Maori herd. It is thus possible to obtain comparable pedigree estimates of all the replacement heifers and the majority of the sires used in the herd since their dams in most cases have performance details in the same environment.

(4) Since the beginning of the 1931-32 season the herd has remained under single ownership. Volume V (1908) of the New Zealand Jersey Cattle Breeders' Association shows that the late Mr. H.B. Lepper first registered a pedigree heifer born in August 1902 and continued to register stock each year until his death. Stock in the Maori herd have been registered under the name of the present owner Mr. C.B. Lepper since 20th September 1931. The present study therefore deals almost entirely with the changes which have taken place during Mr. C.B. Lepper's ownership.

The data also ~~has~~ have certain shortcomings. Briefly these are as follows:-

(1) There were no records available of the sex and subsequent fate of all calves born on the farm. This deficiency in the material though not serious precludes certain analysis.

(2) During the 1930-31 season the "Maori" herd consisted of both pedigree and non-registered stock, and it was not until the 1944-45 season that the herd consisted entirely of pedigree animals. It is possible that pedigree replacements entering the herd during the period of change over from grades to pedigrees were not selected as vigorously as those used for replacement purposes when the herd was entirely pedigree.

(3) The number of annual calvings has varied but since this is fairly typical of New Zealand herds it was not considered a serious deficiency other than the complications caused in the various computational procedures adopted.

Pedigree records were readily available from the herd books of the N.Z. Jersey Cattle Breeders' Association. Performance details were obtained from the copies of the monthly Group Herd Testing returns held by the New Zealand Dairy Board in the case of records up to the 1945-46 season and from copies held by the Taranaki Herd Improvement Association for the later years. The estimation of yields under the Group Herd Testing system is based on a sampling proceedure. The recording officer visits the herd once each calendar month without notification to the owner. Each visit comprises two consecutive milkings at each of which the milk is weighed and proportionately sampled for subsequent testing for butterfat content. This recording system has been demonstrated to give reasonably accurate estimates of actual lactation yields (Campbell 1946).

THE EXTENT AND CAUSES OF HERD IMPROVEMENT.

The most important problem in herd analysis is to apportion trends in production to the factors responsible. Changes in productive levels are determined by genetic and environmental forces and can be entirely accounted for by these two factors and by the interactions between them. Thus the phenotypic variance of a character such as butterfat yield may be divided into the following component parts:-

$$\sigma_p^2 = \sigma_{Ge}^2 + \sigma_E^2 + 2r_{GeE}\,\sigma_{Ge}\,\sigma_E + f\,(GeE).$$

where

σ_p^2 is the phenotypic variance

σ_{Ge}^2 is the hereditary component of the total phenotypic variance.

σ_E^2 is the environmental component of the phenotypic variance.

R_{GeE} is the correlation between heredity and environment.

and $f(GeE)$ is the non-linear genotypye- environment interaction.

The last two terms may be neglected for most practical purposes (Lerner, 1950) and the formula is usually written:-

$$\sigma_p^2 = \sigma_{Ge}^2 + \sigma_E^2$$

Each of these two components of the total variance can be partitioned further. The genetic fraction (σ_{Ge}^2) may be divided into:-

$$\sigma_{Ge}^2 = \sigma_G^2 + \sigma_{Gi}^2$$

where σ_G^2, is the variance due to the additively acting component

and σ_{Gi}^2, is the variance due to the component containing non-additive effects, including epistatic and dominance deviations.

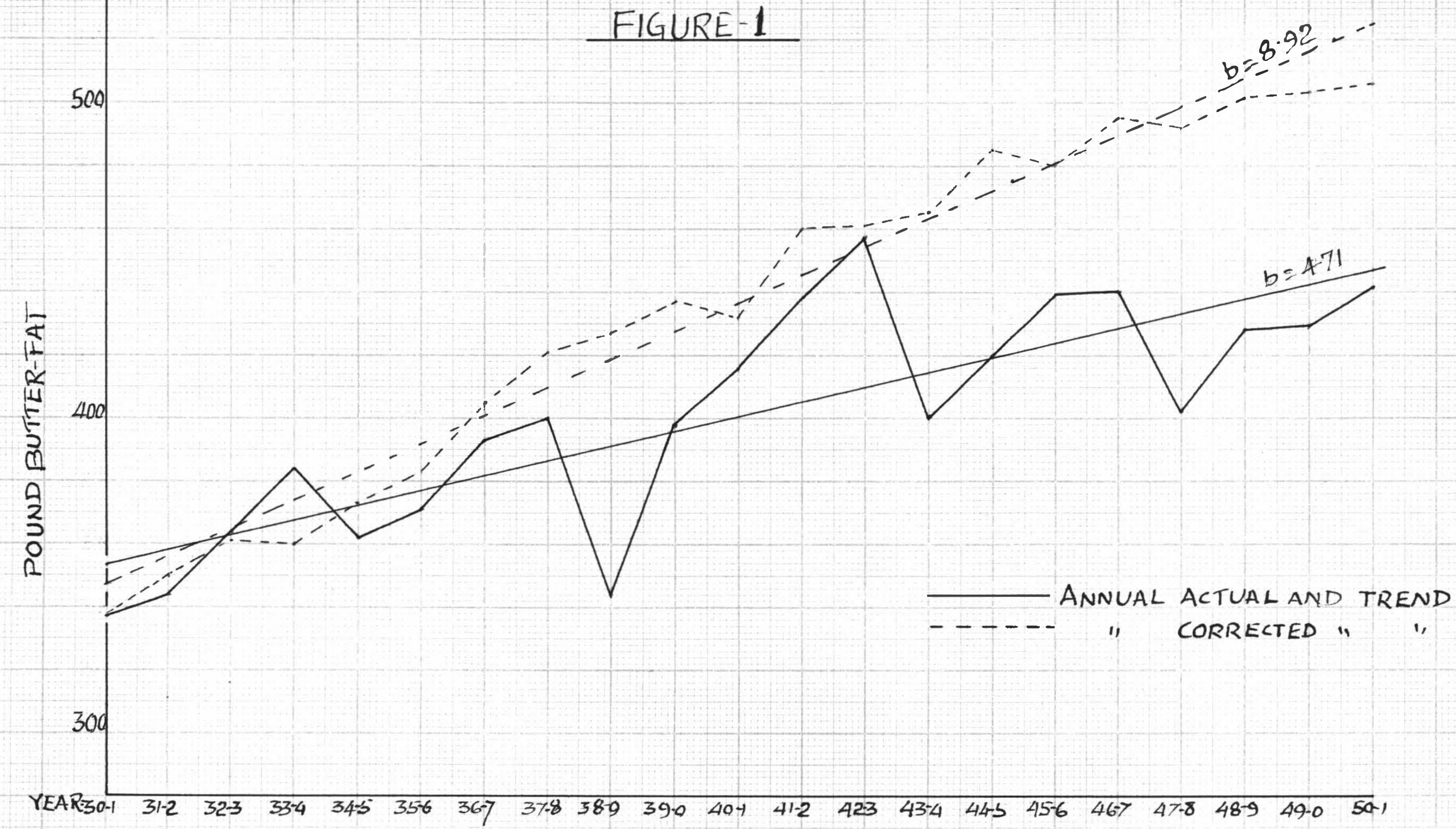
Similarly the environmental component of variance may be subdivided into:-

$$\sigma_E^2 = \sigma_{Ei}^2 + \sigma_c^2$$

where σ_{Ei}^2 is the variance due to the environmental component which varies at random between similar families

and σ_c^2 is the variance due to the environmental component due to the influence common to members of the same family but varying from family to family (primarily non-genetic effects of mother on offspring).

FIGURE-1



b=8·92
b=4·71
500
400
300
POUND BUTTER-FAT
YEAR
30-1
31-2
32-3
33-4
34-5
35-6
36-7
37-8
38-9
39-0
40-1
41-2
42-3
43-4
44-5
45-6
46-7
47-8
48-9
49-0
50-1
ANNUAL ACTUAL AND TREND
" CORRECTED " "

When σ_c^2 does not make large contributions to the total variance then for practical purposes:-

$$\sigma_E^2 = \sigma_{Ei}^2$$

The complete formula may then be written as follows:-

$$\sigma_P^2 = \sigma_G^2 + \sigma_{Gi}^2 + \sigma_{Ei}^2$$

If the effectiveness of a breeding programme is to be appraised it is necessary that the observed changes in productive levels be separated into these environmental and genetic components. An examination of herd averages with respect to changes from one year to another gives no indication of the causes of these changes. Increased production may be the result of improved feeding and management or of improved genetic merit.

The easiest method to estimate the year to year changes in herd invironment is to use the concurrent records. The change from year 1 to year 2 would be the difference between the average of these two years with respect to the selected groups of cows who made records in both these years. Similarly the changes from year 2 to year 3 would be the difference in average production for these two years in a second selected group of cows who made records in both years 2 and 3. This procedure could be carried on for any number of years desired. This method was employed in a preliminary investigation and the results as shown in Table 1. and Figure 1. .

Table 1. Showing annual herd average of mature cows and their corrected records.

Year.	Annual Herd Average Pound Butter Fat.	Annual Corrected Herd Average Pound Butter Fat.
1930-31	337	337
1931-32	344	350
1932-33	364	361
1933-34	384	360
1934-35	362	373
1935-36	371	383
1936-37	393	405
1937-38	400	421
1938-39	344	427
1939-40	398	437
1940-41	416	432
1941-42	438	460
1942-43	457	461
1943-44	400	465
1944-45	420	485
1945-46	439	480
1946-47	440	495
1947-48	402	492
1948-49	428	501
1949-50	429	503
1950-51	441	506

The corrected mature cow average appears reasonable during the earlier years but the wide divergence between raw and corrected records from 1938-39 to 1950-51 indicates that this is not the most efficient possible method of estimating changes. The changes from year 1 to year 3 can be estimated, not only by comparison of the year 1 versus year 2 with the year 2 versus year 3 estimates, but also by comparison within the group of cows with records in both years 1 and 3. It can be seen that there are many combinations of comparisons and the problem arises as to how best to weight them.

Henderson (1949) suggests the method of least squares as a computational procedure with which to weight the various comparisons. A model applicable to the least squares method is as follows:-

$$Y_{ij} = \mu + a_i + c_j + e_{ij}$$

where Y_{ij} is the record made by the jth cow in the i-th year.

μ is the population mean.

a_i is the environmental effect of the i-th year.

c_j is the real producing ability of the jth cow.

and e_{ij} is a random error associated with the record of the jth cow made in the i-th year.

The errors are assumed to be uncorrelated, and in most cases they are assumed to be normally distributed. Essentially all this model says is that the record of a cow can be at least approximately expressed as the sum of the population mean, a cow effect, an environmental effect peculiar to a particular year, and an error which is presumably the sum of many different environmental effects impinging upon a particular cow in a particular year. The real producing ability of the cow is a function of her genotype and of permanent environmental factors peculiar to her. The problem is to assign values to μ, a_i, and c_j in such a way as to minimise the residual sum of squares. The solution to the following set of simultaneous equations accomplishes this objective.

$$n_{..}\hat{\mu} + \sum_i n_{i.}\hat{a}_i + \sum_j n_{.j}\hat{c}_j = \sum_i \sum_j {}_{ij}$$

$$n_{i.}\hat{\mu} + n_{i.}\hat{a}_i + \sum_j n_{ij}\hat{c}_j = \sum_j Y_{ij}$$ (One such equation for each of the a_i)

$$n_{.j}\hat{\mu} + \sum_i n_{ij}\hat{a}_i + n_{.j}\hat{c}_j = \sum_i Y_{ij}$$ (One such equation for each c_j)

where n_{ij} = I if the jth cow made a record in the i-th year.

and n_{ij} = 0 if the jth cow did not make a record in the i-th year

n = the total number of records.

n_i = the number of records made in the i-th year.

and $n_{.j}$ = the number of records made by the jth cow.

The solution to these equations - for $\hat{\mu} + \hat{c}_j = \frac{1}{n_{.j}}\left(\sum_i Y_{ij} - \sum_i n_{ij}\hat{a}_i\right)$.

Utilising this fact, the equations can be reduced to ones involving only the $\hat{a}_i$. Then after improving the restriction $\sum_i \hat{a}_i = 0$ the $\hat{a}_i$ can be solved.

Both the least squares estimate, and the comparisons of yearly averages of cows selected because they had records in two specified years, can give seriously biased results. The bias arises from the fact that if the cows which are culled from the herd have average records below the herd mean, the environment will appear to have been deteriorating whereas there may have been no change. Similarly if the environment has been improving, improvement in environment appears less than it really has been. If the environment has been getting worse, the deterioration in environment will appear worse than it actually has been. Conversely, if the cows culled from the herd are of above average production, the environment will seem to have improved more or to have deteriorated less than is actually the case.

The reason for the bias in the least squares method is the incomplete repeatability of dairy records. It is a well known fact that a group of cows selected because their records were above the herd average during the past one or more years are likely to produce less far above the herd average the next year. Conversely cows selected far below the average production are likely to be less far below the herd average in their succeeding lactations. The reason for this is that cows with above average production more frequently than not receive an above average temporary environmental contribution. Since this temporary factor does not carry over to succeeding lactations, these later records are likely to fall below the earlier ones. The crucial point is that the least squares and similar methods are essentially year to year comparisons of records of the survivors of each year's culling. Therefore, if the survivors of culling made records above the herd average prior to the culling of certain of their mates, we should expect these survivors' records to be less in succeeding years and consequently to make it appear that the environment is becoming poorer from year to year.

What is needed then is some method by which knowledge of repeatability of dairy records and of the year to year culling levels can be utilised to adjust the estimates of the yearly environmental effects. The method of maximum likelihood described below does all of this automatically in a set of simultaneous equations which are little more complex than the least squares equations.

The model used for the least squares analysis may be modified as follows:- (Henderson ibid)

$$Y_{ijk} = \mu + a_i + b_j + c_{jk} + e_{ijk}$$

where Y_{ijk} is the record made in the ith year by the kth cow of the jth group of cows

μ is the population average

a_i is the environmental effect of the ith year

b_j is the average real producing ability of the jth group of cows

c_{jk} is the real producing ability of the kth cow of the jth group

and e_{ijk} is a random environmental effect peculiar to the individual record.

The new element in this model as compared to the least squares model is the b_j. It represents the average real producing ability of a particular group of cows. It might, for example, represent a set of cows born within a specified period. Additional assumptions are necessary - that the c_{jk} are normally and independantly distributed with mean 0 and variance σ_c^2, and the e_{ijk} are normally and independantly distributed with mean 0 and variance σ_e^2, and that the c's and e's are oncorrelated. These assumptions mean that the cows of a particular group are randomly drawn from a normal population whose mean is $\mu + b_j$ and whose variance is σ_c^2. Further temporary environment is not correlated.

With the assumptions specified above joint distribution of the Y_{ijk} and the c_{jk} can be written and can proceed to compute values of μ, a_i, b_j, and c_{jk} which will maximise the probability of obtaining the sample of records actually at hand. The distribution is

$$L = \prod_{ijk} \frac{1}{\sqrt{2\pi\,\sigma_e^2}} e^{-\frac{1}{2\sigma_e^2}(Y_{ijk} - \mu - a_i - b_j - c_{jk})^2} \prod_{jk} \frac{1}{\sqrt{2\pi\,\sigma_c^2}} e^{-\frac{c_{jk}^2}{2\sigma_c^2}}$$

The maximising values are the solution to the following set of the simultaneous equations:

$$n_{...}\tilde{\mu} + \sum_i n_{i..}\tilde{a}_i + \sum_j n_{.j.}\tilde{b}_j + \sum_j \sum_k n_{.jk}\tilde{c}_{jk} = \sum_i \sum_j \sum_k Y_{ijk}$$

$$n_{i..}(\tilde{\mu} + \tilde{a}_i) + \sum_j n_{ij.}\tilde{b}_j + \sum_j \sum_k n_{ijk} = \sum_j \sum_k Y_{ijk},$$ and similarly for all a's.

$$n_{.j.}(\tilde{\mu} + \tilde{b}_j) + \sum_i n_{ij.}\tilde{a}_i + \sum_k n_{.jk}\tilde{c}_{jk} = \sum_i \sum_k Y_{ijk},$$ and similarly for all b's

$$n_{.jk}(\tilde{\mu} + \tilde{b}_j) + \sum_i n_{ijk}\tilde{a}_i + \left(n_{.jk} + \frac{\sigma_e^2}{\sigma_c^2}\right)\tilde{c}_{jk} = \sum_i Y_{ijk},$$ and similarly for all c's.

n_{ijk} = I if the jkth cow has a record in the ith year and = 0 otherwise. A dot in the subscript denotes summation over that particular subscript. That is $n_{...}$ refers to the total number of records, $n_{i..}$ to the number of records in the ith year, $n_{.j.}$ to the number of records made by the cows of the jth group, $n_{.jk}$ to the number of records made by the kth cow of the jth group, and n_{ij} to the number of records made by the jth group in the ith year.

It will be noted that $\frac{\sigma_e^2}{\sigma_c^2}$ appears in certain coefficients. This ratio is closely related to repeatability of dairy records as defined by Lush (1945), and concerning the size of which several estimates have been made in this study (see Appendix I). If repeatability is denoted by $r = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_e^2}$ then $\frac{\sigma_e^2}{\sigma_c^2}$ can be written as $\frac{1-r}{r}$ for example, if r = 0.44, $\frac{\sigma_e^2}{\sigma_c^2}$ =1.3

Solving for $\tilde{c}_{jk}$ in the above equation

$$\tilde{c}_{jk} = \frac{\sigma_c^2}{n_{.jk}\sigma_c^2 + \sigma_e^2}\left(\sum_i Y_{ijk} - n_{.jk}\tilde{\mu} - n_{.jk}\tilde{b}_j - \sum_i n_{ijk}\tilde{a}_i\right)$$

Consequently these expressions may be substituted for $\tilde{c}_{jk}$ in the μ, a, and b equations and thereby eliminate the $\tilde{c}_{jk}$. Then a set if equations remains in which $\tilde{\mu} - \tilde{b}_j$ can be expressed in terms of the $\tilde{a}_i$ and certain observed records and in which by proper substitution the equations can be reduced to one involving only the $\tilde{a}_i$.

Consider the expression for $\tilde{c}_{jk}$ and now assume that μ is known and that all a_i and b_j = 0. This would be the case if it is assumed that there have been no changes in the herd environment nor in the genetic merit of the herd and that the herd average is known without error. Then

$$\tilde{c}_{jk} = \frac{\sigma_c^2}{n_{.jk}\sigma_c^2 + \sigma_e^2}\left(\sum_i Y_{ijk} - n_{.jk}\mu\right)$$

$$= \frac{n_{.jk}\, r}{1 + (n_{.jk} - 1) r}\left(\bar{Y}_{.jk} - \mu\right)$$

This last expression is exactly equivalent to the method derived by Lush (1945) for estimating the real producing ability of a cow. That is, his method is in fact the maximum likelihood method under the assumptions listed above. The method described here (Henderson 1949,a) utilises these same principles but permits the cessumption of changing herd environment and genotype.

As far as can be ascertained, the method has been employed only once in the analysis of herd records. Lush (1951) reports the average butterfat production (first 8 months of the lactation and corrected to mature age) of the Holstein-Friesian herd at Iowa State College during a 12 year period in which the straight line trend of the annual herd averages (mature equivalent) is upward at the rate of 5.9 pounds per year. The genetic component in this is 2.5 pounds or nearly half of the total. He further states that these particular figures do not warrant any generalisation although he does say that no bias was apparent in the method by which they were derived. The figures may be undependable, however, because: (1) they are based on one herd averaging about 50 to 60 milking cows, and hence may have considerable sampling errors; (2) the time involved is only 12 years. This is only about two and one half generations in cattle and is much too short an interval on which to base a dependable trend line, yet, because of high heritability and the amount of selection reasonably possible, he remarks that a genetic improvement of about two or three pounds per year over long periods of time is a reasonable estimate of which one can expect a whole breed of dairy cattle to achieve.

In the present analysis the first problem was to decide the amounts which should be added to immature records (two-year-old and three-year-old) to convert them to their mature equivalents. The New Zealand Dairy Board employ correction factors for Jersey cattle of + 70 lbs to two-year-old records and + 35 lbs to three-year-old records. All normal records (lactation between 100 and 305 days) for two-year-old, three-year-old and mature dams (aged four to nine years) in the herd under study are given in Table 2.

Table 2. Average of normal lactation distribution.

Year.	2 year-old.		3 year-old.		4-9 year-old.	
1930-31	250	(11)	281	(15)	337	(22)
1931-32	284	(14)	292	(8)	344	(44)
1932-33	286	(12)	323	(14)	364	(46)
1933-34	286	(11)	339	(10)	384	(51)
1934-35	248	(3)	342	(12)	362	(60)
1935-36	302	(17)	393	(1)	371	(54)
1936-37	349	(15)	297	(20)	393	(38)
1937-38	312	(13)	340	(16)	400	(41)
1938-39	261	(19)	314	(12)	344	(45)
1939-40	343	(14)	352	(23)	398	(53)
1940-41	335	(14)	410	(15)	416	(62)
1941-42	307	(15)	406	(14)	438	(63)
1942-43	347	(9)	413	(12)	457	(72)
1943-44	295	(11)	362	(9)	400	(66)
1944-45	353	(10)	388	(16)	420	(56)
1945-46	337	(22)	391	(10)	439	(57)
1946-47	331	(13)	393	(21)	440	(48)
1947-48	350	(12)	371	(13)	402	(60)
1948-49	324	(14)	398	(12)	428	(61)
1949-50	367	(13)	353	(13)	429	(60)
1950-51	384	(13)	436	(11)	441	(63)
Average	319	(275)	360	(277)	400	(1120)

(Number of lactations in brackets.)

FIGURE 2

ANNUAL DIFF. BETWEEN 2 YEAR OLD AND MATURE COW AVERAGE PRODUCTION
" " " 3 " " " " " " "
POUND BUTTER-FAT
130
120
110
100
90
80
70
60
50
40
30
20
10
0
YEAR:
30-1
31-2
32-3
33-4
34-5
35-6
36-7
37-8
38-9
39-0
40-1
41-2
42-3
43-4
44-5
45-6
46-7
47-8
48-9
49-0
50-1

The annual differences between the productions of the three age classes are shown in Fig. 2 . Though mature cow productions exceed the two-year old and three-year old productions on the average by 81 and 40 lbs of butterfat respectively, year to year changes are considerable. The differences between mature and two-year old records are, generally speaking, largest in the years in which the mature cow average is high (subsequent to 1940). Differences between the three-year old and mature records are more uniform. Different correction factors for each year would appear desirable but since these would be applied to the data from which they were calculated it would be difficult to justify their use. It was decided that though errors would be introduced by the use of the New Zealand Dairy Board correction factors they were probably the most reliable ones available for New Zealand conditions.

The herd studied was "slow maturing", probably for management reasons and the use of corrections derived from faster maturing animals will suggest that management is getting better (cows corrected first records will be below the true value) and consequently the genetic level declining, even though there may be no change in either.

Thus the use of the New Zealand Dairy Board correction factors derived from estimates made from many recorded herds treated as one population, though open to objections, should tend to underestimate the genetic contributions to the total improvement in the herd studied.

They were used to correct the yields of 2 and 3 year old heifers in the herd under study, which comprised 357 cows with 1892 lactations during 21 seasons.

The simplified method of maximum likelihood was used (Henderson 1949b) which involves combining μ and b_j into a single parameter. The equations are as follows:

$$n_{i..}a_i+\sum_j n_{ij.}(\mu+b_j)+\sum_{jk} n_{ijk}c_{jk}=\sum\sum_{jk} Y_{ijk}$$

and similarly for the other a_i equations:

$$\sum_i n_{ij.}a_i+n_{.j.}(\mu+b_j)+\sum_k n_{.jk}\,c_{jk}=\sum_i\sum_k Y_{ijk}$$

and similarly for the other $\mu + b_j$ equations:

$$\sum_i n_{ijk}\,a_i+n_{.jk}(\mu+b_j)+\left(n_{.jk}+\sigma_e^2/\sigma_c^2\right)c_{jk}=\sum_i Y_{ijk}$$

and similarly for the other equations:

$a_1, a_2, a_3 \, . \, . \, . \, . \, a_{21}$ = the environmental effects peculiar to cows freshening in 1930-31, 1931-32 to 1950-51 seasons respectively.

$\mu + b_1$, $\mu + b_2$, $\mu + b_3$, $\mu + b_4$, $\mu + b_5$ and $\mu + b_6$ = the permanent producing abilities of the sub-populations born before 1930, between 1930-33, 1934-37, 1938-41, 1942-45 and 1946-48 calander year periods.

These sub-populations were chosen to simplify the calculations. By reducing the twenty-one sub-populations classified according to year of birth to six sub-populations each born within specified periods the number of equations to solve is correspondingly reduced. That such reductions can be justified is clear from Fig.9. in which all the animals in the herd between 1930-1951 are shown according to their date of birth and their sire. Considering only the herd entries, those born between 1930 and 1933, 1934 and 1937, 1938 and 1941, 1942 and 1945, and between 1946 and 1949 inclusive do exhibit between group differences so far as sires are concerned and at the same time show considerable uniformity within groups. The classification was considered sufficiently distinct to warrant the grouping of herd entries into the classes specified above.

The cows born in any specified period have been considered a random sample of cows from some infinite sub-population of cows which might have been born in that period in the herd under study. The sub-population is assumed to be normally distributed with means $\mu + b_j$ and variance σ_e^2 .

Mature equivalent records of the 357 cows in the herd under study were first tabulated. Table 3 shows in abbreviated form the lay-out of the raw data corrected to maturity equivalent.

Table 3. Mature Equivalent Records.

Cow	Year of Birth	Season cow freshened.				Cow Sum.
		1930-1	1931-2	....	1950-1	
1	1919	221				221
2	1920	316	253			569
.						
.						
.						
356	1948				433	433
357	1948				320	320
Freshening year sum.		15911	22966		47309	

The total butterfat production of each cow, each year, and of each sub-population were then calculated.

The next step was to calculate the value of c_{jk} for each animal. This was derived from the number of lactations recorded for each animal plus the factor $\frac{1-r}{r}$ = 1.3. The layout of the data for this calculation is shown in Table 4.

Table 4. Maximum Likelihood Equations.

	a_i .... a_{21}	b_i ...... b_6	c_{jk}	Right member.
a_i	49			
⋮				
a_{21}	106			
b_i		406		
⋮				
b_6		75		
c_i	1 0		2.3	221
⋮				
c_{357}	0 1		2.3	320

The top two sections of the table ($a_i - a_{21}$ and $b_i - b_6$) are included to check computations and for subsequent calculations.

Having obtained the c_{jk} for each animal the next step was to reduce the large number of unknowns designated by zero in Table 4. The equations necessary to solve these unknowns may be reduced to 27 in number by making use of the fact that c_{jk} can be expressed in terms of the a_i, $\mu + b_j$ and the right member of the c_{jk} equation. For example:

$$c_i = \frac{1}{2.3} \left(221 - \qquad -1[\mu + b_i]\right)$$

This is facilitated by performing the operation in two steps. First Table 5 was prepared as shown:-

Table 5.

	a_i .... a_{21}	b_i .... b_6	c_{jk}	Right member.
c_1	.4348"	.4348	2.3	96.08""
⋮				
c_7	.3030	.6061	3.3	213.64
⋮				
c_{357}	.4348	.4348	2.3	139.13

" $\dfrac{\text{no of lactations}}{c_{jk}} = \dfrac{1}{2.3}$

"" $\dfrac{\text{sum of lactations}}{c_{jk}} = \dfrac{221}{2.3}$

This enables Table D to be prepared in which c_{jk} can be expressed in terms of other parameters. In these equations the column headings denote the unknowns while the row headings denote the equations. Table 6 is prepared by using information in Tables 4 and 5.

Table 6.

	a_i .... a_{21}	b_i . . . . . b_6	Right member.
a_i	39.34	12.57	3,712.74
⋮			
a_{21}	84.83	15.10	12,957.50
b_i		72.95	25,033.13
⋮			
b_6		29.71	12,675.03

The entry in the upper left-hand corner is calculated from the entry in the a_i column and a_i row of Table 4 minus the cross products of the entries in the a_i column of Table 5.

The entry in the a_2 column a_i row is calculated from the same tables.

The entry in the b_i column a_i row is calculated from b_i column a_i row in Table 4 minus the entries in the b_i column of Table 5.

The entries in the b_i columns and b_i rows are the sums of the b_i columns.

The Right member in Table 6 for the a_i row is calculated from the sum for the a_i row in Table 4 minus the sum of all entries in the Right member column of Table 5 for all the entries of a_i.

It is possible to reduce the equations still further by making use of the fact that b_j can be expressed in terms of a_j and the right members. This step is shown in Table 7.

Table 7.

B_j	a_i .... a_{21}	b_j	Right member.
b_i	.1723	72.95	25,033.13
⋮			
b_6	.5082	29.71	12,675.03

The entry in the a_i column b_i row is calculated from the entry in the b_i column a_i row of Table D divided by the sum of the entries in the b_i column of Table 6.

Entries in the b_j column and the Right member column are obtained direct from Table 6.

The next step is to construct Table 8 in which c_{jk} and b_j have been expressed in terms of a_i and the right members.

Table 8.

	a_i .... a_{21}	Right members
a_i	37.17	- 597.46
⋮		
a_{21}	75.65	+ 2,276.52

The entries in Table 8 are obtained from Table 7 by the same procedure as adopted in constructing Table 6.

There is no solution to the equations of Table 8 as they stand since the sum of all bue one of the equations in each row is equal to the remaining equation with signs changed. This difficulty can be overcome by imposing the restriction that the sum of $a_i = 0_1$ that is $a_i + a_2 + \quad = 0$ This restriction is permissable since yearly environmental effects are thereby expressed as deviations about the mean of such effects. Thus $a_{21} = - a_i - a_2 - - - - - a_{20}$.
The solution of these equations with a large number of unknowns and unequal subclass numbers is difficult and tedious. The procedure may, however, be eimplified by some computational devices. The one employed in this study is the iterative method of solution.

The equations already obtained are not independent. The following procedure to make the equations independent and the diagonal elements as large as possible relative to the off diagonals has been adopted (Henderson 1948).

(a) the a_{21} elements has been deleted
(b) the coefficients of the a_{21} elements have been substracted from the a_i elements in the appropriate row.

Table 9. can then be constructed.

Table 9.

	a_i	a_2	a_{20}	Sum
a_i	37.17	- 9.16		- 597.46
a_2	- 9.16	52.48		
⋮				
a_{20}			101.08	- 493.24

The sum column in Table 9 is obtained from the difference between the right numbers in Table 6 and the product of the entry in a_i column b_i row and the right number in Table 7 i.e. $(+3{,}712.74) - (25{,}633.13 \times 0.1723) = -597.46$.

The iterative method of solution was then employed to obtain Table 11. This method consists of absorbing a_i. The results are given in Table 10.

Table 10.

- 17.07	- 6.86	+ 33.56
- 16.32	- 6.73	
- 16.07	- 6.68	+ 31.86
a_i	a_2	a_{21}

The first entry in the bottom left hand corner of Table 10 is derived from the division of the sum in row a_i of Table 9 by the entry in a_i column a_i row.

$$-597.46 / 37.17 = -16.07$$

The first entry for a_2 in Table 10 is derived from the following equation:

$$-9.16\, a_i + 52.48\, a_2 = -203.57$$

$$\therefore a_2 = \frac{-203.57 - (9.16 \times 16.07)}{52.48}$$

$$= -6.68$$

This procedure is continued across the page.

The second entry for row a_i working upwards is derived from Table 9 as follows:-

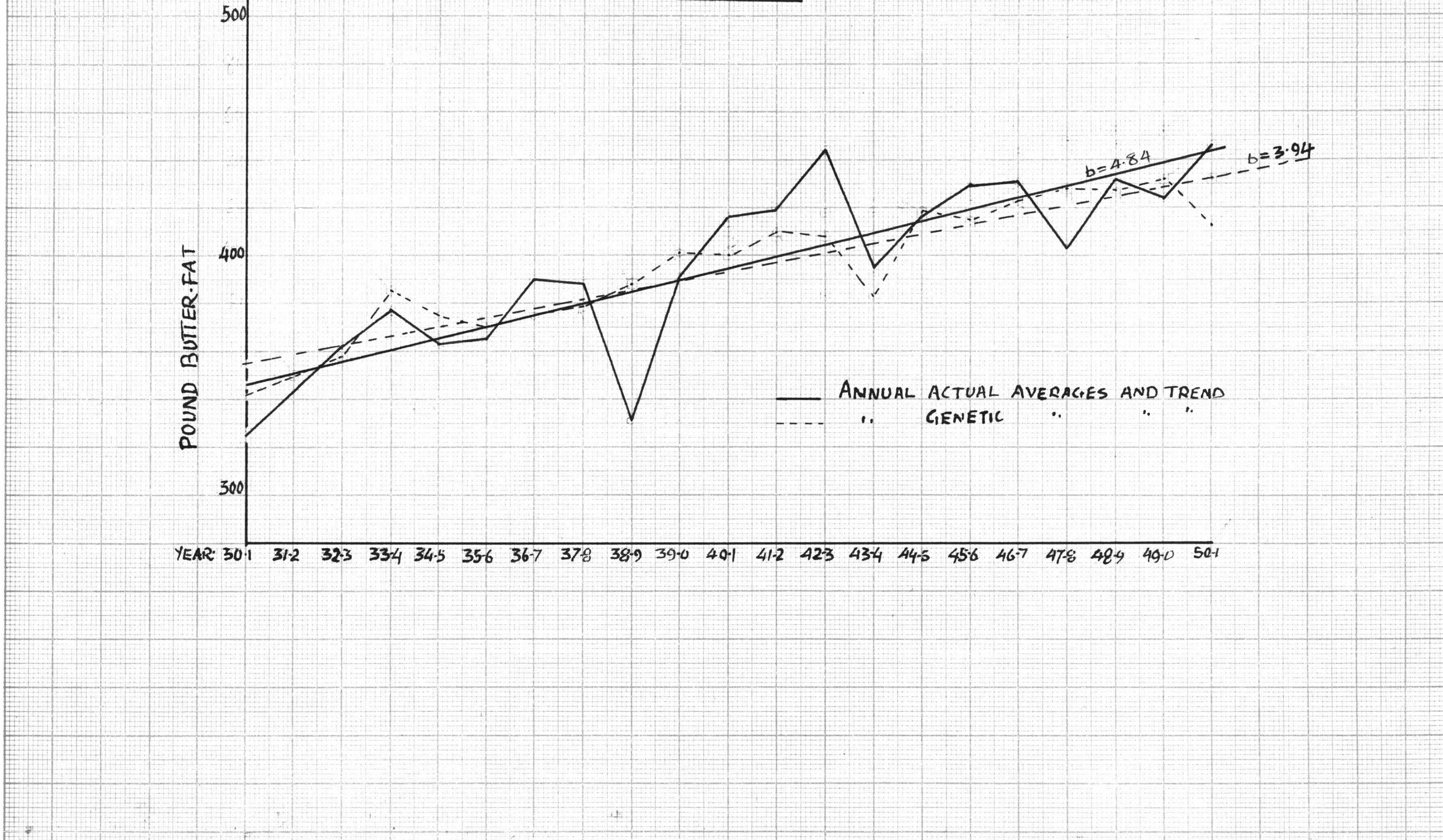
$$\frac{-597.46 + (-9.16)}{37.17} = -16.32.$$

Successive estimates were calculated until the last three in all columns were identical. These estimates are shown in Table 11.

Table 11. The environmental effects peculiar to cows freshening in each season.

a_i	-17.07	a_8	9.32	a_{15}	- 1.96
a_2	- 6.86	a_9	-57.03	a_{16}	14.04
a_3	4.07	a_{10}	-10.01	a_{17}	- 1.83
a_4	- 8.50	a_{11}	15.91	a_{18}	- 25.12
a_5	-12.08	a_{12}	8.87	a_{19}	4.83
a_6	- 4.53	a_{13}	35.70	a_{20}	- 8.40
a_7	14.91	a_{14}	12.18	a_{21}	33.56

FIGURE-3



500
400
300
POUND BUTTER-FAT
YEAR: 30-1 31-2 32-3 33-4 34-5 35-6 36-7 37-8 38-9 39-0 40-1 41-2 42-3 43-4 44-5 45-6 46-7 47-8 48-9 49-0 50-1
b=4.84
b=3.94
ANNUAL ACTUAL AVERAGES AND TREND
" GENETIC " " "

These represent the environmental effects peculiar to cows freshening in each year.

It was then possible to correct the animal records for year to year environmental effects. The results are given in Table 12.

Table 12. Annual Mature Equivalent and Genetic Averages.

Year.	Annual Mature Equivalent Average. x (Pound Butter Fat)	Annual Genetic Average (Pound Butter Fat)
1930-31	325	342
1931-32	343	350
1932-33	362	358
1933-34	377	385
1934-35	363	375
1935-36	365	370
1936-37	390	375
1937-38	388	379
1938-39	331	388
1939-40	391	401
1940-41	416	400
1941-42	419	410
1942-43	444	408
1943-44	395	383
1944-45	416	418
1945-46	429	415
1946-47	421	423
1947-48	403	428
1948-49	432	427
1949-50	424	432
1950-51	446	412

x Maturity Equivalents.

Fig. 3 shows the average butterfat production (corrected to mature age) and the genetic average for the herd during twenty-one years studied. The straight line trend of the actual records is upward at the rate of 4.8 pounds per year. The genetic component of this is 3.9 pounds, approximately 80% of the total improvement, was due to changes in heredity.

Fig 3 shows the regression lines of the actual and the genetic averages.

The amount of reliance which can be placed on this estimate is uncertain. Compared with the findings reported by Lush (1951b) the genetic improvements in the herd studied are large. The material studied was probably superior to that used in the Iowa analysis since it spread over about four cattle generations and the herd averaged approximately 100 cows in milk each year. The material difference is that all normal records between 100 and 305 days duration were included in the analysis whereas the study reported by Lush (ibid) dealt only with the first 180 days of each lactation. The way in which this difference would affect the respective analyses is not clear in view of the absence of repeatability figures for the first 180 days in the present study.

An average animal genetic gain of almost four pounds of butterfat per year over a twenty-one year period represents considerable genetic progress. It represents a genetic improvement of approximately 1% of the average yield per year. Rendel and Robertson (1950) state that the maximum possible rate of genetic improvement in milk yield in a closed herd would be of this order. These workers used a value of 0.25 for the heritability of milk yield based on one lactation. Since the repeatability of records in the herd studied was 0.44 it is possible, though this was not ascertained, that the heritability values for butter fat yield from single lactations was more than 0.25. Thus the maximum average animal genetic gains for butter fat yield may exceed 1% of the average yield per year. If such is the case then the results obtained would not appear unreasonable. There are several reasons for expecting considerable gains:

(a) Apart from two imported sires used, in the period reviewed the herd was closed. Thus the probable breeding value of the sires used could be predicted more accurately than if they were bought in because the management factor would be assessed.

(b) The intensity of selection could have been higher than that normally encountered in pedigree herds. In the first place relatively few sires were used extensively (see Fig. 9.) and they may have been selected from only the few outstanding dams in the herd, rather than the top 5% of the herd which is the usual assumption (Lush 1946 p.147). Secondly a relatively low proportion of the available heifers replacements entered the herd each year particularly in the late years studied (see Fig. 8.). This again would allow more intense selection to be practised although the added genetic contribution from this source is not likely to be large.

On the other hand the low replacement rate noted together with the gradual increase in herd size (see Fig. 7.) would be reflected in longer generation intervals and, since the genetic improvement per year is equal to the genetic selection differential divided by the mean generation length, the advantages accruing from the more intense selection may have been largely dissipated by the increased generation intervals.

(c) According to the breeder, very little emphasis has been placed on selecting for factors other than butterfat yield, e.g. type and butterfat percentage. Selection for these factors would have reduced the selection differential on yield.

The next problem is to find the source of this genetic improvement - whether it comes from dam selection or from sire selection. These problems are dealt with in the remainder of this study.

GENETIC CHANGES DUE TO DAM SELECTION.

In the previous section the total genetic gain in twentyone seasons has been found to be + 3.94 lbs. of butterfat per season. This may have been due partly or entirely to the selection of dams of replacements and in this section an attempt has been made to ascertain the proportion of the genetic gain the breeder has achieved through dam selection.

Importance of dam's level of butterfat production.

As far as possible New Zealand dairy farmers aim to have all the cows in their herd calving at twelve monthly intervals. Under normal circumstances the number of heifers born each year will exceed replacement requirement (N.Z. Dairy Board, 1943). This excess permits the breeder to exercise a choice and, if his aim is primarily to improve the level of butterfat production in his herd, as far as possible he will probably choose as his future breeding dams the offspring of those dams which in his opinion are most likely to transmit desirable hereditary factors for butterfat production. This necessarily involves estimating the breeding values of herd dams and if the effects of dam selection are significant, the care and accuracy with which such estimates are made and the use of them, should be reflected in the subsequent genetic merit of the herd as a whole, and the breeding value of the sires supplied to the industry.

The relative importance of the various aids to selection is fully discussed by Lush (1945) and, in view of the numerous practical difficulties, he concludes that in the use of female dairy cattle estimates of breeding value based on an animal's performance are likely to be most valuable. The reproductive capacity of cows rules out progeny testing as a widespread means of selecting the best breeding dams while selection of dams on pedigree rather than performance is less accurate by itself and should be used only as a preliminary estimate or as additional evidence to performance.

But the performance of an animal is essentially a phenotypic measure and makes no distinction between the genetic and environmental contributions which it comprises. Further, measures of performance are expressed as lactation yields and for any one animal these change from time to time. Hence the breeder must first decide upon the best estimate of phenotype and then appreciate that only a portion of the phenotypic differences between animals is passed from parent to offspring and reflected in the performance of the latter.

After due allowance has been made for age and known environmental effects, differences between the lactation yields of the same animal still exist (Rendel and Robertson, 1949). Since the breeding value of the animal does not alter, temporary or unnoticed changes in environment or errors in measuring yields, either or both working in a positive or negative direction, are of importance. Repeated measurements of the phenotype allow these temporary effects to cancel each other to some extent thus reducing the phenotypic variance. The heritability of the remaining phenotypic variance thus becomes higher. Lush (1948) states that where intra-herd "repeatability"* is about 0.4 selecting on two lactation records per dam would result in 1.2 times as much progress as selecting on one, three records about 1.29 times as much, four records 1.35 times as much and the limit would be 1.58 times as much even if all selection could be postponed until the cow had an indefinitely large number of records.

The importance of a succession of yields is well illustrated by Ward (1951). In the investigational work of the New Zealand Dairy Board the average performance of sires daughters were found to vary appreciably with the performance details of the sire's dam. 63 sons of Lifetime Merit Register cows (2,500 lbs. of butterfat during a period of not more than 8 years) left daughters averaging 11 lbs of butterfat above the expected and 207 sons of cows with single records of over 600 lbs. of butterfat left daughters averaging 4 lbs. above the expected level. Thus the sons of dams producing on the average between 300 and 400 lbs. of butterfat in each of eight seasons efforted almost thrice as much progress in level of fat production as did the sons of dams with a single record exceeding 600 lbs. of butterfat.

Within herds, the breeding values of the dams are essentially comparative. A breeder relying on home-bred stock for replacements is concerned in distinguishing the relative genotypes of the dams comprising his current herd. If numbers are to be maintained, some heifers must be brought into the herd each year. Making the decisions as to which of the young stock enters the herd is, therefore, a more or less continuous process and since it must be related to the merit of the available heifers,

* See Appendix I.

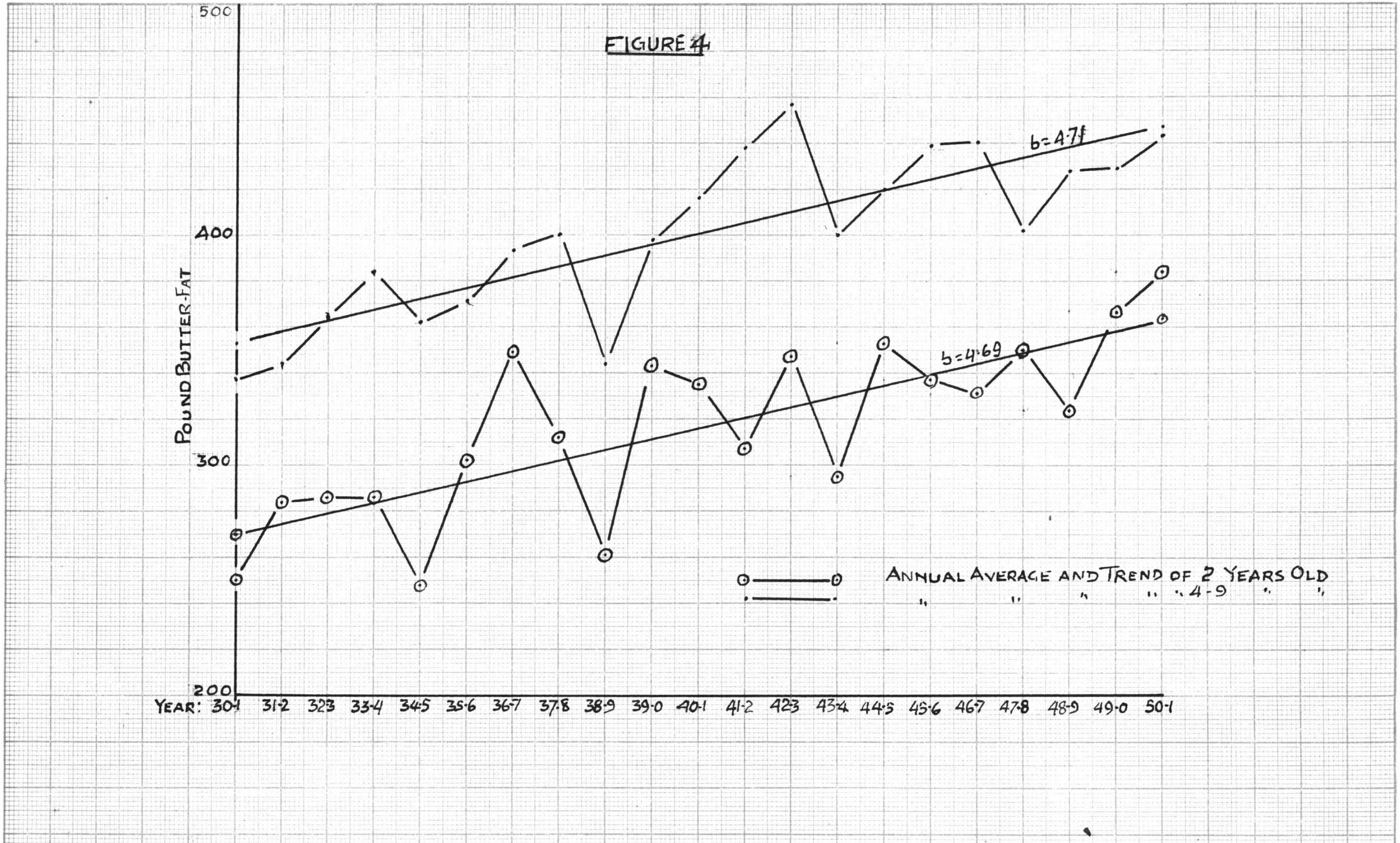


FIGURE 4
POUND BUTTER-FAT
500
400
300
200
b=4·71
b=4·69
ANNUAL AVERAGE AND TREND OF 2 YEARS OLD
" " " " 4-9 " "
YEAR: 30-1 31-2 32-3 33-4 34-5 35-6 36-7 37-8 38-9 39-0 40-1 41-2 42-3 43-4 44-5 45-6 46-7 47-8 48-9 49-0 50-1

changing from time to time as the standard alters. If preference is shown for the progeny of high producing dams, high production relates to the average production of the herd when the records were made. Since herd averages vary from year to year individual productions must be related to them. For example, the progeny of an animal producing on the average 400 lbs. of butterfat each lactation when the herd average is 350 lbs. merits more attention than the progeny of a 400 lbs. cow in the same herd when the average production has risen to 375 lbs.

The necessity for eliminating changing standards of production in the herd under study is clear from Table 2. and Figure 2. in which are shown the annual averages of normal lactations production during the first 305 days of a lactation and for cows in milk for at least 100 days for 2 years, 3 years and 4 - 9 years respectively. Considerable year to year variations are apparent in Figure 4. but there is a distinct upward trend in production levels. There is an upward trend of + 4.69 lbs. per year for 2 year old and + 4.71 for the mature animals. Since the average productivity of recorded cows in New Zealand has risen only 30 - 40 lbs during the period 1930-50 (New Zealand Dairy Board, 1951), the enormously increased productivity of the herd under study, may in a large measure reflect genetic improvements as well as better herd management and improved levels of feeding. However, an examination of Figure 4. in which the 2 year old and mature cow annual averages are shown reveals that the two averages though in general moving together, do not invariably do so. One would anticipate that if the genetic merit of the stock was uniform from year to year then seasonal conditions would affect the productions of the two age groups in a similar manner though not necessarily to the same extent. That such is not the case suggests that the genetic merit of the replacement stock may vary from year to year. For example, during two periods, first between 1939-40 and 1942-43, and secondly between 1944-45 and 1947-48, there is a decrease in production of the 2 year-old group whereas the production of the mature cows shows an upward trend. An attempt has been made to determine whether these differences could be reflected to the selection practised by the breeder concerned.

In view of these findings an attempt has been made to eliminate changing standards of production by calculating for all animals the differences between their individual lactations (Not less than 100 days and not exceeding 305 days duration) and the average yield of all cows in the same calving group in the same year. This method of assessing the relative producing ability of animals was adopted because it resembled the methods probably employed by the breeder. In making comparisons between contemporary cows which were potential dams of replacement stock the breeder would normally interpret performance records in the light of the general herd production in the particular year.. Individual deviations have been calculated and the resultant figure used as an estimate of the producing ability of the dam. An example of this calculation follows:

Lactation.	Age Yrs.mths.	Individual Production. (in pound butterfat)	Average for animals of similar age. (in pound butterfat)	Deviation (in pound butterfat)
1	1 - 11	246	295 (2)*	- 49
2	3 - 0	316	388 (3)	- 72
3	3 - 11	419	435 (4-9)	- 16
4	4 - 11	482	440 (4-9)	+ 42
5	6 - 0	428	403 (4-9)	+ 25
6	7 - 0	406	429 (4-9)	- 23

(Production records based on lactation records of between 100 and 305 days duration).

Sum of deviations in six generations - 95 lbs.

The productive capacity is therefore estimated at -16 lbs. below the herd average based on six lactations.

* Within brackets 2, 3 and 4-9 year-old averages in the same year.

The herd averages for different lactation groups are shown along with the numbers of observations in Table 2. Use of this table in conjunction with individual lactations enabled estimated productive capacities for all of the animals which entered the herd and completed at least one lactation to be calculated. But estimates of productive capacity do not provide an exact measure of transmitting ability. Only some of the difference between individual productions is genetic in origin and offspring only receive a sample half of their dam's genotypes. The only available estimate of the average genetic fraction of the difference between an animal's betterfat production and the herd average under New Zealand conditions is in between 30 to 40 per cent. (Ward, 1944). This figure is in accordance with overseas workers, Plumb (1935), Lush (1940) and Lush and Strauss (1942). It means that if cows exceeding the herd average by 100 lbs. butterfat are mated to sires which are the average of their generation, their daughters will on the average exceed the herd average by 15 to 20 lbs. butterfat. Further the reliability of estimates of productive capacity and therefore of breeding worth increases with the number of recorded lactations (Lush,1945; Berry, 1945). It is thus necessary to weight estimates of productive capacity according to the number of lactations upon which they are based.

With these considerations in mind it was decided to use the methods described by Lush (1945) and to multiply the estimates of the productive capacity by the factors shown in Table 13, so that the resultant estimated breeding-worths would be comparable. Since each dam only passes on a half of her superiority to each daughter, each factor is divided by 2 to give an index of the dam's transmitting ability. For example an animal with a first lactation of 300 lbs. butterfat during a year in which the average of all first lactations was 320 lbs. butterfat would have an esimated breeding value of - 20 x 0.075 or - 0.015 lb. In other words, if this dam was mated to a sire only maintaining the herd average, on the average her progeny would have a genetic capacity - 0.015 lbs. less than the herd average (see Appendix I - "Repeatability").

Table 13. Factors used to convert estimates of producing ability to estimates of transmitting ability.

No. of lactation records.	Heretability.	Factor.
Single records	0.1500	0.075
Average of two records.	0.2500	0.125
" " three "	0.3214	0.161
" " four "	0.3750	0.188
" " five "	0.4167	0.208
" " six "	0.4500	0.225
" " seven "	0.4773	0.239
" " eight "	0.5000	0.250
" " nine "	0.5193	0.260
" " ten "	0.5357	0.268

Estimates of the breeding values of all the animals to complete at least one lactation in the herd have been calculated to the end of each lactation. Thus for any specified date it was possible to calculate the estimated breeding values of all herd dams, the dams of registrations and the dams of replacement heifers. An estimate of the emphasis placed on dam selection was then possible from a comparison of the breeding values of the dams of heifer registrations and the dams of herd replacements when the young stock were yearlings. This was the age at which surplus heifers were usually sold and if the breeder was interested in their dams' productions it is reasonable to assume that all the information available about the dams would be considered.

The average yield of all the cows in milk in a particular year gives an estimate of the average breeding value of herd dams in that particular season. Individual differences from the annual group estimate arranged into convenient classes and are shown in Table 14. Percentage distributions have also been included together with the percentage of registrations used as replacements within each group.

Table 14. Distribution of all heifers registered and of heifers entering the herd according to the estimated breeding value of their dams when the heifers were one year of age.

Estimated breeding value of dams (lbs)	Distribution of heifers.		Percentage of registration to entering herd.	
	Registration.	Herd entry.		
20 and over	9 (1.34)	4 (1.42)	44.44	48.25
15 - 19	19 (2.82)	9 (3.19)	47.37	
10 - 14	44 (6.53)	26 (9.22)	59.09	
5 - 9	99 (14.69)	47 (16.67)	47.47	
0 - 4	144 (21.36	66 (23.40)	45.83	
	413 (46.74)	152 (53.90)		
0 - -4	194 (28.78)	75 (26.59)	38.66	36.21
-5 - -9	103 (15.28)	30 (10.64)	29.13	
-10 - -14	41 (6.08)	16 (5.67)	39.02	
-15 - -19	15 (2.22)	7 (2.48)	46.67	
-20 and over	6 (0.98)	2 (0.71)	33.33	
	356 (53.26)	130 (46.10)		

(Percentage distribution in brackets)

It is clear that during the 18 years for which complete information could be extracted little preference has been shown for the progeny of dams above average in estimated breeding value. In Table 14 it may be seen that 46.74% of the heifers registered were out of dams which were above the average estimated value of the herd and 53.26% were from dams below the average estimated breeding value of the herd one year after that in which the heifer was born. Out of the total 282 heifer replacements during 21 years studied, 152 (53.90%) were from dams which were above the average estimated breeding values of the herd in the year following that in which the heifers were born. Thus the improvement due to dam selection is likely to be small if not negligible even though the breeder has practised some selection based on the performance of the dams between the registration and subsequent herd entry of potential replacements.

To determine whether any improvement was effected, a comparison of the annual mean estimated breeding values of the dams of registered heifer calves was made with the dams of replacement heifers (Table 15, Columns 1 and 2). In column 3 of the same table are included the mean estimated breeding values of the best available dams of registered heifers in the herd in the same year, the number of these dams equalling the number of herd replacements.

These means indicate the maximum genetic gains from dam selection assuming selection was perfect and that all the registrations were available to enter the herd if required. Since the daughters of some of the best dams probably died or were disposed of between registration and the age of normal first calving or failed to get in calf, these estimates of maximum gain are probably over-estimated but the error is likely to be small.

Table 15. The annual mean estimated breeding values of dams of registered heifers, the dams of replacements and the best available dams of heifer registrations (estimated when the daughters were one year of age.)

Year.	Dams of registered heifers.		Dams of replacements		Best available dams.	
	No.	Mean estimated breeding value.	No.	Mean estimated breeding value.	No.	Mean estimated breeding value.
1930-31	20	-0.12	12	+0.01		
1931-32	23	+2.22	13	+3.69	13	+7.35
1932-33	24	-0.19	3	-0.45	3	+15.84
1933-34	27	+2.92	21	+3.56	21	+6.04
1934-35	26	+2.98	21	+3.26	21	+5.00
1935-36	20	+2.58	14	+3.94	14	+5.20
1936-37	30	+2.34	23	+0.74	23	+5.32
1937-38	16	+3.37	15	+3.65	15	+4.84
1938-39	39	+3.13	14	+3.90	14	+9.12
1939-40	36	+2.98	15	+2.37	15	+9.61
1940-41	38	+3.70	10	+5.11	10	+13.79
1941-42	45	+2.36	18	+3.04	18	+9.33
1942-43	43	+2.26	10	+8.54	10	+11.93
1943-44	31	-0.42	23	-0.45	23	+3.21
1944-45	34	+2.59	15	-0.57	15	+9.68
1945-46	47	+1.97	13	+3.10	13	+13.30
1946-47	39	+0.91	15	+1.78	15	+9.15
1947-48	40	+1.45	14	+7.42	14	+9.95
1948-49	44	+1.91	13	+10.34	13	+13.59
1949-50	51	+1.04				
1950-51	1	-11.44				
Total 1931-32 to 1948-49.	602	+1294.78	270	+884.65	270	+2191.20
Average		+2.15		+3.28		+8.11

The means for the dams of registered heifers have been extracted because, in the absence of complete wastage information, details of these dams provide the closest description of the breeding material with which the breeder worked. Heifer calves which were not registered were probably aborted, born dead or died within a month of birth and did not come within the scope of the breeder's selective powers. Further, by considering

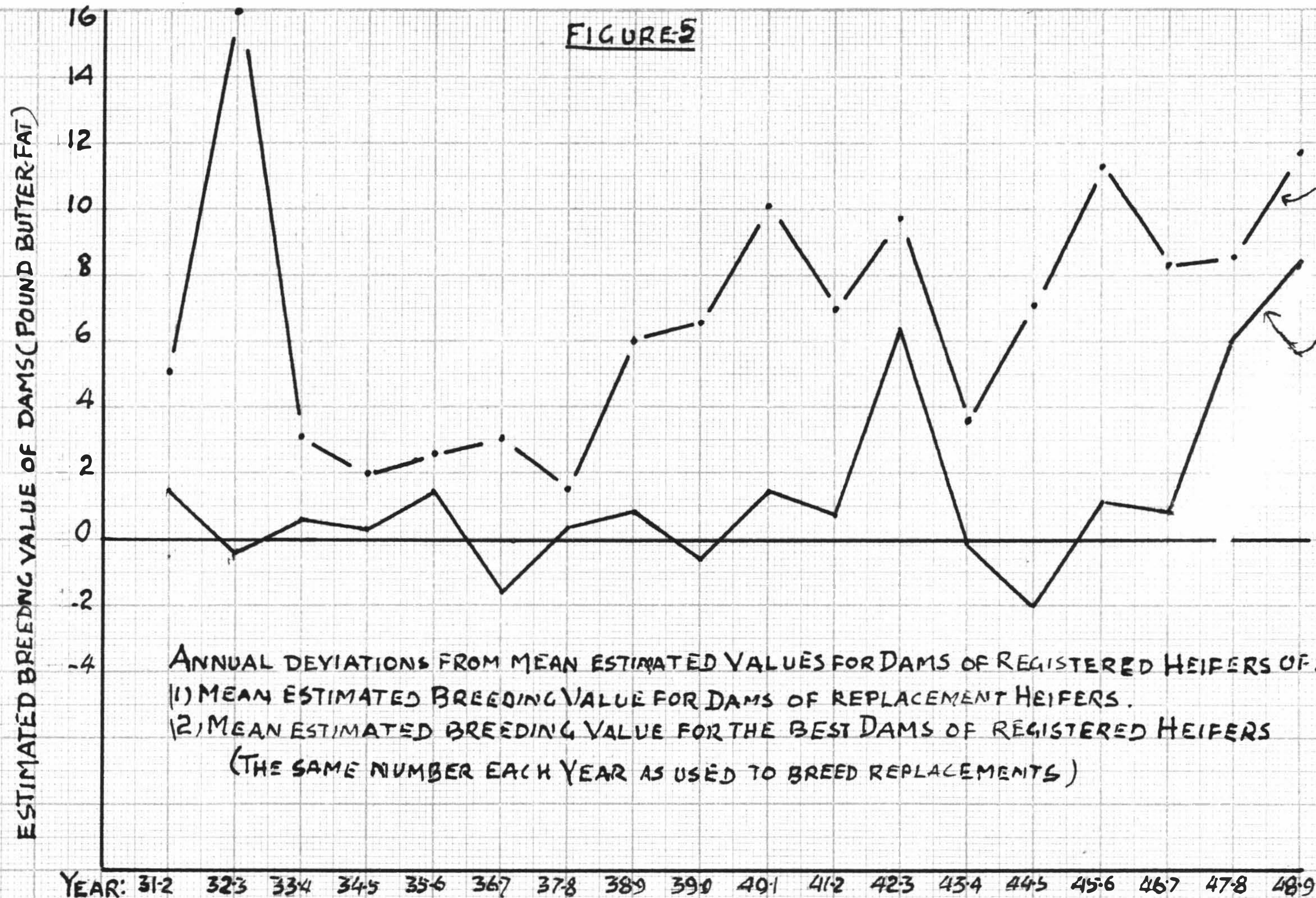


FIGURE 5
ESTIMATED BREEDING VALUE OF DAMS (POUND BUTTER-FAT)
16
14
12
10
8
6
4
2
0
-2
-4
2.
1.
ANNUAL DEVIATIONS FROM MEAN ESTIMATED VALUES FOR DAMS OF REGISTERED HEIFERS OF:
(1) MEAN ESTIMATED BREEDING VALUE FOR DAMS OF REPLACEMENT HEIFERS.
(2) MEAN ESTIMATED BREEDING VALUE FOR THE BEST DAMS OF REGISTERED HEIFERS
(THE SAME NUMBER EACH YEAR AS USED TO BREED REPLACEMENTS)
YEAR: 31-2 32-3 33-4 34-5 35-6 36-7 37-8 38-9 39-0 40-1 41-2 42-3 43-4 44-5 45-6 46-7 47-8 48-9

only dams of heifers, allowance is made for the confusing effects of aberrant sex ratios.

For these reasons the data in Table 15 have been shown in Figure .5. with the annual mean in column 1 plotted as zero and the differences between the means in columns 2 and 1 and between columns 3 and 1 shown. It is clear from Figure that some dam selection has been practised but also that the selection has been far from perfect as far as butterfat production is concerned. In five separate years the mean of the estimated breeding values of the dams of replacement heifers was below that of all dams of heifer registrations. In other words, in these years dam selection had a negative effect.

The total effect of dam selection is shown in Table 15. The dams of the 270 replacements averaged 1.125 lbs. estimated value better than the dams of the 602 heifers registered during the 18 year period. This is equivalent to an average gain of 0.0625 lbs. in estimated breeding value per annum.

If the dam selection had been perfect the maximum genetic gains possible from dam selection would have been (8.11 + 2.15) = 10.26 lbs. in 18 years or 0.57 lbs. per year. The breeder has thus made about one ninth of the genetic improvement theoretically possible by dam selection.

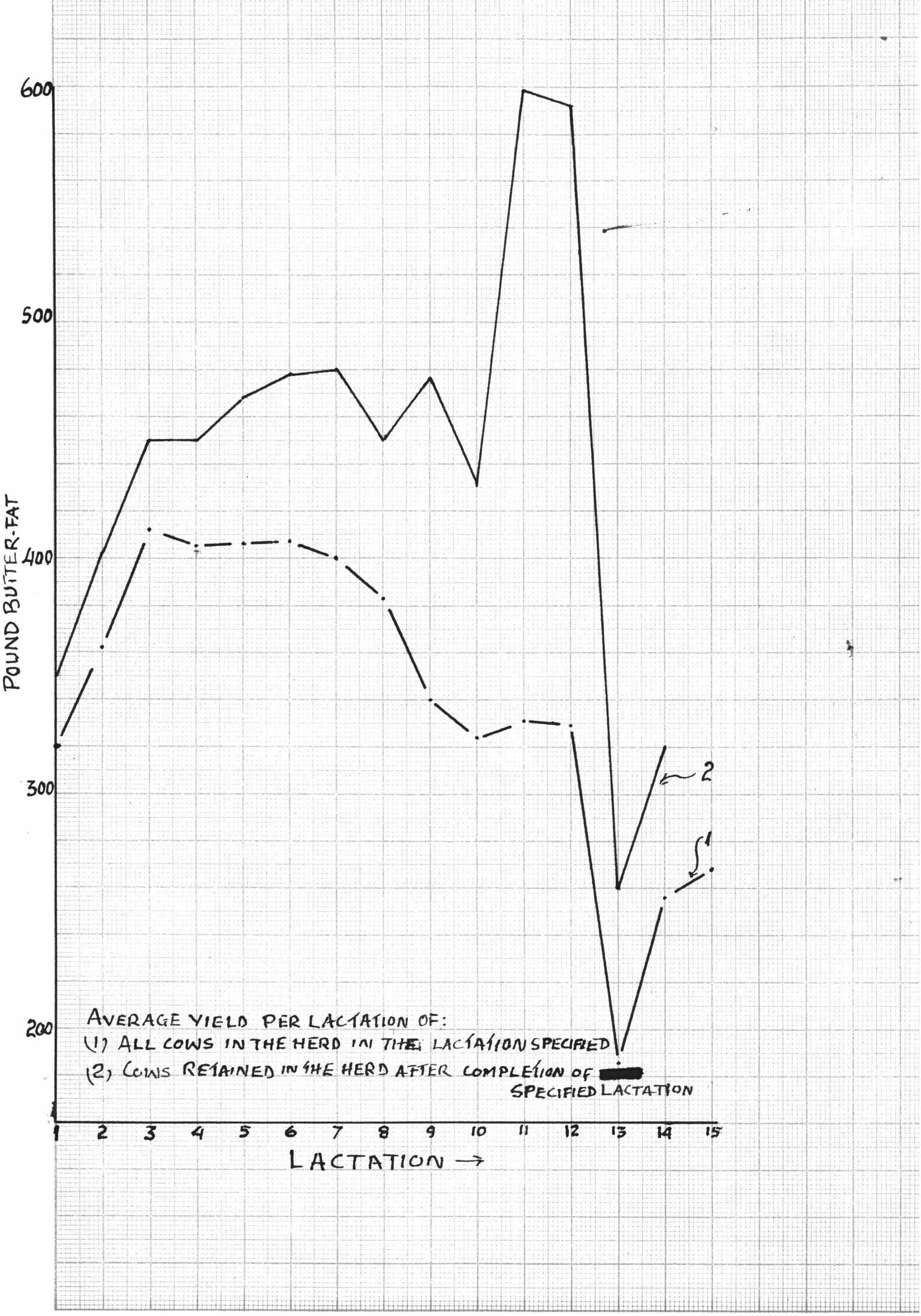
The measure of possible gain of 0.57 lbs. per year closely approximates the estimated gain possible through dam selection demonstrated by Hamilton (1943). Using data collected from recorded herds by the Herd Improvement Associations he calculated that the average annual gain in typical New Zealand breeds could be in thevicinity of 0.61lbs. of betterfat per year.

The problem now is one of establishing whether such faulty dam selection was due to circumstances over which the breeder had no control, failure to appreciate the value of lactation records as estimates of the breeding worth of the dams of replacement stock or to preference for choosing replacements from good sires rather than concerning himself unduly with their dams.

Amount and method of culling practised.

Table 16 and Figure.6. show the averages of all first, second, etc. lactations and those of them pertaining to dams retained in the herd, at the completion of the lactation in question. The figures in brackets indicate the number of animals concerned and show that the breeder did not cull at a specific stage. The lactation averages indicate that culling for low production was carried out continuously. During the early lactations there were differences of 30-40 lbs.

FIGURE-6


600
500
400
300
200
POUND BUTTER-FAT
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
LACTATION →
2
1
AVERAGE YIELD PER LACTATION OF:
(1) ALL COWS IN THE HERD IN THE LACTATION SPECIFIED
(2) COWS RETAINED IN THE HERD AFTER COMPLETION OF [redacted] SPECIFIED LACTATION

of butterfat between all animals and those retained in the herd. This difference becomes larger in later lactations and is strongly suggestive of young cows being given more lattitude than older dams.

Table 16. The average of all 1st, 2nd etc. lactations and the average of dams retained for at least one more year in the herd.

Lactation	Total herd average yield for the lactation. (Pound butter-fat)		Average yield of the dams retained in the herd after completion of lactation. (Pound butter-fat)	
1st	320	(294)	350	(269)
2nd	362	(278)	402	(250)
3rd	412	(260)	450	(238)
4th	405	(227)	450	(204)
5th	406	(196)	468	(170)
6th	407	(154)	478	(131)
7th	400	(120)	480	(100)
8th	383	(94)	450	(80)
9th	340	(77)	476	(55)
10th	324	(52)	432	(39)
11th	331	(38)	598	(21)
12th	329	(18)	592	(10)
13th	186	(7)	260	(5)
14th	256	(5)	320	(4)
15th	268	(3)	-	-

(Figures within the brackets show the total number of lactations in each group.)

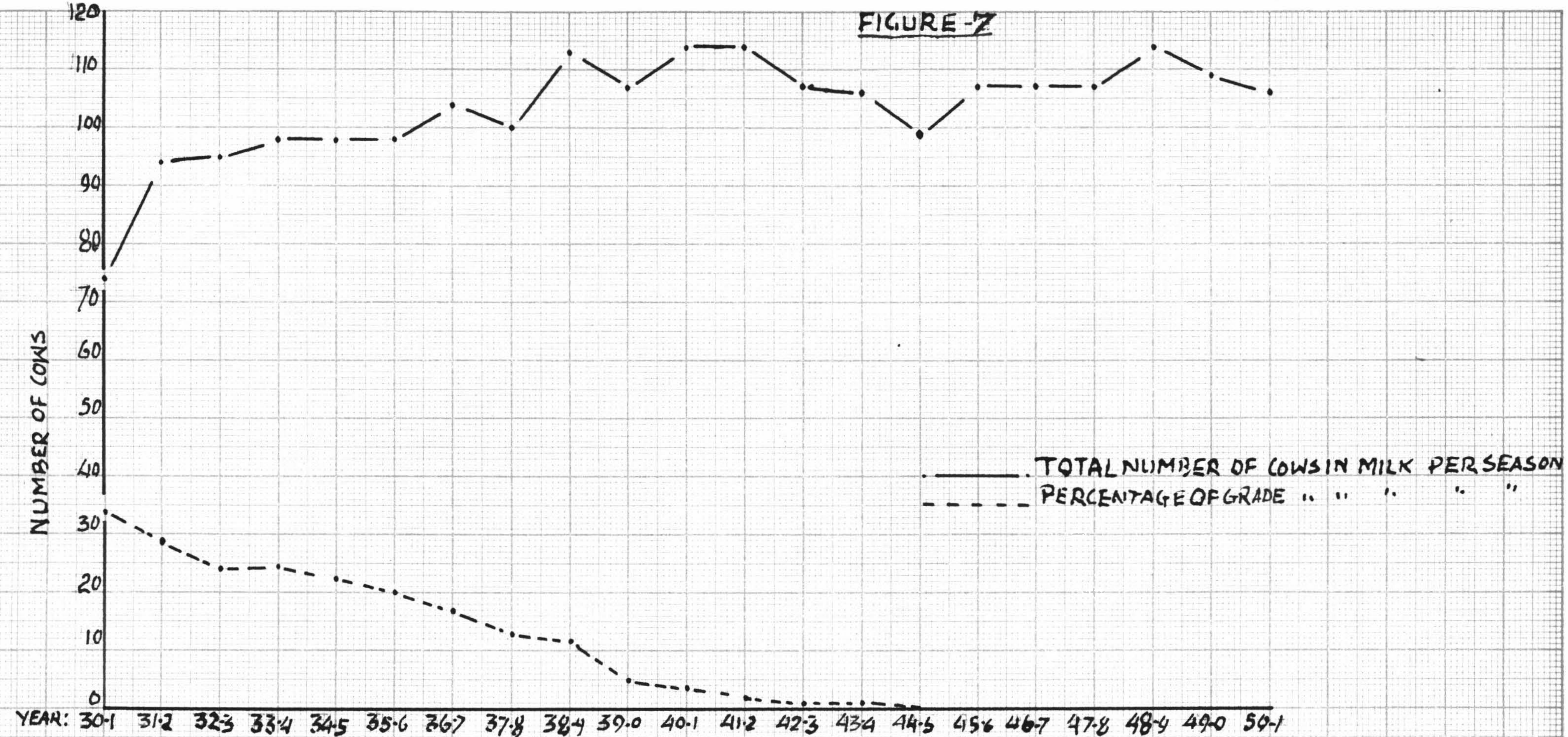
The amount of information available about dams of heifers for replacements.

In Table 17, the 282 replacements have been classified according to the number of complete maternal lactation records available at their birth and herd entry.

Table 17. Distribution of 282 replacement heifers according to the number of complete lactation records available for their dams.

No. of completed lactation records of dams.	Distribution of heifers according to completed lactation record of their dams. At birth			At herd entry.		
0	54	19.15%	43.26%	-	-	17.38
1	32	11.35%		4	1.42%	
2	36	12.77%		45	15.96%	
3	43	15.25%	56.74%	40	14.18%	82.62%
4	33	11.70%		42	14.89%	
5	19	6.74%		44	15.60%	
6 and over	65	23.05%		107	37.94%	
Total	282	100.00%		208	100.00%	

FIGURE-7



NUMBER OF COWS
120
110
100
90
80
70
60
50
40
30
20
10
0
YEAR: 30-1 31-2 32-3 33-4 34-5 35-6 36-7 37-8 38-4 39-0 40-1 41-2 42-3 43-4 44-5 45-6 46-7 47-8 48-9 49-0 50-1
TOTAL NUMBER OF COWS IN MILK PER SEASON
PERCENTAGE OF GRADE " " " " "

Table 18. The annual total number of cows in milk, grade cows in milk, registration of heifers, replacements and percentage of registrations to replacements.

Year.	Total no. of cows in milk in the herd during the year.	Total no. of grade cows in milk.	Total no. of heifers registered.	Total no. of registered heifers entering the herd.	Percentage of registrations to replacements.		
1930-31	74	25 (33.78%)	20	12	60.00	52.13	50.72
1931-32	94	27 (28.72%)	23	13	56.52		
1932-33	95	23 (24.21%)	24	3	12.50		
1933-34	98	24(24.49%)	27	21	77.78		
1934-35	98	22 (22.45%)	26	21	80.77	67.19	
1935-36	98	20 (20.41%)	20	14	70.00		
1936-37	104	18 (17.34%)	30	23	76.67		
1937-38	100	13 (13.00%)	16	15	93.75		
1938-39	113	13 (11.50%)	39	14	35.89		
1939-40	107	5 (4.67%)	36	15	41.67	38.34	
1940-41	114	4 (3.51%)	38	10	26.32		
1941-42	114	2 (1.75%)	45	18	40.00		
1942-43	107	1 (0.93%)	43	10	23.26		
1943-44	106	1 (0.94%)	31	23	74.19		
1944-45	99		34	15	44.12	33.65	27.34
1945-46	107		47	13	27.66		
1946-47	107		39	15	38.46		
1947-48	107		40	14	35.00		
1948-49	114		44	13	29.55		
1949-50	109		51	-			
1950-51	106		1	-			

Table 19. Distribution of registration and herd replacements of heifers born between 1930-31 and 1943-44, according to the estimated breeding worth of their dams.

Estimated breeding worth of dams (Pound butter-fat)	Distribution of heifers.				Percentage of registrations to enter herd.	
	Registration.		Herd entry.			
20 and over	9	264	5	149	55.56	56.44
15 - 19	19		11		57.89	
10 - 14	33		18		54.55	
5 - 9	78		49		62.82	
0 - 4	125		66		52.80	
0 - -4	88	154	34	63	38.64	40.91
- 5 - -9	47		18		38.30	
-10 - -14	13		7		53.85	
-15 - -19	6		4		66.67	
-20 and over	-		-			
Total	418		212		50.71	

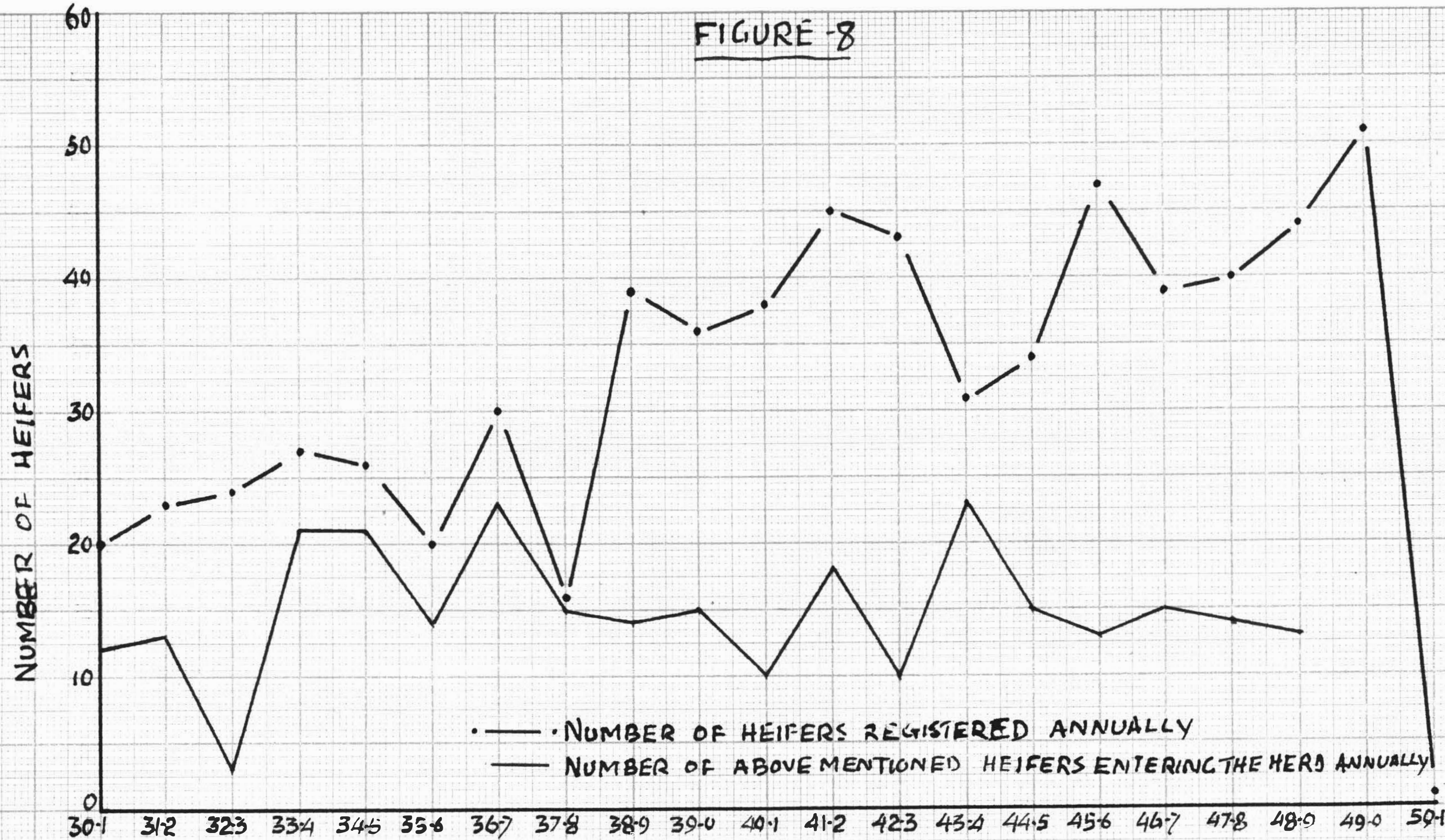


FIGURE - 8
NUMBER OF HEIFERS
60
50
40
30
20
10
0
30-1
31-2
32-3
33-4
34-5
35-6
36-7
37-8
38-9
39-0
40-1
41-2
42-3
43-4
44-5
45-6
46-7
47-8
48-9
49-0
50-1
NUMBER OF HEIFERS REGISTERED ANNUALLY
NUMBER OF ABOVEMENTIONED HEIFERS ENTERING THE HERD ANNUALLY

For 43.26% of the replacements there were less than three records of the dams available when their daughters were born. There is, however, a marked improvement by the time the replacements enter the herd. For 82.62% of the replacement heifers there were at least three maternal records available at the time the replacements entered the herd.

These findings indicate that ample information concerning the performance of dams was available when the replacement heifers entered the herd. The failure of the breeder to select consistently the daughters of dams which exceeded the herd average by the greatest amounts (see p.27) indicates that failure to select on dam performance was not due to lack of information about their producing ability.

Changes in Herd Size and Composition.

Mention has already been made of the alteration in herd size and composition (see p.2). It would be expected that selection among the pedigree heifers would not be so rigorous when there were grade animals in the herd as from the 1943-44 season when the herd consisted entirely of pedigree animals. Table 18 shows that during 1930-31 to 1943-44, the percentage of registered heifers which ultimately entered the herd averaged 50.72% and during 1944-45 to 1950-51 the comparable figures were 27.34%. Figure 7 shows that with the change in the herd from mixed to pedigree stock, there is also a gradual increase in the herd size. Figure 8 when compared with Figure 7 shows that the number of replacements becomes relatively smaller as the total number of registrations increases.

Tables 19 and 20 provide a comparison between the dam selection practised during these two contrasting periods. All heifers have been grouped according to the estimated breeding value of their dams at two separate periods. The number of registrations and herd replacements in each group is shown along with the percentage of registrations which entered the herd. During the two periods the amount of dam selection practised differed to some extent. During each interval some preference was shown for the daughters of high producing dams but it was not marked. There was ample scope for all replacements to be saved from above average dams but this was not taken advantage of. In Table 19 the relatively high percentage of registrations used for replacements during the seasons 1930-31 to 1943-44 is reflected. During this period one of the breeder's aims was probably to change the composition of the herd from mixed to pedigree and also to increase the total number of stock in the herd.

Table 20. Distribution of registration and herd replacements of heifers born between 1944-45 and 1950-51, according to the estimated breeding worth of their dams.

Estimated breeding worth of dams (Pound butter -fat).	Distribution of heifers.				Percentage of registrations to enter herd.	
	Registration.		Herd entry.			
20 and over	9	148	5	47	55.56	31.76
15 - 19	10		4		40.00	
10 - 14	23		11		47.83	
5 - 9	47		15		31.91	
0 - 4	59		12		20.34	
0 - -4	50	108	12	23	24.00	21.30
- 5 - -9	35		5		14.29	
-10 - -14	17		5		29.41	
-15 - -19	5		1		16.67	
-20 and over	1		-			
Total	256		70		27.34	

In Table 20 a rather different picture obtains. The low percentage of registrations used for replacements is noticable. Further, replacements among the registered daughters of well above average dams (estimated breeding worth of five or more pounds of butterfat above the herd average) were generally preferred in the period 1944-45 to 1950-51.

From these findings it is clear that unless the herd history is divided into certain periods a confusing picture results. Though dam selection as such has contributed little to the overall improvement of the herd it appears to have become more important during the later years studied (see Tables 19 and 20 and Figure 8.). Whether this is the result of the lower replacement needs during the period 1944-45 to 1950-51 is to a greater appreciation of the gains possible through dam selection is not clear.

GENETIC CHANGES DUE TO SIRE SELECTION.

Had dam selection in the herd studied been perfect the average annual gains from this source would have been of the order of 0.6 lb. per year. The breeder has, however, made only 0.063 lb. per year from dam selection or about a month of the genetic progress theoretically possible by this method. Since there was an average annual genetic gain of 3.94 lbs. per year clearly some other source of genetic improvement was of major importance. The large gains may have resulted from the non-additive effects of genes - the building up and maintenance of desirable conbinations of genes - or from the accummulation of desirable genes acting in an additive fashion. The first alternative may be of some importance since the herd was almost entirely closed and pedigrees appeared to follow regular patterns in many instances. However, the printed studies so far conducted on the effects of mild line-breeding (Lush 1951a) suggest that epistatic effects are not likely to have effects large enough to be responsible for the gains recorded. If it is assumed that these gains are due to additively acting genes then clearly the gains made must be due to the sires used. For this reason a study of the methods of the selection employed by the breeder has been made.

The selection of sires of replacement stock.

Though it is at present impossible to distinguish between the numerous genes concerned with the large number of characters which, in combination, result in high yielding cattle, it is essential that some estimate be made of the genotypes of the animals from which parents are to be selected if genetic progress within a herd is to be made. Though pedigree and performance may give estimates of breeding value, the most accurate evaluation of individuals is obtained from a study of way in which animals breed - by discovering their relative merits in transmitting favourable genes to their progeny. Since no measure of performance in respect of butterfat production is possible in males, pedigree selection and progeny testing is of major importance in the correct choice and extended use of sires.

Obviously a breeder who is basing his programme of herd improvement on the widespread use of sires which, by the performance of their sample offspring, have proved themselves to be well above the genetic level of the breed, will endeavour to select his young sires for test-matings as carefully as possible. Considering only production aspects, the best criteria appear to be those presented by Ward (1951) who has analysed the performance of a number of categories of sires in New Zealand herds. He found that:-

18 sons of Merit sires out of Elite Lifetime Merit cows sired daughters averaging 18 lbs. of butterfat above expected level.

63 sons of Merit sires out of Lifetime Merit cows sired daughters averaging 11 lbs of butterfat above expected level.

34 sons of Elite Lifetime Merit cows sired daughters averaging 12 lbs. of butterfat above expected level.

158 sons of Lifetime Merit cows sired daughters averaging 7 lbs. of butterfat above expected level.

207 sons of cows with single records over 600 lbs. of butterfat sired daughters averaging 4 lbs. of butterfat above expected level.

478 sons of cows with single records of between 400 to 600 lbs. of butterfat sired daughters averaging 2 lbs. of butterfat above expected level.

136 sons of cows with single records below 400 lbs. of butterfat sired daughters averaging 4lbs. of butterfat below expected level.

205 sons of Merit sires sired daughters averaging 7 lbs. of butterfat above expected level.

60 sons of sires with survey result 20 lbs. of butterfat below average sired daughters averaging 8 lbs. of butterfat below expected level.

It must be remembered that the expected level of production is not constant for all sire categories. Owners of poor-producing herds will usually buy a bull of inferior quality to that sought or purchased by the owners of high-producing herds and Ward's (1950) use of an expectancy table is a practical method of demonstrating how much better or how much worse are the results of any particular survey when studied in comparison with the results of all bulls used in herds of the same pr oduction standard. Ward's data are supported by the results obtained in the dairy cattle breeding project at Beltsville, U.S.A., which produce an excellent example of the way in which the element of chance may be reduced in sire selection. About twenty-one percent of the bulls selected by usual criteria for service in dairy herds sire daughters which exceed the production of their dams (Ward 1949).

The Beltsville results show that "selection for herd duty of young bulls that are sons of bulls definitely proven to be meritorious, and have dams and other female ancestors all by meritorious sires would ensure, with some certainty, that the untried bulls have germplasm likely to give rise to high production" (Kelley, 1946). Young sires were leased for service in commercial herds near Bettsville and, despite the fact that these were high producing herds, in 1946 the daughters of 65 of the 85 Holstein sires and 59 of the 71 Jersey sires exceeded in milk yield and butterfat content the production of their dams (New Zealand Dairy Board Report, 1946). The chance of obtaining a young sire whose daughters will exceed the production of their dams have been increased to 76% and 83% respectively for the two breeds used in the project.

In view of the inaccurate dam selection practised (see Section I.) despite which there appeared to be a steady upward trend in production levels during the period under study, it is of interest to examine the quality of the sires used within the pedigree herd under study, will give an indication of the extent to which the breeder appreciated the methods of stock improvement based on modern genetic concepts.

Importance of progeny testing in the herd.

The apparent lack of connection between an animal's breeding value and its phenotype has led many writers on animal breeding to advocate more complicated methods for judging genotype. The most popular of these at the moment is the progeny test. This is particularly true in dairy cattle in which only the cow can be judged on her phenotype and the bull must be assessed on his pedigree or his progeny test. Prentice (1935), has ably presented the argument for progeny testing. It is reinforced by arguments, largely of a qualitative kind, as to the inefficiency of phenotypic selection, based on the apparent lack of improvement in performance in the past when such selection was the main constructive breeding method used. It can be shown that selection within a closed herd of about 100 cows should, if practised in the optimum manner, leads to an increase in 305 days milk yield of 1.0% per annum, but that the maximum probable improvement in most pedigree herds in Great Britain is around 0.6% per year (Rendel and Robertson, 1950).

The main argument for progeny testing has been that, whereas an animal's own performance measures its phenotype, the performance of its offspring measures its genotype. Lush (1935) in discussing this, points out that there is a minimum number of daughters required from a dam before her genotype is as well

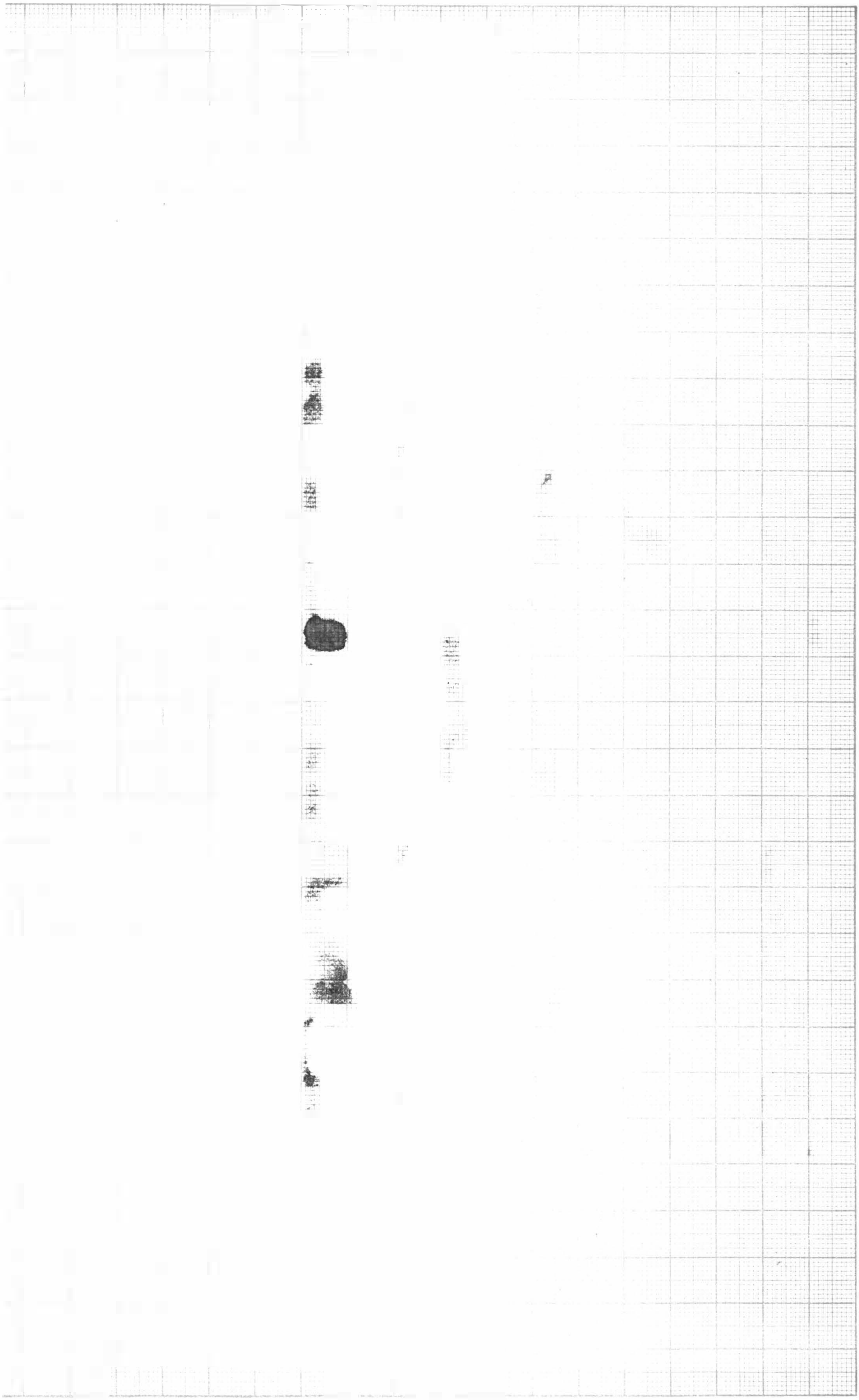
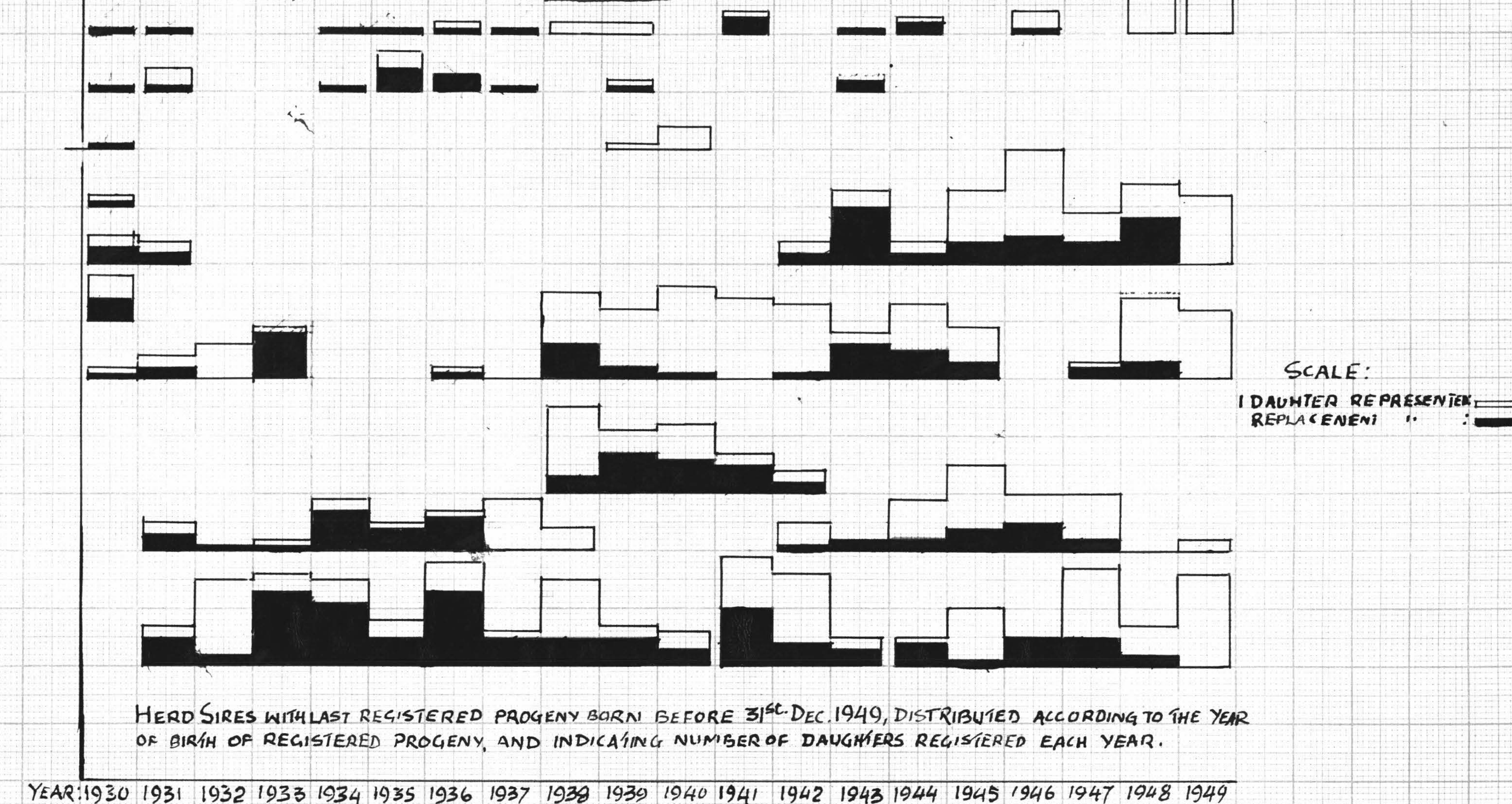


FIGURE-9



HERD SIRES WITH LAST REGISTERED PROGENY BORN BEFORE 31st. DEC. 1949, DISTRIBUTED ACCORDING TO THE YEAR OF BIRTH OF REGISTERED PROGENY, AND INDICATING NUMBER OF DAUGHTERS REGISTERED EACH YEAR.

measured by their average performance as by her own. He shows that theoretically in ordinary circumstances, at least five daughters are required. Tayler and Hyatt (1948) have by analysis of Ayrshire records shown that a single record of the dam is a more accurate guide to the yield of subsequent daughters than the average of her three daughters.

Dickerson and Hazel (1944) have thrown a new light on the subject by pointing out in an important paper that the criterion by which any breeding programme must be judged is the genetic improvement per year rather than per generation. The extra information about a sire's genotype which a progeny test provides must be weighed against the increase in generation length resulting from his use. They concluded that in breeding for butterfat production in dairy cattle in a closed herd of 120 cows, the genetic improvement will actually be faster with accurate pedigree selection and without progeny testing.

In small herds two further points are of importance: first, when young sires have been used sufficiently to provide an adequate test of their value, there are few cows left on which to use the tested bulls; and secondly, the number of bulls from which a selection can be made is restricted and hence the value of the selection is strictly limited.

Lerner and Dempster (1947) have extended the method of Dickerson and Hazel to the improvement of egg production. They found that the value of progeny-testing males depended on the average age of breeding females. If the breeding stock were mostly pullets, it did not increase the annual improvement above that possible from the selection of males on the performance of their full sisters. On the other hand, if the breeding females were 2-year-old hens, progeny testing was then valuable. In the former case, the increased accuracy of selection did not offset the increased generation length.

In the herd under study, there were 674 registered heifers out of the 348 herd dams with the last calving before 31st December, 1949. There were 36 bulls used to sire the offspring, one of which sired only registered bull calves. The remaining 35 bulls registered an average of about 19 daughters (19.25). When this figure is compared with that obtained by Fahimuddin (1952), for the whole industry, in which bulls sired on the average four registered daughters (3.98), it is clear that the use of bulls in the herd under study differs widely from the general picture obtaining in the industry. Figure 9 shows diagramatically the number of registered daughters and the herd replacements sired by each bull. All the sires which have sired registered heifers during three of more years have been shown on the lower portion of the figure. There were 622 registered heifers born before the 31st December, 1948 sired by these 35 bulls, 282 of which entered the herd as replacements and these have been shown as shaded portions of the figure. It is clear that of the 35 sires used during this 19 year period (between 1930 and 1948), only 10 sires have been used extensively - two sires have more than 90 registered daughters (34.41% of the total registration in this period), five sired more than 40 registered daughters (41.61%), two more than 20 registered daughters (10.13%) and one more than 10 registered daughters (2.89%). The remaining registered heifers are by 25 other sires used in the herd.

It is possible that the breeder mated some of his yearling heifers intended for sale to yearling bulls merely to sell the females as in-calf heifers. If this were so, one would expect that any heifers resulting from such mating would not be used as herd replacements.

Table 21 shows that 57.5% of the registered heifers belonging to half-sister groups smaller in number than six were retained for replacements, and 44.5% of the heifers belonging to half-sibs group of six or more heifers entered the herd.

Table 21. Distribution of registered and replacements according to the size of paternal half-sib groups at registration.

Size of paternal half-sib groups Registrations.		Distribution of heifers.		Percentage registration to enter herd	
		Registered (No.)	Entering herd (No.)		
0	(2)X	-	-	-	
1	(9)	9	8	88.89	57.50
2	(4)	8	6	75.00	
3	(2)	6	5	83.33	
4	(3)	12	4	33.33	
5	(1)	5 (11.41%)	-	00.00	
6	(1)	6	4	66.67	44.50
7	(-)	-	-	-	
8	(2)	16	4	25.00	
9	(1)	9	5	55.56	
10 - 19	(1)	18 (2.89%)	6	33.33	
20 - 39	(2)	63 (10.13%)	33	53.24	
40 - 89	(5)	256 (41.16%)	115	44.92	
90 and over	(2)	214 (34.41%)	92	42.99	
Total	(35)	622	282		

X Number of sires in brackets.

Apparently the daughters of extensively used bulls were, relatively speaking, no more likely to enter the herd than those of the bulls used less widely in the herd. On the contrary it appeared that the daughters of bulls used lightly were given every opportunity to enter the herd. This may be indicative of an attempt on the part of the breeder to obtain some form of the early progeny test information concerning all the bulls used. To determine whether this was so herd replacements have been distributed in Table 22 according to the number of half-sister lactations available at the date of their conception. It may be seen in this table that of the 282 heifers to enter the herd, lactation details of a single-sister were not available for 183 (65%) of them at the time of their conception. Thirty-three (11.35%) replacements had between one and four half-sib lactations available at the time oftheir conception and the remaining sixty-six (23.75%) had five or more half-sib lactations available at the time of their conception.

Table 22. The distribution of herd replacements According to the number of half-sib lactations available at the date of conception.

No. of half-sib lactations available at conception.	No. of replacements.	Percentage of total.
40 and over	3	1.06 (1.06)
30 - 39	10	3.55 (4.61)
20 - 29	-	-
10 - 19	25	8.87 (13.48)
9	6	2.12 (15.60)
8	-	-
7	1	0.35 (15.95)
6	13	4.61 (20.56)
5	9	3.19 (23.75)
4	13	4.61 (28.36)
3	8	2.84 (31.20)
2	5	1.77 (32.97)
1	6	2.13 (35.10)
0	183	64.89 (99.99)

Figures within brackets refer to cumulative percentage total.

The features of Table 22 are firstly the size of some of the paternal half-sib groups, the largest comprising almost fifty replacement heifers and secondly the low proportion of replacement heifers conceived when lactation records of a relatively large number of half-sisters were available. Of the 282 replacements heifers 20.56% were conceived where there were lactation records for at least six paternal half-sisters available and 15.6% were conceived when at least one lactation record was available for ten paternal half-sisters.

Clearly the breeder paid minor attention to adequate progeny testing information of sires as it is generally defined in the choice of herd replacements. It appears that he used sires sparingly as young bulls and then proceeded to exploit some of them before their first daughters calved. According to the generally accepted principles of adequate progeny testing a minimum of at least five daughters is necessary. However, the information acted upon by the bfeeder probably included fairly accurate pedigree assessments of the sires used. For this reason it is of interest to study the pedigree selection of sires practised.

THE IMPORTANCE OF PEDIGREE.

Production of sire's dams.

For the obvious reason that males do not produce butterfat the breeding worth of sires can be estimated only through the production of their female relatives. Within a herd some indication of a breeder's general attitude towards bull selection can be derived from a study of his choice of bull calves for registration. If only a portion of the bull calves born have been registered and they were predominantly from the higher producing dams in the herd, one could reasonably assume that the breeder regarded the productive level of bull-mothers of some importance. One would expect a breeder to retain only the best home-bred bulls for use in a closed herd, and if he paid attention to the productive performances of sires' dams, to choose these bulls mainly from the dams which were the highest producers of butterfat in the herd.

A method of estimating the breeding value of dams has been described (see Section I). It is used in the following section to measure the comparative breeding values of the dams of bull calves and to enable an assessment of the importance attached by the breeder to dam productivity in his choice of bull calves for registration and for use in his herd.

It has been pointed out that nearly all the heifers alive were registered and that the breeder's preferences could not be recognised until heifers were chosen to enter his herd. A lower percentage of the bull calves born were registered and some decision on the relative merit of bull calves must have been made at an earlier stage than in the case of heifer calves. To 31st December, 1949, 424 of the bull calves born were registered and they have been classified according to the estimated breeding worth of their dams in Table 23.

Table 23. Distribution of registered bull calves according to the estimated breeding worth of their dams.

Estimated breeding worth of dams (Pound butterfat)	Distribution of registered heifers.	
20 and over	21	67.91
15 - 19	24	
10 - 14	63	
5 - 9	88	
0 - 4	92	
0 - -4	87	32.08
-5 - -9	36	
-10 - -14	8	
-15 - -19	4	
-20 and over	1	
Total	424	(100.00)

Table 23 shows that 67.91% of the bull calves registered were from above-average dams and 32.08% from below-average dams. It is apparent that some preference has been shown for the bull calves of the better dams in respect of butterfat production but it is equally clear that that breeder's choice has been far from accurate in this respect.

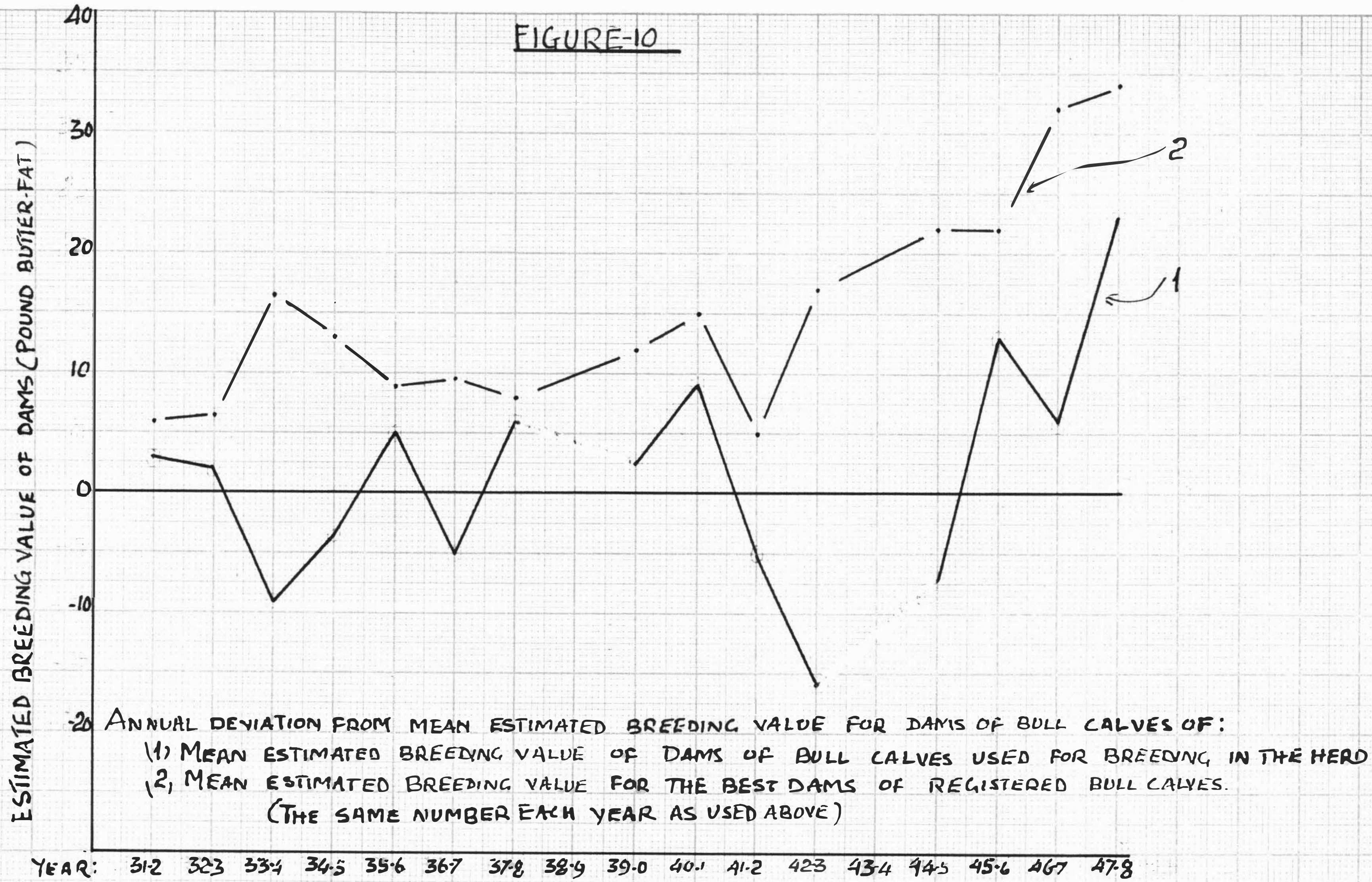
For each year the average estimated breeding values of (a) dams of all the registered bull calves, (b) the dams of registered bull calves used in the herd, (c) the best dams of bull calves corresponding with the number of registrations have been calculated and are shown in Table 24.

Table 24. The annual estimated breeding value of the dams of registered calves used in the herd and the best available dams of bull calves.

Year.	Dams of registered bull calves.		Dams of registered calves which were used in the herd.		Best available dams.	
	No.	Mean estimated breeding value (Pound butter-fat.)	No.	Mean estimated breeding value (Pound butter-fat.)	No. X	Mean estimated breeding value (Pound butter-fat.)
1930-31	10	+ 1.28	-	-	-	-
1931-32	11	+ 0.83	1	+ 3.63	1	+ 6.75
1932-33	7	+ 8.01	1	+10.28	1	+14.47
1933-34	14	+ 5.39	1	- 3.38	1	+21.89
1934-35	13	+ 7.38	2	+ 3.74	2	+20.10
1935-36	14	+ 6.67	2	+11.96	2	+15.86
1936-37	11	+ 6.29	1	+ 1.46	1	+16.80
1937-38	13	+ 5.91	2	+11.57	2	+13.59
1938-39	18	+ 4.64	-	-	-	-
1939-40	17	+ 4.44	2	+ 6.95	2	+16.15
1940-41	19	+ 4.71	2	+13.44	2	+20.12
1941-42	22	+ 7.39	3	+ 1.93	3	+12.24
1942-43	21	+ 5.48	1	- 9.38	1	+22.56
1943-44	29	+ 6.06	-	-	-	-
1944-45	35	+ 3.54	1	- 3.76	1	+25.58
1945-46	32	+ 2.49	2	+15.38	2	+24.34
1946-47	35	+ 4.74	1	+0.32	1	+37.00
1947-48	36	+ 4.37	1	+27.56	1	+37.96
1948-49	35	+ 3.19	-	-	-	-
1949-50	32	+ 4.88	-	-	-	-

X Numbers correspond with those in Col. (2)

FIGURE-10


ESTIMATED BREEDING VALUE OF DAMS (POUND BUTTER-FAT)
40
30
20
10
0
-10
-20
YEAR: 31-2 32-3 33-4 34-5 35-6 36-7 37-8 38-9 39-0 40-1 41-2 42-3 43-4 44-5 45-6 46-7 47-8
1
2
ANNUAL DEVIATION FROM MEAN ESTIMATED BREEDING VALUE FOR DAMS OF BULL CALVES OF:
(1) MEAN ESTIMATED BREEDING VALUE OF DAMS OF BULL CALVES USED FOR BREEDING IN THE HERD.
(2) MEAN ESTIMATED BREEDING VALUE FOR THE BEST DAMS OF REGISTERED BULL CALVES.
(THE SAME NUMBER EACH YEAR AS USED ABOVE)

The difference between (b) and (a), and (c) and (a) are shown in Figure 10. In two out of the 17 years no home-bred bulls were retained for use in the herd under study. In seven of the 15 years the dams of registered bulls retained for herd use were of lower average estimated breeding value than the dams of all bull calves registered in the same year. It seems that bull calves out of dams with the highest breeding values have not always been retained for use in the herd.

One is led to the conclusion that so far as the home-bred bulls were concerned the production records of dams did not receive as much emphasis as one would anticipate.

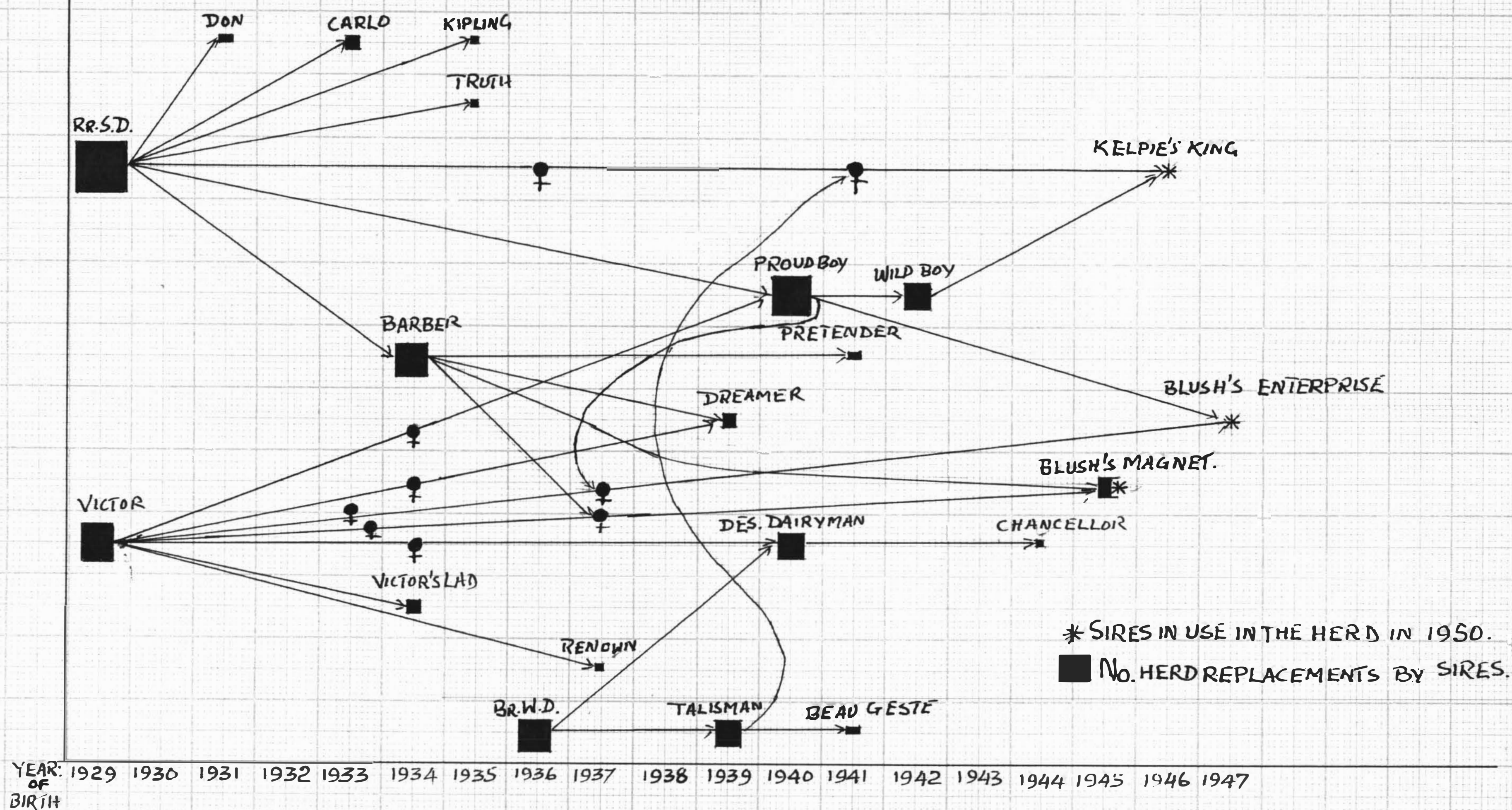
However two of the most important herd sires were imported animals and consequently have been omitted from the above table. Further no attempt has been made to weight the home-bred sires according to their reproductive importance. Consequently though the average breeding value of home-bred bulls used to breed herd replacements may appear disappointingly low, their differential use and the effects of the two imported sires may explain the large genetic gains noted earlier.

Lastly an attempt was made to find out if the breeder in using his home-bred sires gave preference to daughters of those bulls out of dams with outstanding performance records. Figure 11 and Table 25 show the bulls used in the herd according to the year of their birth and the number of their daughters entering the herd as replacements. On the whole the breeding worth of dams of these bulls were between five to ten pounds or more above the herd average; the breeding worth of the last two sires which were in use in the herd at the time of this study were + 23.2 pounds and + 27.6 pounds respectively.

Table 25. Showing home-bred sires used in the herd, their dam's breeding worth and the number of herd replacements.

Name of Bull.	Year of birth.	Breeding worth of bull's dam (Pound butter-fat.)	No. of heifers by the bull entering the herd as replacements.
Don	1931	+ 3.63	2
Carlo	1933	- 3.38	4
Barber	1934	+15.60	25
Victor's Lad	"	- 8.11	3
Truth	1935	+12.48	1
Kipling	"	+11.44	1
Renown	1937	+ 9.00	1
Dreamer	1939	+ 7.14	3
Talisman	"	+ 6.76	17
Proud Boy	1940	+ 9.40	35
Beau Geste	1941	- 4.35	2
Pretender	"	+ 1.10	2
Wild Boy	1942	- 9.40	17
Chancellor	1944	- 3.76	1

FIGURE 11


DON
CARLO
KIPLING
TRUTH
RR.S.D.
KELPIE'S KING
PROUD BOY
WILD BOY
BARBER
PRETENDER
DREAMER
BLUSH'S ENTERPRISE
BLUSH'S MAGNET.
VICTOR
DES. DAIRYMAN
CHANCELLOR
VICTOR'S LAD
RENOWN
BR.W.D.
TALISMAN
BEAU GESTE
YEAR OF BIRTH
1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947
* SIRES IN USE IN THE HERD IN 1950.
No. HERD REPLACEMENTS BY SIRES.

Blush's Magnet	1945	+23.18	-
Kelpie's King	1946	+ 0.32	-
Blush's Enterprise	1947	+27.56	-

Four of the home-bred bulls have been used extensively to sire herd replacements. With one exception these bulls have been from dams of outstanding production ability. Each of these sires was closely related to either Brampton Standard Dance (Imp.) or Maori Victor and it is possible that these sires for which no pedigree assessments were possible were ultimately responsible for the large genetic gains made.

SUMMARY.

I. The records of a New Zealand pedigree Jersey herd of approximately one hundred cows which was continuously recorded under the Group Herd Test System for twenty-one years (1930-1950) have been studied to determine the extent and cause of any genetic changes which may have taken place during the period reviewed. The records of 357 dams with 1892 lactations were involved. The Repeatability of records was estimated to be 0.43.

2. The straight line trend of the annual mature equivalent averages was upward at the rate of 4.8 lbs. of butterfat per year. The genetic component of this was 3.9 lbs. or approximately 80% of the total improvement.

3. The producing ability of each dam was calculated at the end of each lactation. Of the 282 heifer replacements entering the herd during the period studied only 152 (53.9%) were from dams above the average of the herd in the year in which the heifers were born. Had dam selection been perfect a genetic improvement of 0.57 lbs. of butterfat per year would have resulted. The actual genetic gains from dam selection were of the order of 0.06 lbs. of butterfat per annum. Dam selection appears to have received more emphasis during the last seven seasons studied.

4. Thirty-six sires were used in the herd during the period reviewed, ten of them extensively. Adequate progeny testing played little or no part in determining the choice of herd sires. Home-bred sires were generally chosen from dams well above the herd average though this was not invariably so. The most important bulls, judged by the number of replacements sired, were either imported or chosen from herd dams before continuous animal recording was practised. Two of these sires appear to be largely instrumental in effecting the improvements noted and in view of the inadequate information available from which to make pedigree estimates of these two bulls it must be concluded that the breeder was extremely fortunate in his early selection of sires.

ACKNOWLEDGMENTS.

The writer is indebted to the New Zealand Dairy Board, Taranaki Herd Improvement Association and the New Zealand Jersey Cattle Breeders' Association (Inc.), for the data used in this study, and to the members of the Dairy Husbandry and Sheep Husbandry Departments for their kind help, and especially to Dr. Alan Stewart for his constant guidance and supervision throughout the investigation and lastly to Prof. A. L. Rae without whose kind encouragement and help this study would not have been complete.

APPENDIX I.

REPEATABILITY OF RECORDS.

An examination of the data was made to determine whether the heritability factors employed were reasonable estimates. The differences in productivity between individual dams can be subdivided into that part caused by temporary environmental conditions and that due to inherent differences. Temporary environment effects are not transmitted from parent to offspring. Inherent differences include hereditary differences which may be transmitted, those which may not be transmitted (such as the effects of dominance and epistasis and permanent differences in environment).

"Heritability" measures the proportion of the total variance in the character due to hereditary effects which are transmitted. "Repeatability" measures the proportion of inherent differences in the total variance (including the heritable fraction).

Two methods of calculating repeatability were employed. The first was that described by Berry (1945) in which the study was restricted to those animals for which the first three lactation records were available. Correlation coefficients between adjacent records, and records separated by one lactation were calculated and the average used as an estimate of "repeatability". The second method was that described by Snedecor (1946) in which all available records were considered and intra-class correlations calculated.

FIRST METHOD (BERRY, 1945).

The data consisted of the records of 205 dams in the herd studied which completed their first three normal lactations (the production records based on lactation records to 305 days and for cows in milk for at least 100 days). Since the correction factors used in New Zealand involve the addition of constant amounts to the two-year-old and three-year-old lactation records, records were not corrected to a mature basis.

One estimate of repeatability is measured by the average correlation between records of the same cow. The separate correlations between adjacent records were therefore calculated and records separated by one lactation (first and third lactations) were calculated. The correlations are shown in Table I.

Table I. Correlation between records of cows for which the first three lactation records were available.

Lactation Records compared.	Correlation Coefficients.	
Adjacent		
$r_{2,1}$	0.6043)	0.5702
$r_{3,2}$	0.5361)	
1 record intervening		
$r_{3,1}$	0.4196	
Average of all correlations.	0.5200	

The correlations were grouped according to proximity of records and an average value for all separate correlations obtained. The estimate of the "Repeatability" of records by this method is thus:

$$R = 0.520.$$

SECOND METHOD (SNEDECOR, 1946).

(a) The same data used in thefirst method was studied - 205 cows for which details of their first three lactations were available - and intra-class correlations were calculated. The details of the analysis of variance are as follows:-

Source.	d.f.	Sum of squares.	Mean squares.
Total	614	3,003,804	4,892.1
Between cows	204	2,506,192	12,285.2
Within cows	410	497,612	1,213.7

Repeatability is estimated by the ratio of thetwo variances as follows:-

$$r_1 = \frac{\sigma_m^2}{\sigma_m^2 + \sigma^2}$$

The numerator was calculated as follows:-

$$\sigma_m^2 = \frac{12,285.2 - 1,213.7}{3}$$

$$= 3690.5$$

The intra-class correlation was then calculated as follows:-

$$r_1 = \frac{\sigma_m^2}{\sigma_m^2 + \sigma^2}$$

$$= \frac{3690.5}{3690.5 + 1213.6}$$

$$= 0.7525$$

Thus the estimate of Repeatability using this method and the restricted information is thus:

$$R = 0.75.$$

(b) The differences in the two estimates R - 0.52 and R - 0.75 suggested that the use of restricted data did not give reliable estimates and it was decided to use all the information available and to correct for the varying numbers of lactations for each animal by the method described by Snedecor (1946) page 234.

The performance details of 357 cows with 1892 lactations (2 year-old and 3 year-old heifers' yield corrected to mature age by the correction factors employed by the New Zealand Dairy Board, 1951) were next examined. The repeatability of records for (i) cows with one or more lactations and (ii) cows with two or more lactations were calculated in the manner described by Snedecor (1946).

(i) Repeatability of records for all cows in the herd under study.

n - 357
SX - 755,673
$(SX)^2$ 571,041,682,929
SX^2 - 313,100,453
SK^2 - 13,794
SK - 1,892.

Due to the varying numbers of lactations for each animal (Ko) the average number of records per cow was calculated from the following formula:-

$$Ko = \frac{1}{n-1} \left(SK - \frac{SK^2}{SK}\right)$$

$$= \frac{1}{356} \left(1892 - \frac{13794}{1892}\right)$$

$$= 5.294$$

The correction factor $\frac{(SX)^2}{SK}$, was then calculated as follows:

$$C.F. = \frac{(SX)^2}{SK}$$

$$= 301,819,071.3$$

Total sum of squares = $(SX^2 - C.F.)$

$$= 11,281,381.7$$

Sub-sample means = $\frac{Si^2}{Ki} + \ldots + \frac{Sn^2}{Kn} - C.F.$

$$= 6,158,874.2$$

Where Si is the sum of the lactations in the first year and Ki the number of lactations in the same year.

The analysis of variance is then :

Source.	d.f.	Sums of squares	Mean squares.
Total	1,891	11,281,381.7	
Between cows	356	6,158,874.2	17,300.208
Within cow	1,535	5,122,507.5	3,337.138

The intra-class correlation $= \frac{\sigma m^2}{\sigma m^2 + \sigma^2}$ was then calculated after measuring $\sigma m^2 = 2,637.527$.

The intra-class correlation thus calculated is as follows:-

$$r_I = \frac{\sigma m^2}{\sigma m^2 + \sigma^2}$$

$$= \frac{2,637.527}{2,637.527 + 3,337.384}$$

$$= 0.441$$

Thus R = 0.44.

(ii) Repeatability of records of cows with two or more lactations in the herd under study.

To determine whether the use of all records which enabled a more accurate estimate of σ^2 was necessary, only the records of those animals for which two or more records were available were considered. The estimate of repeatability using the method described above was as follows:

n - 313
SX - 740,076
(SX)2- 547,712,485,776
SX^2 - 307,108,612
SK^2 - 13,750
SK - 1,848
C.F.- 296,381,215.2
Total S.S. - 11,281,381.7
Sub-sample means - 6,158,874.2
Ko - 5.899

The analysis of variance is :

Source	d.f	Sum of squares	Mean squares
Total	1,847	10,727,396.8	
Between cows	312	5,604,889.3	17,964.389
Within cow	1,535	5,122,507.5	3,337.138

The intra-class correlation thus calculated after finding out σm^2 is as follows:

$$r_I = \frac{\sigma m^2}{\sigma m^2 + \sigma^2}$$

$= 0.426$

Thus $R = 0.43$.

The small differences between these two measures of Repeatability suggests that either provides a reliable estimate of "R" and that based on all records has been preferred because of the more accurate estimate of σ^2.

In this study "R" has been taken to have a value of ;

$R = 0.44.$

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