SELECTION INDICES ON GOATS-
A COMPARATIVE STUDY

BY

REMA T. P.

THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF

Master of Science (Agricultural Statistics)

FACULTY OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF STATISTICS

COLLEGE OF VETERINARY AND ANIMAL SCIENCES

MANNUTHY - TRICHUR

1985

DECLARATION

I hereby declare that this thesis entitled "SELECTION INDICES ON GOATS-- A COMPARATIVE STUDY" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

REMA T.P.

Mannuthy

18-6-1985

CERTIFICATE

Certified that this thesis entitled " SELECTION INDICES ON GOATS-- A COMPARATIVE STUDY " is a record of research work done independently by Smt. Rema, T.P. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Mr. K. L. SUNNY,

Mannuthy,

Assistant Professor of Statistics.

(Chairman, Advisory Board).

ACKNOWLEDGEMENT

I place on record most sincerely, my gratitude to Mr. K.L.Sunny, Assistant Professor of Statistics and chairman of advisory board for his ardent encouragement, stable support,friendly guidance and constructive criticisms at each stage.

I am equally grateful to Dr. K.C.George, Professor of Statistics who has been a constant source of succour and inspiration to me by his vast erudition and untiring perseverence.

Grateful acknowledgement is made to Dr. B.R.Krishnan Nair, Professor of Animal Breeding and Genetics and Dr. A.Ramakrishnan, Professor of Poultry Science for the unstinted help rendered by them during the period of study.

My thanks are also due to Mrs. T.K. Indirabai, Assistant Professor of Statistics and Dr.(Mrs) N.Kunjikutty, Professor of Animal Nutrition for the help rendered by them in collecting the data.

I wish to express my thanks to Dr. M.Krishnan Nair, Dean, Faculty of Veterinary and Animal Sciences for providing facilities for the study.

I am grateful to Kerala Agricultural University for granting me fellowship for undergoing the post graduate studies.

And last but not the least, I record my heartful thanks to my husband, Dr. N.R.Viswambharan for inspiration and persuation.

REMA.T.P.

CONTENTS

Introduction

INTRODUCTION

One of the important aspects of animal breeding is selection or choosing of superior parents for the next generation. Individual selection is the simplest form, in which individuals with better phenotypic value for a trait are selected with the objective of increasing the mean value of that trait in future generations. But, the relative economic merit of individuals in a breed or variety will often depend on the better performance in different traits and how should one take them all into account in selection? Simultaneous selection for several characters, when all the characters considered are not equally important, is most effectively accomplished by constructing selection indices.

Since various traits are weighted, selection on the basis of selection index gives the best possible economic results. The advantages of this method are:

1. The relative net economic importance of a change in each of the traits, assumes importance as a composite of the several traits, weighted by their relative net economic importance, forms the goal of improvement rather than a single trait.

2. The heritability or the magnitude of the genetic

variance for each of the traits and phenotypic variance for each trait also get due consideration.

3. The phenotypic and genetic covariances among each trait form part of the index or phenotypic and genetic correlations are also considered.

If relative economic values (a_i) are assigned to the traits, the net breeding value or merit H of an individual can be defined as a weighted function of breeding value (G_i) for various traits. ie $H = \sum_i a_i G_i$. Now the problem of index construction is to find out a suitable function I of phenotypic observations (P_i) available on each individual in such a manner that the individuals with higher H values can be identified. It is the simplest to have a linear function $I = \sum_i b_i P_i$, where b_i's are estimated in such a manner that the correlation ($r_{H,I}$) becomes maximum.

The major difficulty in the construction of selection indices lies in establishing the relative economic value of each trait required in framing the net merit of the individual. The relative economic values depend upon the amount by which each unit of variation in it actually increases or decreases the net profit. Smith (1983) reported that the efficiency of index construction is very sensitive to changes in economic weights. So the use of economic values based on the information about the cost of production will always improve the efficiency of index selection.

This index $I = \sum_{i} b_i P_i$ is expected to result in maximum progress in the aggregate genotypic economic value H. While the use of I result in maximum progress in H, the means of G_i will change either in a positive or negative direction depending on the genetic association between them. That is to say, the use of the selection index may sometimes result in depressing the genotypic value of the component traits. In this case the breeder is interested in that selection index which would maximise the economic value, but at the same time ensure constant mean performances in some of the component traits or some linear functions of these. Such restricted selection indices were first constructed by Kempthorne and Nordskog (1959).

The function of selection index is to make optimal use of the information available about the animals for selection. The prospective parent can be selected based on the information of own performance and of the progenies. But as far as sex limited characters are concerned, the record of own performance which is limited to the other sex cannot be observed. In this case optimum selection indices can be constructed combining information from full-sib and half-sib family averages, considering equivalent individual characters. Based on the intensity of selection those animals having the highest scores would be selected.

The efficiency of production of a dairy goat would depend on the birth weight, age at first kidding, body weight at first kidding and first lactation milk yield. The production per day per goat in the flock would combine these characters and could be considered as a criterion for comparison among animals within breed and among breeds. Some of the characters deciding the worth of an animal are available sufficiently late in life. It will therefore be necessary to consider traits available early in life which can predict efficiently the production capacity of an individual having high heritabilities and bear large genetic correlation with milk production. Selection based on such traits separately or in combination may allow maximization of genetic gain in milk production. Comparison of various selection indices and identifying more efficient among them and suitable under local conditions would certainly help future selection procedures for goats for given traits.

The objectives of the present investigation are:

1. To compare the different selection indices which provide estimates of breeding worth of individual goats under K.A.U farm conditions.

2. To study the relative efficiencies of different selection indices based on goats maintained in the K.A.U farm.

3. To suggest a suitable selection index on the basis of the above.

Review of Literature

REVIEW OF LITERATURE

In practice, selection can seldom be limited to a single trait, and several traits have to be considered simultaneously. The old method of evaluation of animals by scoring with different maximum points for different traits and then adding the points alloted, was an attempt to achieve a balance between the traits. The weight given to individual traits should express their comparative economic importance. This must be taken as an important step in striving for rationalisation in animal production.

Selection index is a numerical score assigned to individual to estimate its breeding value and is constructed by combining credits for the individual's merits and penalties for its defects. It brings about maximum genetic gain by giving an appropriate weightage to all the characters considered at selection.

This index is the best estimate of the individual's true breeding value by the following properties:

1. It maximises the correlation between the true breeding value and the index.

2. It maximises the probability of correctly ranking the individuals on their true breeding value.

3. It maximises the genetic progress through selection .

4. it maximises the mean square difference between the true breeding value and the index.

In as early as 1936, Fairfield Smith constructed an index for selecting varieties of Wheat. He expressed the value of a plant as a linear function of its characters. Then using the concept of a 'discriminant function', a linear function of the observable characters is derived which will be the best available guide to the genetic value of each line. He showed how the expectation of 'genetic advance' over the mean of the unselected population for any given selection intensity may be estimated and used to compare the relative efficiencies of various breeding programmes.

Hazel and Lush (1942) compared the efficiency of index selection with that of the other two methods, tandem selection and independent culling method. They showed, the genetic gain from these three methods are in the rank order index selection > independent culling > tandem selection.

Hazel (1943) extended the technique of selection index to selection between individuals in an interbreeding population. He developed a method of computation of linear selection index on the basis of Wright's path coefficients.

Panse (1946) compared straight selection with selection index constructed on the basis of 'discriminant function' in poultry. The traits included in his study were rate of lay, egg weight, age and body weight at first egg. Based on this study he concluded that selection index method is superior to straight selection.

Lerner <u>et al.</u> (1947) conducted a study in a randomly selected sample of the progeny of a New Hampshire flock with respect to body weight, shank length, keel length and breast width at twelve weeks of age. The results expected from the use of indices involving these characters were found to increase the efficiency in rate of improvement by 10 to 14 percent.

Krueger <u>et al.</u> (1952) constructed an index for selecting birds to improve egg production. The h^2 of their particular measure of this character was 0.28; that of the index which involved seven other traits (early and later body weight, sexual maturity, extent of short and long pauses in the course of the laying period, persistency of production and viability) was 0.35.

Bernard <u>et al.</u> (1954) constructed two selection indices for the improvement of pigs under farm conditions.

Abplanalp and Asmundson (1956) tested the effectiveness of a selection index for the improvement of breast width in New Hampshire Fryers. Two lines were derived from a single population by means of mass selection. Parents of the line were selected for increased breast width. Those of the second were selected on the basis of an index by combining body weight, breast width, shank length and keel length. Index selection had been predicted to give 13 percent more rapid gains in breast width than selection on the basis of breast width only.

Osborne (1957b) explained the use of sire and dam family averages in increasing the efficiency of selective breeding under hierarchical mating system.

Hanson and Johnson (1957) developed methods for calculating and evaluating a general selection index obtained by pooling information from two or more experiments. A point of interest noticed by them was that the ratio of expected genetic advance expected for the data utilizing a selection index is the expected correlation between the indices of phenotypic values obtained with the two indices.

Yamada (1958) constructed an index in Poultry by incorporating the traits sexual maturity, egg production, egg weight and body weight for the use under Japanese conditions.

Nogsett and Nordskog (1958) studied the application of selection indices using data from fifteen lines of poultry at Iowa State University. The characters included were egg weight, body weighh and laying rate. The authors found that placing restriction on egg weight would cause a reduction in net efficiency by only 8 percent compared to the index in which no such restriction was placed on any character. But placing restriction on body weight reduced the net efficiency by 46 percent. Selection on laying rate alone would reduce the net efficiency by 35 percent.

Kempthorne and Nordskog (1959) presented an interesting method of maximizing genetic progresses under the restrictions that progress in certain linear functions be zero.

Ahmed (1961) constructed selection index for Haryana cattle of Indian Veterinary Research Institute using five traits; age at first calving, first calving interval, first lactation yield, body weight at first calving and butter fat percentage. The first index was formed by combining all the five traits, second one involving the first four traits and the third involving only the first three traits. The third index was found to be the most efficient (R_{HI}=0.625).

Tallis (1962) extended the method of Kempthorne (1959) in the case of selection for an optimum genotype.

Binet (1965) dealt with indirect selection where some components of value were not included in the index. He treated only the case of two traits, but indicated the possibility of extension to many traits.

Acharya (1966) developed the index for Haryana cattle of Government Live Stock Farm, Hissar using three characters: age at first calving, first lactation milk yield and first calving interval. In this case the correlation between I and H was 0.86.

James (1968) obtained an index to maximize genetic improvement in linear functions of several traits under the condition that linear restrictions are imposed on the index coefficients and on changes in the means of certain characters. Through this modification changes in some of the characters can be restricted without affecting the development in the others.

Singh, Acharya and Sundaresan (1968) showed the method of calculating the relative economic values. In this paper different selection indices for genetic advancement in Haryana cattle were calculated by using the six characters: birth weight, weight at first calving, age at first calving, milk yield in the first lactation, first service period and first dry period. Two series of selection indices, each comprising of the same types of 18 indices incorporating different combinations of six traits were developed. In the first series, the economic weightages assigned to all the six characters were the same as that actually been calculated for each. In the second series equal economic weightage was given to service period and dry period whereas for the other traits those remained the same as before. Comparison of the relative efficiencies of the selection indices of the two series showed that the index incorporating all the six traits was the most efficient for both series (R_{HI}=0.9099). The second best was the index computed by omitting birth weight in both series.

Singh, Acharya and Biswas (1970) constructed an index comprising age at first kidding and first lactation milk yield. The use of this index resulted in an increase of 21.5 kg in first lactation milk yield, a decrease in age at first kidding by 80.6 days and an increase in kidding interval by 14.2 days.

Marutiram, Jain and Gopalan (1972) constructed selection index for the improvement of Poultry based on the combined information of full-sib and half-sib families by combining information on dam in addition to full-sibs and half-sibs. The breeding value of a bird was given by them as:

$$I = \hat{G} = b_1 P + b_2 \overline{H} + b_3 \overline{C} + b_4 D$$

where P = own performance

$\overline{H}$ = mean of it's paternal half-sibs

$\overline{C}$ = mean of it's full-sibs

D = dam's performance

For selection among females, two combinations with and without the use of record of dam were considered. Similar combinations were considered for selection among males excluding the individual's performance which will not be available for sex limited characters. From the comparisons of the indices, it was observed that the inclusion of dam's record in addition to information on sibs resulted in an appreciable gain of 4 to 6 percent in females and 6 to 33 percent in males when sire and dam families were small and heritability is low.

Prasad and Prasad (1973) constructed three selection indices for improving Tharparkar herd at Patna. The traits included in their study were first lactation yield, lactation length, first calving interval and age at first calving.

A comparison of selection indices was done by Bouillon and Ricordeau (1975) for the three characters; 100 day milk yield, milking time and milk protein content in goats. They constructed five selection indices incorporating all these characters and estimated the genetic gain associated with each of them. It was concluded that selection for protein yield is as effective as any other selection index.

Ranganathan et al. (1979) made a comparative study of index selection for egg production and egg weight versus selection for egg mass in chicken.

Part record egg number and percent production upto 280 days of age were compared by Kotaiah and Renganathan (1980) by using them as components of indices constructed along with age at sexual maturity, body weight and egg weight using different sets of economic values in White Leghorn flock.

Singh and Acharya (1980) constructed selection indices for a closed flock of Beetal goats located at Hissar, Haryana. Henderson's modification of Hazel's method of constructing selection indices (Karam et al. 1953) to maximize genetic gain in lifetime production was used in this investigation. Indices were computed with possible combinations of age at first kidding, first lactation yield, first lactation length and first kidding interval. It was concluded that an index combining all the four traits would maximize not only the genetic gains in lifetime production but would maximize improvement in all these traits. However, if selection was to be based only on one trait, the selection based on the first lactation milk yield will bring the largest direct positive response in first lactation milk yield and also the largest correlated response in lifetime production. The correlated responses in the other traits in a desirable direction would be rather small relative to direct selection for these traits or selection based on the index combining all the traits.

Akbar (1981) made a study for commercial egg production in two breeds, Barred Plymouth Rock and Rhode Island Red. Eighteen selection indices were constructed from the four traits viz. rate of lay, age at first egg, adult body weight and mature egg weight for each breed. These included one conventional index, two non-weighted indices, six restricted indices, six optimum indices, two retrospective indices and one base index. These indices were ranked according to (1) correlation between aggregate breeding value and the index and (2) the expected progress in genetic economic value after one generation. The two methods gave identical results. The conventional index was the most effective linear combination of the four traits for each breed.

Ahuja, Prakash Babu and Aggrewal (1981) constructed selection indices for the improvement of four week body weight in Japanese quail.

Saxena, Mohapetra and Mehta (1982) collected data on White Rock and New Hampshire females over two generations and constructed indices for dam line stock. The traits considered were body weight at 10 week of age, rate of lay to 40 week and egg weight at 40 week age. The accuracy of those indices were 0.64 and 0.46 for White Rock and New Hampshire respectively.

Narayanikutty (1983) made a comparative study of selection indices in Poultry. The characters under her study were 20 week and 40 week body weights, egg weight and egg production. Of the general selection indices constructed for selection among males and females, the one including the record of dam was found to be more efficient than the one without the record of dam. The simultaneous selection index combining all the traits was found to be superior to straight selection. From the three restricted selection indices constructed by restricting egg weight, 40 week body weight independently and egg weight and 40 week body weight combinedly, only the restriction on egg weight was found to be effective. Out of the seven phenotypic indices constructed, the index between the main trait egg production and the auxiliary traits 20 week body weight and 40 week body weight was found to be the best in improving the main trait egg production. Combined selection indices for males combining information from full-sib and half-sib family averages were also constructed for each character and these indices were arranged in descending order to choose the best parents. The expected response due to this index was also calculated for each trait.

The importance of clutch size in a multi-trait selection index was studied by Renganathan et al. (1983) in single comb White Leghorn parents. The characters included in his study were clutch size with egg number, egg mass, egg weight and age at sexual maturity. Nine selection indices were constructed ; these included clutch size with various combinations of their production traits. The most efficient index was the one which included all the characters. Omission of clutch size reduced the net efficiency of the index by 15 to 20 percent.

Dev Roy et al. (1983) constructed four selection indices in male, female and in combined sex, taking combinations of body weights at 4,6 and 8 weeks of age in broiler chicks. The accuracy of the indices ranged from 0.47 to 0.51 in males; 0.62 to 0.65 in females and 0.51 to 0.52 in the combined sex. Maximum genetic gain was expected from the index incorporating parameter estimates of female progenies.

Materials and Methods

MATERIALS AND METHODS

The data collected for the present investigation pertain to the Malabari, Sannen X Malabari (SM), Alpine X Malabari (AM) and AM X AM (F_2 A) goats maintained under the same management practices in the farm of the AICRP on goats for milk at Mannuthy. These include records from 71 Malabari goats, mates of 10 sires; 95 SM goats, mates of 8 sires; 143 AM goats, mates of 5 sires and 64 F_2A goats, mates of 5 sires. The data were spread over 11 years (1974 through 1984). Kidding took place throughout the year. Birth weight, body weight at first kidding and first lactation yield in 120 days of lactation were recorded in kilograms whereas age at first kidding was taken in days. Sires with atleast 3 progenies were only considered.

Heritability coefficients for the four characters were estimated using half-sib analysis for each breed.

Relative Economic Values:

Relative economic values were calculated according to the method presented by Singh *et al.* (1968). The relative economic value for the two traits viz. age at first kidding and first lactation milk yield were calculated by taking into consideration the amounts of feeds and fodders fed per head per day to the various categories of animals, their monthly labour, supervisory and miscellaneous charges. For this purpose, animals were categorised as kids (upto 3 months of age), female young stock(3 to 6 months of age) and female stock (6 months to age at first kidding). Relevant information was collected for a period of 2 complete years, from January 1982 to December 1983. Information on such items as the amount of grass grazed in the pasture, expenses on housing and shelter provided, medicinal charges and income from animals in the form of manure and sale proceeds of goats were not directly available and hence not collected. Costs for the different varieties of feeds and fodders during this period were also collected. Appropriate cost for total amounts of different varieties of feeds and fodders fed during this period to the various categories of animals were calculated. To these the labour, supervisory and miscellaneous charges evaluated separately for each category of animals were added. The organisation of labour was such that one separate labourer was engaged for every 20 kids, for every 30 animals of female young stock and for every 40 adult animals. Two stockman and an animal attendent each drawing a salary of 500 rupees per month are taking care of the animals. The cost per head per day for attaining the age at first kidding was computed by giving due weightage to the length of age and labour paid to the different categories of animals. The cost value of milk was calculated from the rates at which milk was sold during the different parts of the 2 years. The economic values for birth weight and body weight at first kidding were estimated directly on the basis of the simple regression of first lactation milk yield on these two traits.

<u>Simultaneous Selection Indices:</u>

Selection index was constructed by combining the four important economic traits, viz. birth weight, age at first kidding, body weight at first kidding and first lactation milk yield according to the construction of Smith's discriminent function (1936).

Let P_i be the phenotypic value of the character i for an individual, made up additively of two parts, a genotypic value G_i defined as the average of the population values possible over a population of environments, and an environmental contribution E_i, ie. $P_i = G_i + E_i$

Assume that the genotypic value G_i is composed entirely of additive effect of genes and therefore G_i is also the breeding value of the character i, and G_i and E_i are uncorrelated. Further

$H = \sum_{i=1}^{4} a_i G_i$ define the net merit of an individual and a_i, the relative economic weight given to the trait i.

Since G_i's are unknown, H cannot be used as a criterion of selection. Under the circumstances, selection has to be based on some phenotypic values of the various characters. Now the function

$I = \sum_{i=1}^{4} b_i P_i$ where b_i's are unknown coefficients to be determined; in such a manner that the function I may best discriminate those individuals with the highest genotypic economic score, H. The principle of determining b_i's, therefore is that the correlation r_{HI} between H and I is a maximum. For this the normal simultaneous equations for the four traits were set up as:

$$\sum_{i=1}^{4} b_i P_{ij} = \sum_{i=1}^{4} a_i G_{ij} = A_j$$

$$\text{ie.} \quad \underset{\sim}{P}\underset{\sim}{b} = \underset{\sim}{G}\underset{\sim}{a}$$

$$\text{Hence} \quad \underset{\sim}{b} = \underset{\sim}{P}^{-1}\underset{\sim}{G}\underset{\sim}{a}$$

where $\underset{\sim}{P} = (P_{ij})$ is the phenotypic variance-covariance matrix.

$\underset{\sim}{G} = (G_{ij})$ is the genotypic variance-covariance matrix.

$\underset{\sim}{b}$ = the column vector of regression coefficients.

$\underset{\sim}{a}$ = the column vector of economic values.

The discriminant function or the selection index was then constructed as

$I = b_1X_1+b_2X_2+b_3X_3+b_4X_4$ where b_1, b_2, b_3 and b_4 are the weighting factors determined from the normal equations and X_1, X_2, X_3 and X_4 represent the characters birth weight, age at first kidding, body weight at first kidding and first lactation milk yield respectively.

The expected genetic advance at five percent intensity of selection was calculated using the formula

$$\frac{z}{q}\sqrt{\sum_{j=1}^{4} b_j A_j}$$

where q is the intensity of selection and z is the ordinate of the unit normal distribution corresponding to the point of selection.

The expected genetic advance due to straight selection was obtained by putting $b_i = a_i$ and using the formula

$$\frac{z}{q}\,\frac{\sum_i \sum_j a_i\ a_j\ G_{ij}}{\sqrt{\sum_i \sum_j a_i\ a_j\ P_{ij}}}$$

for the same intensity of selection.

The percent gain in efficiency in expected genetic advance due to selection index over that due to straight selection was calculated using the formula:

$$\left(\frac{\text{Expected genetic advance due to selection index}}{\text{Expected genetic advance due to straight selection}} - 1\right) \times 100$$

This index was constructed ~~for each character~~ and for each breed.

<u>Restricted Selection Indices:</u>

The principle underlying the consruction of restricted selection indices is to maximize the aggregate genotypic economic value $A = \sum_{i=1}^{n} a_i G_i$ based on n characters, subject to the constraints that the genotypic value of r (<n)

characters do not change. ie. $G_k = V_k$ (k = 1, 2, 3,......,r)

The linear function $I = \sum_{i=1}^{n} b_i P_i$ of phenotypic values are to be determined such that r_{AI} is maximum subject to the condition $\text{cov}(I, G_k) = 0$

$$r_{AI} = \frac{a' G b}{\sqrt{(a' G a)(b' P b)}}$$

If

$$C_1 = \begin{bmatrix} 1 \\ 0 \\ 0 \\ \cdot \\ \cdot \\ 0 \end{bmatrix} \qquad C_2 = \begin{bmatrix} 0 \\ 1 \\ 0 \\ \cdot \\ \cdot \\ 0 \end{bmatrix} \quad \cdots\cdots \; C_r = \begin{bmatrix} 0 \\ 0 \\ \cdot \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

be the column vectors each of n elements, then

$\text{cov}(I, G_k) = b' G C_k$, k = 1, 2, ...,r

Maximizing r_{AI} subject to the condition $\text{cov}(I, G_k) = 0$, we get

$$\underset{\sim}{b} = [\, \underset{\sim}{I} - \underset{\sim}{P}^{-1} \underset{\sim}{G} \underset{\sim}{C} \, (\underset{\sim}{C}' \underset{\sim}{G} \underset{\sim}{P}^{-1} \underset{\sim}{G} \underset{\sim}{C})^{-1} \underset{\sim}{C} \underset{\sim}{G} \,] \; \underset{\sim}{P}^{-1} \underset{\sim}{G} \, \underset{\sim}{a}$$

where $\underset{\sim}{I}$ = n X n identity matrix

$\underset{\sim}{P}^{-1}$ = inverse of the phenotypic variance-covariance matrix

$\underset{\sim}{G}$ = genotypic variance-covariance matrix

$\underset{\sim}{a}$ = column vector of economic values

The restricted selection index $I = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4$ imposing restriction on birth weight (X_1) was constructed. In this case, the transpose of coefficient vector was taken as (1 0 0 0)

The estimate of 'b' values which maximizes the correlation between the breeding value A of the individual and the index (I) and at the same time do not allow any change in X_1 was obtained from the above formula for four characters.

The S.D of b (restricted) was obtained from $SD = \sqrt{a' G b}$

The genetic advance (ΔX) in individual characters was calculated using the formula:

$$\Delta X_i = \frac{G b}{\sqrt{a' G b}}$$

Similar procedure was adopted for the construction of restricted selection index for each of the other two charactors- age at first kidding and body weight at first kidding.

Restricted selection index imposing restriction on both birth weight and age at first kidding was also constructed. The coefficient vector taken in this case was

$$C' = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

The 'b' values were obtained as estimated in the above case.

The genetic advance in individual character was calculated as

$$\triangle X_i = \frac{z}{q} \frac{G\, b}{\sqrt{a' G\, b}}$$

Similarly selection indices were constructed to determine the effect of various combinations of the three traits viz. birth weight, age at first kidding and body weight at first kidding for each breed.

Phenotypic Selection Indices

Phenotypic selection indices for selection of the main trait first lactation milk yield (Y) was constructed according to Narain and Mishra (1975) by taking into consideration the auxiliary traits birth weight (X_1), age at first kidding (X_2) and body weight at first kidding (X_3).

The phenotypic index between the main trait- first lactation milk yield (Y) and birth weight (X_1) was given by

$$I_1 = Y - b_1 X_1$$

b_1, the regression coefficient of Y on X was calculated as

$$b_1 = \rho_{YX_1} \frac{\sigma Y}{\sigma X_1}$$

where

ρYX_1 = phenotypic correlation between first lactation milk yield (Y) and birth weight (X_1).

σY = phenotypic S.D of the main trait first lacation milk yield (Y)

σX_1 = phenotypic S.D of the trait, birth weight (X_1).

Efficiency of this index was estimated as

$$E = \frac{1 - \rho YX_1 (\gamma YX_1 \; h_{x_1} / h_y)}{\sqrt{1 - \rho^2 YX_1}}$$

where

γYX_1 = genetic correlation between the traits, first lactation milk yield (Y) and birth weight (X_1).

h_{x_1} = square-root of the heritability coefficient for the trait birth weight (X_1).

h_y = square-root of the heritability coefficient for the trait, first lactation milk yield (Y).

The phenotypic index between the main trait- first lactation milk yield (Y) and the auxiliary trait- age at first kidding (X_2) was calculated as

$$I_2 = Y - b_2 X_2$$

where b_2 = regression of Y on X_2

$$= \rho Y X_2 \frac{\sigma Y}{\sigma X_2}$$

ρYX_2 = phenotypic correlation between Y and X_2

σX_2 = phenotypic S.D of X_2 .

Efficiency of this index was tested by

$$E = \frac{1 - \rho_{YX_2}(r_{YX_2} \; h_{x_2} / h_y)}{\sqrt{1 - \rho^2_{YX_2}}}$$

Phenotypic index between the main trait- first lactation milk yield (Y) and the auxiliary trait- body weight at first kidding (X_3) was calculated as $I_3 = Y - b_3X_3$.

where $b_3 = \rho_{YX_3} \dfrac{\sigma Y}{\sigma X_3}$

where ρ_{YX_3} = phenotypic correlation between Y and X_3 .

h_{x_3} = square-root of the heritability coefficient for the trait X_3.

Phenotypic index between the main trait- first lactation milk yield (Y) and the auxiliary traits- birth weight (X_1) and age at first kidding (X_2) was constructed as

$$I_4 = Y - b_1X_1 - b_2X_2$$

where $$b_1 = \frac{\sigma Y}{\sigma X_1} \frac{(\rho_{YX_1} - \rho_{YX_2}\rho_{X_1X_2})}{(1-\rho^2_{X_1X_2})}$$

and $$b_2 = \frac{\sigma Y}{\sigma X_2} \frac{(\rho_{YX_2} - \rho_{YX_1}\rho_{X_1X_2})}{(1-\rho^2_{X_1X_2})}$$

where $\rho_{X_1X_2}$ = phenotypic correlation between X_1 and X_2.

Efficiency of this index was given by

$$E = \frac{(1-\rho^2_{X_1X_2}) - \rho_{YX_1}\left(\gamma_{YX_1}\frac{h_{x_1}}{h_y} - \gamma_{YX_2}\frac{h_{x_2}}{h_y}\rho_{X_1X_2}\right) + \rho_{YX_2}\left(\gamma_{YX_1}\frac{h_{x_1}}{h_y}\rho_{X_1X_2} - \gamma_{YX_2}\frac{h_{x_2}}{h_y}\right)}{\sqrt{(1-\rho^2_{X_1X_2})(1-\rho^2_{YX_1}-\rho^2_{YX_2}-\rho^2_{X_1X_2}+2\rho_{YX_1}\rho_{YX_2}\rho_{X_1X_2})}}$$

The phenotypic index between the main trait- first lactation milk yield (Y) and the auxiliary traits- birth weight (X_1) and body weight at first kidding (X_3) was fitted as

$$I_5 = Y - b_1X_1 - b_3X_3$$

where
$$b_1 = \frac{\sigma_Y}{\sigma_{X_1}}\;\frac{(\rho_{YX_1} - \rho_{YX_3}\rho_{X_1X_3})}{(1-\rho^2_{X_1X_3})}$$

$$b_3 = \frac{\sigma_Y}{\sigma_{X_3}}\;\frac{(\rho_{YX_3} - \rho_{YX_1}\rho_{X_1X_3})}{(1-\rho^2_{X_1X_3})}$$

where $\rho_{X_1X_3}$ = phenotypic correlation between X_1 and X_3 .

To test efficiency of this index, the following formula was used.

$$E = \frac{(1-\rho^2_{X_1X_3}) - \rho_{YX_1}\left(\gamma_{YX_1}\frac{h_{x_1}}{h_y} - \gamma_{YX_3}\frac{h_{x_3}}{h_y}\rho_{X_1X_3}\right) + \rho_{YX_3}\left(\gamma_{YX_1}\frac{h_{x_1}}{h_y}\rho_{X_1X_3} - \gamma_{YX_3}\frac{h_{x_3}}{h_y}\right)}{\sqrt{(1-\rho^2_{X_1X_3})(1-\rho^2_{YX_1}-\rho^2_{YX_3}-\rho^2_{X_1X_3}+2\rho_{YX_1}\rho_{YX_3}\rho_{X_1X_3})}}$$

The phenotypic index between the main trait- first lactation milk yield (Y) and the auxiliary traits- age at first kidding (X_2) and body weight at first kidding (X_3) was given by

$$I_6 = Y - b_2 X_2 - b_3 X_3$$

where
$$b_2 = \frac{\sigma_Y}{\sigma_{X_2}} \frac{(\rho_{YX_2} - \rho_{YX_3} \rho_{X_2X_3})}{(1 - \rho^2_{X_2X_3})}$$

$$b_3 = \frac{\sigma_Y}{\sigma_{X_3}} \frac{(\rho_{YX_3} - \rho_{YX_2} \rho_{X_2X_3})}{(1 - \rho^2_{X_2X_3})}$$

where $\rho_{X_2X_3}$ = phenotypic correlation between X_2 and X_3 .

Efficiency of this index was tested by

$$E = \frac{(1 - \rho^2_{X_2X_3}) - \rho_{YX_2}\left(r_{YX_2}\frac{h_{x_2}}{h_y} - r_{YX_3}\frac{h_{x_3}}{h_y}\rho_{X_2X_3}\right) + \rho_{YX_3}\left(r_{YX_2}\frac{h_{x_2}}{h_y}\rho_{X_2X_3} - r_{YX_3}\frac{h_{x_3}}{h_y}\right)}{\sqrt{(1 - \rho^2_{X_2X_3})(1 - \rho^2_{YX_2} - \rho^2_{YX_3} - \rho^2_{X_2X_3} + 2\rho_{YX_2}\rho_{YX_3}\rho_{X_2X_3})}}$$

The phenotypic index I_7 constructed between the main trait- first lactation milk yield (Y) and the auxiliary traits- birth weight (X_I), age at first kidding (X_2) and body weight at first kidding (X_3) was given by

$$I_7 = Y - b_1 X_1 - b_2 X_2 - b_3 X_3$$

b_1, b_2, b_3 were evaluated by the following formulae:

$$b_1 = \frac{\frac{\sigma_Y}{\sigma_{X_1}}\left[\rho_{YX_1}(1-\rho^2_{X_2X_3}) + \rho_{X_1X_2}(\rho_{YX_3}\rho_{X_2X_3} - \rho_{YX_2}) + \rho_{X_1X_3}(\rho_{YX_2}\rho_{X_2X_3} - \rho_{YX_3})\right]}{(1-\rho^2_{X_1X_2}-\rho^2_{X_1X_3}-\rho^2_{X_2X_3}+2\,\rho_{X_1X_2}\rho_{X_1X_3}\rho_{X_2X_3})}$$

$$b_2 = \frac{\frac{\sigma_Y}{\sigma_{X_2}}\left[\rho_{YX_2}(1-\rho^2_{X_3X_1}) + \rho_{X_2X_3}(\rho_{YX_1}\rho_{X_3X_1} - \rho_{YX_3}) + \rho_{X_2X_1}(\rho_{YX_3}\rho_{X_3X_1} - \rho_{YX_1})\right]}{(1-\rho^2_{X_1X_2}-\rho^2_{X_1X_3}-\rho^2_{X_2X_3}+2\,\rho_{X_1X_2}\rho_{X_1X_3}\rho_{X_2X_3})}$$

$$b_3 = \frac{\frac{\sigma_Y}{\sigma_{X_3}}\left[\rho_{YX_3}(1-\rho^2_{X_1X_2}) + \rho_{X_3X_1}(\rho_{YX_2}\rho_{X_1X_2} - \rho_{YX_1}) + \rho_{X_3X_2}(\rho_{YX_1}\rho_{X_1X_2} - \rho_{YX_2})\right]}{(1-\rho^2_{X_1X_2}-\rho^2_{X_1X_3}-\rho^2_{X_2X_3}+2\,\rho_{X_1X_2}\rho_{X_1X_3}\rho_{X_2X_3})}$$

Efficiency of this index was tested by

$$E = \frac{\begin{aligned}&[\,(1-\rho^2_{X_1X_2})(1-\rho^2_{X_1X_3})(1-\rho^2_{X_2X_3}) + \\ &\rho_{YX_1}(\gamma_{YX_2}\tfrac{h_{x_2}}{h_y}\rho_{X_1X_2} - \gamma_{YX_1}\tfrac{h_{x_1}}{h_y}) + \\ &\rho_{YX_2}(\gamma_{YX_3}\tfrac{h_{x_3}}{h_y}\rho_{X_2X_3} - \gamma_{YX_2}\tfrac{h_{x_2}}{h_y}) + \\ &\rho_{YX_3}(\gamma_{YX_1}\tfrac{h_{x_1}}{h_y}\rho_{X_3X_1} - \gamma_{YX_3}\tfrac{h_{x_3}}{h_y})\,]\end{aligned}}{\sqrt{\begin{aligned}&[\,(1-\rho^2_{X_1X_2})(1-\rho^2_{X_1X_3})(1-\rho^2_{X_2X_3})(1-\rho^2_{YX_1}-\rho^2_{YX_2}- \\ &\rho^2_{YX_3}-\rho^2_{X_1X_2}-\rho^2_{X_1X_3}-\rho^2_{X_2X_3}+2\,\rho_{YX_1}\rho_{YX_2}\rho_{X_1X_2}+ \\ &2\,\rho_{YX_2}\rho_{YX_3}\rho_{X_2X_3}+2\,\rho_{YX_1}\rho_{YX_3}\rho_{X_1X_3})\,]\end{aligned}}}$$

Combined Selection Indices:

Optimum selection indices for the selection of males and females for the four characters separately were constructed according to Narain *et al.* (1973 a,b). Information on the breeds- Malabari, SM, AM and F_2A were pooled together because of the insufficiency of full-sibs in individual flocks.

The optimum selection index combining information from individual's own performance with those of full-sib and half-sib family averages was given by

$$I_f = (P - \bar{P}) + \bar{b}_1 (P_{FS} - \bar{P}) + \bar{b}_2 (P_{HS} - \bar{P})$$

P = daughter's own performance

$\bar{P}$ = flock average

P_{FS} = full-sib family average

P_{HS} = half-sib family average

$$b_1 = \frac{2\,\bar{n}_i (1 - h^2)}{[4 + (\bar{n}_i - 2)h^2]}$$

$$b_2 = \frac{4\,\bar{n}_i \bar{d}\,(1 - h^2)(2 - h^2)}{[4 + (\bar{n}_i - 2)\,h^2]\,[4 + \{\bar{n}_i(1 + \bar{d}) - 2\}\,h^2]}$$

where $\bar{d}$ = average number of dams per sire.

$\bar{n}_i$ = average number of daughters per dam family for the sire i.

h^2 = heritability value for the trait.

The optimum selection index for the selection of males combining information from full-sib and half-sib family averages was also constructed as

$$I_m = b_1 (P_{FS} - \bar{P}) + b_2 (P_{HS} - \bar{P})$$

b_1 and b_2 can be calculated using the formulae given above.

The expected response due to selection for females based on the index at 25% intensity of selection was given by

$$R_f = \frac{1}{2} i_f \sigma p\, h^2 \left[\frac{(\bar{n} - 1)}{2 \bar{n} (2 - h^2)} + \frac{(\bar{d} - 1) (\bar{n} + 2)}{4 \bar{n} \bar{d} [4 + (\bar{n} - 2) h^2]} \frac{\{ \bar{n} (1 + \bar{d}) + 2 \}}{4 \bar{n} \bar{d} [4 + \{ \bar{n} (1 + \bar{d}) - 2 \} h^2} \right]^{1/2}$$

where

$i_f = \frac{z}{q}$ where q is the intensity of selection and z is the ordinate at the point of selection.

σp = phenotypic S.D of the trait.

h^2 = heritability value.

$\bar{d}$ = average number of dams per sire.

$\bar{n}$ = average number of daughters per dam family.

The expected response due to selection for males based on an index combining information from full-sib and half-sib family averages for the intensity of selection i_m was given by the formula

$$R_m = \frac{1}{2} i_m \sigma_p h^2 \left[\frac{\bar{n}}{\bar{d}} \left\{ \frac{(\bar{d} - 1)}{[4 + (\bar{n} - 2) h^2]} + \frac{(\bar{d} + 1)^2}{[4 + \{\bar{n}(\bar{d} + 1) - 2\} h^2]} \right\} \right]^{1/2}$$

where $i_m = \frac{z}{q}$ where q is the intensity of selection and z is the ordinate at the point of selection.

<u>General Selection Indices:</u>

Marutiram *et al.* (1972) reported that the index with the use of record of dam was more efficient than the one without the use of record of dam for selection among females and males. But information pertaining to the four characters under study were not available for most of the dams. Also the number of full-sibs in each breed was found to be very less. So general selection indices for the selection among males were constructed according to the modified form of Osborne's index (1957b)

$$I = \hat{A} = b_1 P + b_2 \bar{H}$$

even though this index was proved to be less efficient than the Marutiram's index (1972).

where P = own performance

$\bar{H}$ = mean of it's 'n' paternal half-sibs.

The 'b' values were estimated using the formulae

$$b_1 = h^2 \ (16 - h^2 N) \ / \ Q$$

$$b_2 = 4 \ h^2 N \ (1 - h^2) \ / \ Q$$

where $Q = 16 - h^4 N$

$$N = \frac{n}{1 + (n - 1) \ h^2/4}$$

where h^2 is the heritability coefficient.

The multiple correlation between the index (I) and the breeding value (A) was obtained from

$$R_{AI} = \sqrt{b_1 + \frac{1}{4} b_2}$$

These indices were constructed for each character and for each breed.

RESULTS

The relative economic values for the four traits viz. birth weight, age at first kidding, body weight at first kidding and first lactation milk yield were calculated by taking into consideration the cost of production of each trait.

Cost for the different varieties of feeds and fodders during the period (January, 1982 to December, 1983) were as given below

Average cost of kid-startor = 1.93 Rs/Kg

Average cost of concentrated feed = 1.57 Rs/Kg

Average cost of fodder including transportation charges = 0.19 Rs/Kg

Average quantity of milk fed to a kid based on its body weight during the period of the first three months had been calculated as 511 gms/day.

Table 1. Cost Per Head Per Day on Various Categories of Goats.

Sl.No	Category	Feed items (daily ration): conc.feed (gm)	fodder (kg)	milk fed (gm)	No.of goats	cost of labour (Rs)	Cost/ head/ day (Rs)
1.	Kids	390 (kid-starter)	0.75	511	369	0.07	1.94
2.	Female young stock	400 (kid-starter)	1.25	-	317	0.05	1.06
3.	Adult				372	0.03	1.12
	Adults	400	2.00	-			
	4th month of pregnancy	600	3.00	-			
	5th month of pregnancy	700	3.00	-			

The cost per head per day for attaining the age at first kidding was computed by giving due weightage to the length of age (in days) pertaining to kids, female young stock and adults as follows:

$$= \frac{\text{Rs } 1.94 \times 90 \text{ days} + \text{Rs } 1.06 \times 90 \text{ days} + \text{Rs } 1.12 \times 423 \text{ days}}{90 \text{ days(kids)} + 90 \text{ days(female young stock)} + 423 \text{ days(adults)}}$$

= 1.23 Rs. per head per day

or 36.9 Rs. per head per month.

The cost value of milk was calculated from the rates at which milk was sold at different parts of the 2 years. Different rates were:

Rate from 1.1.82 to 15.9.83 (for 20.5 months) = 2.20 Rs/kg

Rate from 15.9.83 to 31.12.83 (for 3.5 months) = 2.60 Rs/kg

The average rate at which milk was sold comes to

$$\frac{2.20 \times 20.5 + 2.60 \times 3.5}{24} = 2.26 \text{ Rs/kg}$$

The regression coefficient of milk yield on birth weight was 12.96 and on weight at first kidding was 3.83.

Since older age at first kidding is not desirable from the economic point of view, the relative economic weight for this trait was assigned a negative sign. The economic weights for the other three traits were given positive signs, because any increase in each of them would consequently increase the net value of the animals. To make the calculations easy and meaningful, a constant value of +17 had been added to each of them.

Table 2. Relative Economic Values of the four Characters.

Trait	Unit of measurement	Cost/unit (Rs)	Relative economic values	Corrected relative economic values
Birth weight(X_1)	Kg	29.28	12.96	29.96
Age at first kidding(X_2)	Month	36.90	-16.33	0.67
Weight at first kidding(X_3)	Kg	8.66	3.83	20.83
First lactation milk yield(X_4)	Kg	2.26	1.00	18.00

The corrected economic values coded in Table 2. were used in the construction of selection indices.

Estimate of heritability coefficients, computed by half-sib analysis method for the breeds Malabari, Sannen X Malabari (SM), Alpine X Malabari (AM) and AM X AM (F_2A) were presented in Table 3.

Selection indices were constructed by different methods for each breed separately to make a comparative study of these indices breedwise for the improvement of goats.

Simultaneous Selection Indices

Simultaneous selection indices were constructed by incorporating the four important economic traits viz. birth weight, age at first kidding, body weight at first kidding and first lactation milk yield. The relative economic value for each trait in rupees was calculated as 29.96 for birth weight, 9.67 for age at first kidding, 20.83 for body weight at first kidding and 18.00 for first lactation milk yield.

The index $I = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4$ constructed for each breed was given in Table 4.

The expected genetic advance due to the index constructed for Malabari breed at five percent intensity of selection was found to be 5442.7574 and that due to straight selection was 2561.2345. The percent gain in efficiency in expected genetic advance due to selection index over that due to straight selection was worked out as 112.51% (Table 4). From this it was concluded that selection based on an index was more efficient than straight selection.

In the case of the breed SM, the expected genetic advance due to selection index at five percent intensity of selection was calculated as 769.1024 and that due to straight selection was 312.3529. The percent gain in efficiency in expected genetic advance due to selection index over that due to straight selection was found to be 146.23% (Table 4). It was confirmed that index selection is superior to straight selection.

The selection index constructed for the breed AM, brought about an expected genetic gain of 265.7435 at five percent intensity of selection and that due to straight selection was only 114.3664. The percent gain in efficiency in expected genetic advance due to selection index over that due to straight selection was found to be 132.36% (Table 4).

The expected genetic advance due to selection index was found to be 1052.9766 for the breed, F_2A and that due to straight selection was 817.7718. The percent gain in efficiency in expected genetic advance due to index selection over that due to straight selection was worked out as 28.76% (Table 4). This showed that selection based on selection index was more efficient than straight selection.

Restricted Selection Indices

Restricted selection index for each breed constructed by imposing restriction on birth weight was given in Table 5. The expected genetic advance obtained in individual characters were also presented in the same table. The expected genetic advance for birth weight was found to be zero for the breeds Malabari, SM and F_2A. Hence we can conclude that the index constructed by imposing restriction on birth weight would maximize the genetic progress in the other three characters without any change in birth weight. But effective restriction on birth weight was not possible for the breed AM. In this case, the expected genetic advance of the restricted character was not equal to zero.

Another index, imposing restriction on age at first kidding was also constructed for each breed. The genetic advance obtained for the four characters were also presented in Table 5. For none of the breeds, the expected genetic advance for age at first kidding was equal to zero. Hence it was not able to maximize the genetic advance in the other three characters, by imposing restriction on age at first kidding.

The third index was construted by imposing restriction on body weight at first kidding. The expected genetic advances in individual characters were also calculated and presented in Table 5. The genetic progress in the character, body weight at first kidding was found to be equal to zero for the breeds AM and F_2 A. Hence it was able to achieve maximum genetic advances in the other three characters by stabilizing any improvement in body weight at first kidding. But in the case of Malabari and SM breeds, the expected genetic advance for the restricted trait was not equal to zero. This indicated that effective restriction of body weight at first kidding was not possible for these breeds.

Restricted selection indices, constructed by imposing restrictions on birth weight and age at first kidding simultaneously were presented in Table 5. From the genetic advances obtained for the four characters, it was found that for none of the breeds, the genetic advances for the restricted characters were not equal to zero. Hence it was not possible to attain maximum genetic advances in body weight at first kidding and first lactation milk yield, without any change in birth weight and age at first kidding.

Restricted selection indices were also constructed by restricting the characters, birth weight and body weight at first kidding. The genetic advances obtained in individual characters corresponding to this index in each breed were also presented in Table 5. For none of the breeds, the genetic advances in the restricted traits were found to be equal to zero. Hence it was not possible to maximize the genetic advances in age at first kidding and first lactation milk yield , by keeping birth weight and body weight at first kidding at constant levels.

Restricted selection indices, constructed for each breed, by imposing restriction on age at first kidding and body weight at first kidding were also presented in Table 5. The expected genetic advances for the four characters, in each case were also worked out and given in the same table. For none of the breeds, the genetic advances in age at first kidding and body weight at first kidding were found to be equal to zero. Hence the genetic advances in birth weight and first lactation milk yield could not be maximized, by restricting the improvements in age at first kidding and body weight at first kidding.

The expected genetic advances obtained for the four characters, corresponding to the restricted selection index, constructed for each breed, by imposing restriction on birth weight, age at first kidding and body weight at first kidding were also given in Table 5. The expected genetic advances for the restricted traits were not equal to zero in any breed. This showed that maximum genetic progress in milk yield could not be attained without any progress in the other three traits.

Phenotypic Selection Indices

For each breed, seven phenotypic selection indices were constructed for the selection of the main trait- first lactation milk yield (Y) by taking into consideration the auxiliary traits viz. birth weight (X_1), age at first kidding (X_2) and body weight at first kidding (X_3). The efficiency of each phenotypic index for selection as compared to phenotypic value of the main trait Y alone, was given in Table 6.

The index $I_1 = Y - 7.897925\ X_1$ for improving the first lactation milk yield (Y) in Malabari goats by taking into consideration the auxiliary trait- birth weight (X_1), brought about a decline in the efficiency of selective breeding by 25.52%. The phenotypic index constructed was

$$I_2 = Y - 0.001920\ X_2$$

when age at first kidding was taken as auxiliary trait. But the decrease in effiiency of selective breeding was only 7% in this case. The phenotypic index formed between the main trait Y and the auxiliary trait- body weight at first kidding was

$$I_3 = Y - 1.819596\ X_3$$

This index resulted in a decrease in efficiency of selective breeding by 26.48%.

The relative efficiency of the index,

$$I_4 = Y - 7.944020\ X_1 + 0.080595\ X_2$$

constructed by using both the auxiliary traits- birth weight and age at first kidding simultaneously to correct variations in milk production, was found out to be decreased by 12.39%.

The use of birth weight and body weight at first kidding as auxiliary traits resulted in a decline in efficiency of selective breeding by 59.85%. The index, so constructed was

$$I_5 = Y - 5.273175\ X_1 - 1.734767\ X_3.$$

The index $I_6 = Y + 0.00920\ X_2 - 1.956887\ X_3$ resulted in a decrease in efficiency of selective breeding by 25.62% ; when age at first kidding and body weight at first kidding were used as auxiliary traits, to correct variations in first lactation milk production.

Efficiency of selective breeding was the least for the index,

$$I_7 = Y - 5.879830\ X_1 + 0.010649\ X_2 - 1.883882\ X_3$$

where the auxiliary traits considered were birth weight, age at first kidding and body weight at first kidding to correct variations in first lactation milk production. In this case, the efficiency of selective breeding was decreased by 69.87%.

The above results indicated that selection based on the phenotypic value of main trait- first lactation milk yield was the most efficient method compared to any phenotypic selection index for the Malabari goats.

Phenotypic indices constructed for the selection of the main trait, first lactation milk yield (Y) in SM goats by considering the auxiliary traits viz. birth weight (X_1), age at first kidding (X_2) and body weight at first kidding (X_3) were given in Table 6. The relative efficiencies of these indices were also presented in the same table.

From the index $I_1 = Y - 6.484287\ X_1$ for selection of the main trait- first lactation milk yield by using birth weight as the auxiliary trait resulted in a decrease in the efficiency of selective breeding by 14.6 percent. The most efficient among this series of indices was

$$I_2 = Y - 0.021071\ X_2$$

where age at first kidding was used as the auxiliary trait. In this case, the efficiency of selective breeding was increased by 12.33 percent. But the efficiency was decreased by 27.3 percent in

$I_3 = Y - 2.752958\ X_3$ when body weight at first kidding was used as auxiliary trait. In the case of

$$I_4 = Y - 6.014413\ X_1 - 0.019841\ X_2$$

when both birth weight and age at first kidding were used as auxiliary traits simultaneously, the relative efficiency was decreased by 2.45 percent.

There was 42.43 percent decrease in efficiency in

$$I_5 = Y - 1.757431\ X_1 - 0.079792\ X_3$$

when both birth weight and body weight at first kidding were used as auxiliary traits simultaneously to correct variations in milk production.

The index $I_6 = Y + 0.021811\ X_2 - 3.102313\ X_3$ showed a decrease in efficiency of 45.10 percent when both age at first kidding and body weight at first kidding were used simultaneously as auxiliary traits. The relative efficiency was decreased by 23.95 percent in

$$I_7 = Y - 1.583389\ X_1 + 0.736968\ X_2 - 3.067000\ X_3$$

when all the three traits viz. birth weight, age at first kidding and body weight at first kidding were used as auxiliary traits to correct variations in milk production.

Seven phenotypic selection indices for AM goats

$I_1 = Y - b_1X_1$

$I_2 = Y - b_2X_2$

$I_3 = Y - b_3X_3$

$I_4 = Y - b_1X_1 - b_2X_2$

$I_5 = Y - b_1X_1 - b_3X_3$

$I_6 = Y - b_2X_2 - b_3X_3$

$I_7 = Y - b_1X_1 - b_2X_2 - b_3X_3$

constructed between the main trait- first lactation milk yield (Y) and the auxiliary traits viz. birth weight (X_1), age at first kidding (X_2) and body weight at first kidding (X_3) and their relative efficiencies were given in Table 6.

The index $I_1 = Y - 9.698900\ X_1$ when birth weight was used as auxiliary trait for improving the main trait- first lactation milk yield, resulted in an increase in efficiency of selective breeding by about 23.60 percent.

The increase in efficiency was 10.45 percent for the index

$I_2 = Y - 0.042736\ X_2$ when age at first kidding was used as the auxiliary trait.

The third phenotypic index formed was

$$I_3 = Y - 2.893867\ X_3$$

when body weight at first kidding was used as the auxiliary trait for improving the first lactation milk yield. This index increased the efficiency of selective breeding by about 42.40 percent. The index,

$$I_4 = Y - 6.397871\ X_1 - 0.036259\ X_2$$

where birth weight and age at first kidding were used as auxiliary traits simultaneously to correct variations in milk production, resulted in an increase in efficiency of selective breeding by 16.85 percent.

The increase in efficiency was risen to 52.16 percent for the index

$$I_5 = Y - 3.698261\ X_1 - 2.898186\ X_3$$

when birth weight and body weight at first kidding were used as auxiliary traits simultaneously for improving the first lactation milk yield .

In the case of $I_6 = Y - 0.004767\ X_2 - 2.831548\ X_3$, when both age at first kidding and body weight at first kidding were used as auxiliary traits simultaneously, the relative efficiency of selective breeding was increased by about 42.91 percent.

It was interesting to note that the relative efficiency was the highest for the index

$$I_7 = Y - 3.584284\ X_1 - 0.001716\ X_2 - 2.788382\ X_3$$

when all the three characters viz. birth weight, age at first kidding and body weight at first kidding were used as auxiliary traits to correct variations in milk production. In this case, the increase in efficiency of selective breeding was found to be 71.21 percent.

A similar type of seven phenotypic selection indices were constructed for F_2 A goats also. The relative efficiency of selective breeding was also calculated for each index and was presented in Table 6.

The index $I_1 = Y - 22.298827\ X_1$, between the main trait milk production and birth weight as auxiliary trait resulted in a decrease in efficiency of selective breeding by 16.31 percent.

In the case of the index $I_2 = Y - 0.018437\ X_2$, when age at first kidding was used as the auxiliary trait to correct variations in milk production, the decrease in efficiency was found to be 11.88 percent.

But the efficiency was decreased by 27.60 percent in $I_3 = Y - 1.910154\ X_3$, when body weight at first kidding was used as auxiliary trait.

In the case of $I_4 = Y - 23.059273\ X_1 - 0.024765\ X_2$, when both birth weight and age at first kidding were used as auxiliary traits simultaneously, the relative efficiency was decreased by 34.33 percent.

There was 38.08 percent decrease in efficiency in

$$I_5 = Y - 17.588452\ X_1 - 1.616655\ X_3$$

when both birth weight and body weight at first kidding were used as auxiliary traits to correct variations in milk yield.

The index $I_6 = Y - 0.010231\ X_2 - 0.074330\ X_3$ showed a decrease in efficiency of selective breeding by 34.48 percent, when both age at first kidding and body weight at first kidding were used as auxiliary traits simultaneously.

The relative efficiency was decreased by 66.78 percent in

$$I_y = Y - 18.268427\ X_1 - 0.016652\ X_2 - 1.558772\ X_3,$$

when all the three traits viz. birth weight , age at first kidding and body weight at first kidding were used as auxiliary traits simultaneously, to correct variations in first lactation milk production.

Combined Selection Indices

Optimum selection indices combining information from individual's performance with those of full-sib and half-sib family averages were constructed for individual characters. These indices in descending order were presented in Table 7 to 10. If 25 percent best animals are to be selected as parents, corresponding to the intensity of selection (0.32/0.25) = 1.27, we have to choose the first 17 animals with scores given in Table 11.

In the case of birth weight, the score of the selected animals ranged from 0.4569 to 1.9607. For the character age at first kidding, the individuals with the least scores were preferred. The selection scores of the animals ranged from -262.9947 to -506.0299.(Reduction in age at first kidding increases the economic value of the animal). But for the trait body weight at first kidding, the scores ranged from 7.0349 to 25.7974. The range was found to be 35.8352 to 137.4889 for the trait first lactation milk yield.

The expected responses due to combined selection for females, when the information from individual's performance was combined with full-sib and half-sib family averages in an optimal manner were also calculated and given in Table 11.

The expected response due to selection of females for the traits birth weight, age at first kidding, body weight at first kidding and first lactation milk yield were found to be 24.29 percent, 1878.99 percent, 38.45 percent and 543.42 percent respectively.

Optimum selection indices were constructed for males combining information from full-sib and half-sib family averages for individual characters. The calculated scores of the full-sib families in descending order for each character were given in Table 12 to 15. 7 out of 33 families were selected with an intensity of selection 1.335.

The selection scores of the selected males ranged from 0.001771 to 0.004835 for birth weight, -152.5735 to -197.5535 for age at first kidding, 6.4083 to 13.0312 for body weight at first kidding and 24.3403 to 48.9525 for first lactation milk yield. The expected responses due to selection of males, combining information from full-sib and half-sib family averages from Table 16 showed 49.50 percent for birth weight, 5479.93 percent for age at first kidding, 67.24 percent for body weight at first kidding and 868.37 percent for first lactation milk yield.

General Selection Indices

General selection indices for the selection among males were constructed for each character and for each breed. The values of b_1, b_2, the multiple correlation R_{AI} and the range of $\hat{A}$ for males were given from Table 17 through 20. The range of values of R_{AI} for the above traits were found to be 0.7366 to 0.7532, 0.6962 to 0.7178, 0.7110 to o.7308 and 0.5790 to 0.6166 respectively for Malabari breed; 0.7560 to 0.7736, 0.8080 to 0.8191, 0.6482 to 0.6852 and 0.4835 to 0.5505 respectively for the breed SM; 0.7022 to 0.7209, 0.7443 to 0.7565, 0.7343 to 0.7479 and 0.6067 to 0.6421 respectively for the breed AM; 0.6634 to 0.6920, 0.7363 to 0.7541, 0.6838 to 0.7091 and 0.6324 to 0.6661 respectively for the breed F_2A.

Table 3. Heritabilities with Standard Errors.

Breed	Characters	Heritability with S.E.
Malabari	Birth weight	0.5241 ± 0.4442
	Age at first kidding	0.4636 ± 0.4287
	Body weight at first kidding	0.4855 ± 0.4344
	First lactation milk yield	0.3109 ± 0.3861
SM	Birth weight	0.5547 ± 0.4104
	Age at first kidding	0.6403 ± 0.4399
	Body weight at first kidding	0.3988 ± 0.3615
	First lactation milk yield	0.2113 ± 0.2906
AM	Birth weight	0.4478 ± 0.3703
	Age at first kidding	0.5144 ± 0.4034
	Body weight at first kidding	0.4994 ± 0.3961
	First lactation milk yield	0.3119 ± 0.2980
F_2A	Birth weight	0.4120 ± 0.4638
	Age at first kidding	0.5195 ± 0.5126
	Body weight at first kidding	0.4405 ± 0.4771
	First lactation milk yield	0.3704 ± 0.4439

Table 4. Simultaneous selection indices for the breeds under study

Breed	Simultaneous selection index	% gain in efficiency
Malabari	$-554.6106X_1 - 4.3909X_2 + 935.7179X_3 - 93.2678X_4$.	112.51
SM	$821.6769X_1 - 2.9747X_2 + 75.7503X_3 - 2.9935X_4$.	146.23
AM	$-101.0579X_1 + 0.6199X_2 + 15.3065X_3 - 1.5552X_4$.	132.36
F A	$238.6300X_1 + 2.3150X_2 + 40.4416X_3 + 3.9022X_4$.	28.76

X_1 = Birth weight

X_2 = Age at first kidding

X_3 = Body weight at first kidding

X_4 = First lactation milk yield

Table 5. Restricted selection indices and their expected genetic gains.

Breed: Malabari

Character(s) on which restriction(s) is(are) imposed	Restricted selection index constructed	Genetic advance in individual characters obtained	
Birth weight	$30099.2514X_1 - 7.7516X_2 -$	$\Delta X_1 =$	0.0010
	$24.0268X_3 - 141.8009X_4$	$\Delta X_2 =$	-1330.5190
		$\Delta X_3 =$	731.5087
		$\Delta X_4 =$	2.3772
Age at first kidding	$753.5414X_1 - 0.0805X_2 +$	$\Delta X_1 =$	53.7171
	$514.8775X_3 - 29.6436X_4$	$\Delta X_2 =$	-0.0581
		$\Delta X_3 =$	79.9820
		$\Delta X_4 =$	5.1312
Body weight at first kidding	$-58.0864X_1 - 3.0996X_2 +$	$\Delta X_1 =$	88.9093
	$685.7276X_3 - 68.0574X_4$	$\Delta X_2 =$	189.8078
		$\Delta X_3 =$	-6.6845
		$\Delta X_4 =$	4.2673
Birth weight and age at first kidding simultaneously	$477.4936X_1 + 5.9725X_2 +$	$\Delta X_1 =$	30.0900
	$103.2241X_3 + 58.4046X_4$	$\Delta X_2 =$	85.0997
		$\Delta X_3 =$	162.4001
		$\Delta X_4 =$	21.1516

Table 5. contd.....

Character(s) on which restriction(s) is(are) imposed	Restricted selection index constructed	Genetic advance in individual characters obtained
Birth weight and body weight at first kidding simultaneously	$-3.7264X_1+0.8747X_2+1.3269X_3+7.0422X_4$	$\Delta X_1=$ -0.4891 $\Delta X_2=$ 334.6170 $\Delta X_3=$ -1.0786 $\Delta X_4=$ 19.9987
Age at first kidding and body weight at first kidding simultaneously	$14.4199X_1-5.6462X_2+386.7211X_3-74.4720X_4$	$\Delta X_1=$ 129.4389 $\Delta X_2=$ -0.3041 $\Delta X_3=$ 0.0387 $\Delta X_4=$ -9.2517
Birth weight, Age at first kidding, Body weight at first kidding simultaneously	$279.4633X_1-0.0697X_2+2.6405X_3-1.6005X_4$	$\Delta X_1=$ 0.8948 $\Delta X_2=$ -150.8476 $\Delta X_3=$ 1.9195 $\Delta X_4=$ 18.8134

Table 5. contd.....

Breed: SM

Character(s) on which restriction(s) is(are) imposed	Restricted selection index constructed	Genetic advance in individual characters obtained
Birth weight	$-42.4762X_1+0.1631X_2+27.2706X_3-0.1265X_4$.	$\Delta X_1 = -0.000008$
		$\Delta X_2 = 118.5601$
		$\Delta X_3 = 2.5440$
		$\Delta X_4 = 2.2426$
Age at first kidding	$263.4564X_1-2.5090X_2+61.9948X_3-2.5954X_4$.	$\Delta X_1 = 0.7272$
		$\Delta X_2 = -157.8669$
		$\Delta X_3 = -1.2178$
		$\Delta X_4 = 21.1774$
Body weight at first kidding	$354.0430X_1-2.9261X_2+75.9906X_3-2.9573X_4$.	$\Delta X_1 = 0.7926$
		$\Delta X_2 = -162.8066$
		$\Delta X_3 = -0.9753$
		$\Delta X_4 = 23.0105$
Birth weight and Age at first kidding simultaneously	$-36.4476X_1+0.0603X_2-1.0682X_3+32.2500X_4$.	$\Delta X_1 = 0.9487$
		$\Delta X_2 = -207.5204$
		$\Delta X_3 = 5.7185$
		$\Delta X_4 = 41.1176$
Birth weight and Body weight at first kidding simultaneously	$-55.9611X_1-7.9934X_2+229.2489X_3-0.2234X_4$.	$\Delta X_1 = 2.0973$
		$\Delta X_2 = -398.8841$
		$\Delta X_3 = -4.1209$
		$\Delta X_4 = 71.1377$

Table 5. contd.....

Character(s) on which restriction(s) is(are) imposed	Restricted selection index constructed	Genetic advance in individual characters obtained	
Age at first kidding and Body weight at first kidding simultaneously	$41.1711X_1-0.8011X_2+35.7529X_3-3.8215X_4$.	$\Delta X_1=$	0.5969
		$\Delta X_2=$	0.0881
		$\Delta X_3=$	-0.0025
		$\Delta X_4=$	17.9091
Birth weight, Age at first kidding and Body weight at first kidding simultaneously	$279.4633X_1-0.0697X_2+2.6405X_3-1.6005X_4$.	$\Delta X_1=$	0.8948
		$\Delta X_2=$	-150.8476
		$\Delta X_3=$	1.9195
		$\Delta X_4=$	18.8134

Table 5. contd......

Breed: AM

Character(s) on which restriction(s) is(are) imposed	Restriction selection index constructed	Genetic advance in individual characters obtained
Birth weight	$-150.4183X_1+0.6132X_2+$	$\Delta X_1= -0.1737$
	$6.8171X_3+0.8260X_4.$	$\Delta X_2= 34.0446$
		$\Delta X_3= 0.9605$
		$\Delta X_4= 5.7723$
Age at first kidding	$-108.9744X_1+0.3236X_2-$	$\Delta X_1= -0.1923$
	$1.6773X_3+0.9761X_4.$	$\Delta X_2= 0.7106$
		$\Delta X_3= -0.2590$
		$\Delta X_4= 4.5351$
Body weight at first kidding	$-132.0594X_1+0.2727X_2+$	$\Delta X_1= -0.1531$
	$2.5984X_3+0.6411X_4.$	$\Delta X_2= 11.9042$
		$\Delta X_3= 0.0086$
		$\Delta X_4= 4.2539$
Birth weight and Age at first kidding simultaneously	$3.8242X_1-0.0049X_2+$	$\Delta X_1= 0.0250$
	$0.0244X_3+0.1508X_4.$	$\Delta X_2= 7.3590$
		$\Delta X_3= 0.5234$
		$\Delta X_4= -1.1195$
Birth weight and Body weight at first kidding simultaneously	$-45.4839X_1-0.1594X_2+$	$\Delta X_1= -0.0529$
	$7.1841X_3-0.3599X_4.$	$\Delta X_2= 28.8645$
		$\Delta X_3= -0.6864$
		$\Delta X_4= 4.1268$

Table 5. contd.....

Character(s) on which restriction(s) is(are) imposed	Restricted selection index constructed	Genetic advance in individual characters obtained
Age at first kidding and Body weight at first kidding simultaneously	$-76.6006X_1+9.8842X_2-5.5612X_3+1.1350X_4$.	ΔX_1= 1.1620 ΔX_2= 570.4113 ΔX_3= 23.7693 ΔX_4= -7.1521
Birth weight, Age at first kidding and Body weight at first kidding simultaneously	$-927.4260X_1+27.1049X_2+7.4001X_3+0.0057X_4$.	ΔX_1= 1.6551 ΔX_2= 909.8280 ΔX_3= 943.9732 ΔX_4= -6.3599

Table 5. contd.....

Breed: F_2A

Character(s) on which restriction(s) is(are) imposed	Restricted selection index constructed	Genetic advance in individual characters obtained
Birth weight	$-141.2684X_1+2.1198X_2+8.4023X_3+5.2540X_4$.	$\Delta X_1 = 0.0042$ $\Delta X_2 = 96.0227$ $\Delta X_3 = 2.8017$ $\Delta X_4 = 15.6321$
Age at first kidding	$-119.1193X_1+0.8613X_2+23.8838X_3-6.9352X_4$.	$\Delta X_1 = -0.8268$ $\Delta X_2 = 16.3459$ $\Delta X_3 = -0.2178$ $\Delta X_4 = 9.9642$
Body weight at first kidding	$-236.9347X_1+0.6148X_2+20.1670X_3-3.1681X_4$	$\Delta X_1 = -0.0417$ $\Delta X_2 = 42.3065$ $\Delta X_3 = 0.0013$ $\Delta X_4 = 8.7989$
Birth weight and Age at first kidding simultaneously	$240.5623X_1+1.1326X_2+0.1956X_3-1.6688X_4$.	$\Delta X_1 = 2.1620$ $\Delta X_2 = 64.9329$ $\Delta X_3 = 4.1932$ $\Delta X_4 = 22.0954$
Birth weight and Body weight at first kidding simultaneously	$-195.1164X_1+0.4487X_2+25.4147X_3-3.9776X_4$.	$\Delta X_1 = -0.0018$ $\Delta X_2 = 67.2143$ $\Delta X_3 = -0.0146$ $\Delta X_4 = 18.3598$

Table 5. contd.....

Character(s) on which restriction(s) is(are) imposed	Restricted selection index constructed	Genetic advance in individual characters obtained
Age at first kidding and Body weight at first kidding simultaneously	$98.0021X_1+0.7791X_2+18.9450X_3-6.1157X_4$.	ΔX_1 = 0.0958 ΔX_2 = 13.1010 ΔX_3 = 1.6128 ΔX_4 = 20.7115
Birth weight, Age at first kidding and Body weight at first kidding simultaneously	$6.0578X_1+3.4078X_2+10.2871X_3-5.2266X_4$.	ΔX_1 = -0.0832 ΔX_2 = 152.7978 ΔX_3 = 4.6465 ΔX_4 = 36.2421

Table 6. Phenotypic selection indices and their relative efficiencies.

Brred	Phenotypic selection indices	Relative efficiency%
Malabari	$I_1 = Y - 7.897525X_1$	74.48
	$I_2 = Y - 0.001920X_2$	97.00
	$I_3 = Y - 1.819596X_3$	73.52
	$I_4 = Y - 7.944020X_1 + 0.000595X_2$	87.61
	$I_5 = Y - 5.273175X_1 - 1.734767X_3$	40.15
	$I_6 = Y + 0.009202X_2 - 1.956887X_3$	74.38
	$I_7 = Y - 5.879830X_1 + 0.010649X_2 - 1.883882X_3$	30.13
	Selection on Y alone	100.00
SM	$I_1 = Y - 6.404287X_1$	85.60
	$I_2 = Y - 0.021071X_2$	112.33
	$I_3 = Y - 2.752958X_3$	72.70
	$I_4 = Y - 6.014413X_1 - 0.019841X_2$	97.55
	$I_5 = Y - 1.757431X_1 - 0.079792X_3$	57.57
	$I_6 = Y + 0.021611X_2 - 3.102313X_3$	54.90
	$I_7 = Y - 1.583389X_1 + 0.736968X_2 - 3.067000X_3$	76.05
	Selection on Y alone	100.00

Table 6. contd.....

Breed	Phenotypic selection indices	Relative efficiency%
AM	$I_1 = Y - 9.698900X_1$	123.60
	$I_2 = Y - 0.042736X_2$	110.45
	$I_3 = Y - 2.893867X_3$	142.40
	$I_4 = Y - 6.397871X_1 - 0.036259X_2$	116.85
	$I_5 = Y - 3.698261X_1 - 2.808186X_3$	152.16
	$I_6 = Y - 0.004767X_2 - 2.831548X_3$	142.91
	$I_7 = Y - 3.584284X_1 - 0.001716X_2 - 2.788382X_3$	171.21
	Selection on Y alone	100.00
F_2A	$I_1 = Y - 22.298827X_1$	83.69
	$I_2 = Y - 0.018437X_2$	88.12
	$I_3 = Y - 1.910154X_3$	72.40
	$I_4 = Y - 23.059273X_1 - 0.024765X_2$	65.67
	$I_5 = Y - 17.588452X_1 - 1.616655X_3$	61.92
	$I_6 = Y - 0.010231X_2 - 0.074330X_3$	65.52
	$I_7 = Y - 18.268427X_1 - 0.016652X_2 - 1.558772X_3$	33.22
	Selection on Y alone	100.00

Table 7. Birth weight: Combined selection index for females combining information from individual's performance with those of full-sib and half-sib family averages.

Sire no:	Dam no:	Daughter no:	$P - \bar{P}$	$b_1 (P_{FS} - \bar{P})$	$b_2 (P_{HS} - \bar{P})$	I_f
S293	58	715	1.9559	0.0035	0.0013	1.9607
59	249	6675	1.6559	0.0027	0.0001	1.6587
62	A25	6505	1.5590	0.0027	0.0016	1.1584
59	161	6180	1.1559	0.0011	0.0001	1.1571
S293	63	795	1.0559	0.0024	0.0013	1.0597
S293	80	690	0.9559	0.0015	0.0013	0.9587
S293	63	796	0.7559	0.0024	0.0013	0.7597
S293	58	716	0.6559	0.0035	0.0013	0.6607
S293	119	756	0.6559	0.0015	0.0013	0.6587
62	A25	6506	0.6559	0.0027	-0.0002	0.6584
84	A89	921	0.6559	0.0018	-0.0001	0.6576
84	A89	922	0.6559	0.0018	-0.0001	0.6576
58	58	6376	0.6559	0.0011	-0.0002	0.6568
62	A62	6397	0.6559	0.0005	-0.0002	0.6562
62	28	6418	0.6559	-0.0006	-0.0002	0.6551
S293	119	757	0.4559	0.0015	0.0013	0.4587
6304	6226	41	0.4559	0.0009	0.0001	0.4569
62	185	6195	0.4559	-0.0012	-0.0002	0.4545
S293	85	713	0.3559	0.0007	0.0013	0.3579
S293	80	609	0.1559	0.0015	0.0013	0.1587
S293	85	714	0.1559	0.0007	0.0013	0.1579
6304	6226	42	0.1559	0.0009	0.0001	0.1569
58	58	6377	0.1559	0.0011	-0.0002	0.1568
58	A97	6365	0.1559	0.0004	-0.0001	0.1561
58	A97	6366	0.1559	0.0004	-0.0001	0.1561
62	114	6239	0.1559	-0.0003	-0.0002	0.1555
402	280	3166	0.1559	0.00001	-0.0007	0.1552
59	A24	6185	0.0559	-0.0004	0.0001	0.0556
62	290	6319	0.0559	-0.0001	-0.0002	0.0556
62	290	6320	-0.1441	-0.0001	-0.0002	-0.1444
402	280	3222	-0.1441	-0.0001	-0.0007	-0.1448
402	60	3241	-0.2441	-0.0008	-0.0007	-0.2440
6304	6252	34	-0.2441	-0.0004	0.0001	-0.2444
84	290	949	-0.2441	-0.0007	-0.0001	-0.2449
84	290	950	-0.2441	-0.0007	-0.0001	-0.2449
6162	6468	185	-0.2441	-0.0012	-0.0011	-0.2451
59	221	6284	-0.3441	-0.0016	0.0001	-0.3426
59	161	6012	-0.3441	0.0011	0.0001	-0.3429
402	A41	3202	-0.3441	-0.0016	-0.0007	-0.3432
62	A62	6619	-0.3441	0.0005	-0.0002	-0 3438
402	60	3242	-0.3441	-0.0008	-0.0007	-0.3440
59	A24	6498	-0.3441	-0.0004	0.0001	-0.3444

Table 7. contd.....

Sire no:	Dam no:	Daughter no:	$P - \bar{P}$	$b_1 (P_{FS} - \bar{P})$	$b_2 (P_{HS} - \bar{P})$	I_f
62	114	6343	-0.3441	-0.0003	-0.0002	-0.3445
59	290	6696	-0.3441	-0.0009	0.0001	-0.3449
59	290	6697	-0.3441	-0.0009	0.0001	-0.3449
62	494	6744	-0.3441	-0.0010	-0.0002	-0.3453
62	494	6745	-0.3441	-0.0010	-0.0002	-0.3453
58	A126	6471	-0.3441	-0.0016	-0.0002	-0.3459
402	3027	3177	-0.3441	-0.0016	-0.0007	-0.3464
59	249	6288	-0.3441	0.0027	0.0001	-0.3531
58	A40	6500	-0.3441	-0.0009	-0.0002	-0.3536
58	A40	6501	-0.3441	-0.0009	-0.0002	-0.3536
62	28	6709	-0.4441	-0.0006	-0.0002	-0.4449
62	A82	6163	-0.4441	-0.0013	-0.0002	-0.4456
62	A82	6164	-0.4441	-0.0013	-0.0002	-0.4456
6162	6468	186	-0.5441	-0.0012	-0.0011	-0.5451
84	1	969	-0.5441	-0.0016	-0.0001	-0.5458
84	1	970	-0.6441	-0.0016	-0.0001	-0.6448
59	221	6693	-0.8441	-0.0016	-0.0001	-0.8426
402	A41	3263	-0.8441	-0.0016	-0.0007	-0.8432
62	28	6710	-0.8441	-0.0006	-0.0002	-0.8449
62	185	6704	-0.8441	-0.0012	-0.0002	-0.8455
62	185	6705	-0.8441	-0.0012	-0.0002	-0.8455
58	A126	6472	-0.8441	-0.0016	-0.0002	-0.8459
402	3027	3178	-0.8441	-0.0016	-0.0007	-0.8464
6162	6297	172	-0.8441	-0.0025	-0.0011	-0.8464
6162	6297	173	-0.8441	-0.0025	-0.0011	-0.8464

Table 8. Age at first kidding: Combined selection index for females combining information from individual's performance with those of full-sib and half-sib family averages.

Sire no:	Dam no:	Daughter no:	$P - \bar{P}$	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_f
6304	6226	42	373.5588	175.2994	282.9493	831.8075
59	161	6180	507.5588	252.7396	22.3161	782.6145
6304	6252	34	231.5588	96.1609	282.9493	610.6690
6304	6226	41	142.5588	175.2994	282.9493	600.8075
S293	119	756	281.5588	172.9218	88.5896	543.0702
59	161	6012	236.5588	252.7396	22.3161	511.6145
S293	119	757	227.5588	172.9218	88.5896	489.0702
6304	6252	33	51.5588	96.1609	282.9493	430.6690
59	A24	6185	208.5588	62.5356	22.3161	293.4105
S293	85	714	127.5588	67.2907	88.5896	283.4391
58	A77	6365	184.5582	19.0604	59.3825	263.0017
S293	85	713	70.5588	67.2907	88.5896	226.4391
58	58	6376	144.5582	10.9088	59.3825	214.8501
58	A126	6472	89.5582	39.0997	59.3825	188.0404
S293	80	690	71.5588	23.7492	88.5896	182.8976
62	290	6319	263.5588	11.6567	-92.3350	182.8805
402	60	3242	143.5588	89.7076	-57.4458	175.8206
84	1	969	153.5588	55.7426	-38.1514	171.1500
58	A40	6500	66.5588	44.8738	59.3825	170.8151
58	A40	6501	65.5588	44.8738	59.3825	169.8151
402	60	3241	120.5588	89.7076	-57.4458	152.8206
58	A126	6471	25.5582	39.0997	59.3825	124.0404
S293	58	716	16.5588	8.8709	88.5896	114.0193
S293	80	689	-3.4412	23.7492	88.5896	108.8976
S293	58	715	9.5588	8.8709	88.5896	107.0193
62	A62	6397	156.5538	29.6375	-92.3350	93.8563
62	28	6418	238.5582	-72.2537	-92.3350	73.9695
59	A24	6498	-24.4412	62.5356	22.3161	60.4105
62	A25	6506	103.5588	43.1231	-92.3350	54.3469
84	1	970	10.5588	55.7426	-38.1514	28.1500
S293	63	795	-11.4412	-59.3988	88.5896	17.7496
59	249	6288	2.5588	-45.1335	22.3161	-20.2586
402	A41	3263	58.5508	-24.7545	-57.4458	-23.6415

Table 8. contd.....

Sire no:	Dam no:	Daughter no:	$P - \bar{P}$	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_f
84	290	950	9.5588	3.7761	-38.1514	-24.8165
84	290	949	1.5588	3.7761	-38.1514	-32.8165
62	A25	6535	11.5282	43.1231	-92.3350	-37.6237
58	58	6377	-112.4412	10.9088	59.3825	-42.1499
58	A77	6366	-128.4412	19.0604	59.3825	-49.9988
62	A82	6163	72.5588	-46.8381	-92.3350	-59.8143
402	3027	3178	26.5588	-69.2486	-57.4458	-100.1356
6162	6297	173	26.5588	-32.5664	-107.1863	-113.1939
6293	63	796	-163.4412	-59.3988	88.5896	-134.2504
62	A62	6619	-77.4412	29.6375	-92.3350	-140.1387
59	249	6675	-135.4412	-45.1335	22.3161	-158.2586
6162	6468	135	4.5588	-70.2676	-107.1863	-172.8951
59	221	6284	-108.4412	-91.6655	22.3161	-177.7906
62	185	6195	-2.4412	-103.7201	-92.3350	-198.4963
402	A41	3202	-131.4412	-24.7545	-57.4458	-213.6415
59	221	6693	-161.4412	-91.6655	22.3161	-230.7906
62	494	6744	-41.4412	-90.4757	-92.3350	-232.2519
6162	6297	172	-122.4412	-32.5664	-107.5664	-262.1939
62	114	6239	-65.4412	-105.2185	-92.3350	-262.9947
59	290	6696	-177.4412	-124.9512	22.3161	-280.0763
59	290	6697	-190.4412	-124.9512	22.3161	-293.0763
62	A82	6164	-179.4412	-40.8381	-92.3350	-311.8243
62	290	6320	-232.4412	11.6567	-92.3350	-313.1195
402	280	3222	-150.4412	-105.9308	-57.4458	-313.8178
84	A89	922	-166.4412	-114.4221	-38.1514	-319.0147
84	A89	921	-170.4412	-114.4221	-38.1514	-323.0147
402	280	3166	-161.4412	-105.9308	-57.4458	-324.8178
62	28	6709	-86.4412	-72.2537	-92.3350	-351.0299
402	3027	3177	-230.4412	-69.2486	-57.4458	-357.1356
62	185	6704	183.441	-103.7201	-92.3350	-379.4963
6162	6468	186	-211.4412	-70.2676	-107.1863	-388.8951
62	498	6745	-221.4412	-98.4757	-92.3350	-412.2519
62	114	6343	-215.4412	-105.2185	-92.3350	-412.9947
62	185	6705	-229.4412	-103.7201	-92.3350	-425.4963
62	28	6710	-341.4412	-72.2537	-92.3350	-506.0299

Table 9. Body weight at firt kidding: Combined selection index for females combining information from full-sib and half-sib family averages.

Sire no:	Dam no:	Daughter no:	$P - \bar{P}$	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_f
S293	63	795	13.7779	7.4372	4.5823	25.7924
58	58	6376	10.7779	4.4312	6.7964	22.0055
58	A40	6501	8.2779	6.2348	6.7964	21.3091
58	A40	6500	7.2779	6.2348	6.7964	20.3091
S293	63	796	4.7779	7.4372	4.5823	16.7974
S293	119	756	9.7779	1.8260	4.5823	16.1862
6304	6226	42	7.7779	5.0324	3.2295	16.0398
6304	6226	41	4.7779	5.0324	3.2295	13.0398
S293	85	714	6.7779	2.0664	4.5823	12.9266
58	A77	6365	5.7779	-0.5788	6.7964	11.9955
58	58	6377	0.2779	4.4312	6.7964	11.5055
59	161	6012	8.7779	2.0264	-0.1101	10.6942
62	A25	6505	8.2779	5.8151	-3.5581	10.5349
58	A126	6471	3.2779	0.2228	6.7964	10.2971
62	28	6418	12.2779	1.5541	-3.5581	10.1739
S293	80	689	3.7779	0.1426	4.5823	8.5028
62	A25	6506	4.7779	5.8151	-3.5581	7.0349
S293	85	713	-1.1221	2.0664	4.5823	5.5266
59	A24	6105	2.7779	2.2268	-0.1101	4.8946
59	A24	6498	2.7779	2.2268	-0.1101	4.8946
402	60	3241	2.7779	2.2268	-0.6016	4.4031
402	60	3242	2.7779	2.2268	-0.6016	4.4031
58	A126	6472	-2.7221	0.2228	6.7964	4.2971
402	3027	3178	3.2779	0.8240	-0.6016	3.5003
84	1	969	2.7779	1.0244	-0.4695	3.3328
S293	80	690	-3.4221	0.1426	4.5823	1.3028
S293	119	757	-5.2221	1.8260	4.5823	1.1862
S293	58	716	-0.7221	-2.7832	4.5823	1.0770
59	249	6288	0.7779	-0.2983	-0.1101	0.3695
84	1	970	-0.2221	1.0244	-0.4695	0.3328
84	290	950	1.2779	-0.5790	-0.4695	0.2296
62	28	6710	-2.2221	1.5541	-3.5581	0.2181
62	185	6195	3.7779	-0.3463	-3.5581	-0.1265

Table 9. contd.....

Sire no:	Dam no:	Daughter no:	$P - \bar{P}$	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_f
402	A41	3263	1.7779	-1.3804	-0.6016	-0.2041
402	3027	3177	-1.2221	0.8240	-0.6016	-0.9997
58	A77	6366	-7.2221	-0.5788	6.7964	-1.0045
62	A62	6397	4.2779	-1.7567	-3.5581	-1.0369
59	161	6180	-3.7221	2.0264	-0.1101	-1.8058
62	494	6745	2.7779	-1.0886	-3.5581	-1.8688
9	249	6675	-1.5221	-0.2983	-0.1101	-1.9305
402	280	3222	0.7779	-2.5828	-0.6016	-2.4065
6304	62	5233	-3.2221	-2.5828	3.2295	-2.5754
6304	6252	34	-3.2221	-2.5828	3.2295	-2.5754
84	A89	921	-1.2221	-0.9796	-0.4695	-2.6712
84	A89	922	-1.2221	-0.9796	-0.4695	-2.6712
59	298	6697	-0.2221	-2.3824	-0.1101	-2.7146
59	221	6284	-1.7221	-1.9816	-0.1101	-2.8138
84	290	949	-2.7221	-0.5788	-0.4695	-3.7704
S293	58	715	-6.2221	-2.7832	4.5823	-4.4230
62	185	6704	-2.2221	-0.3463	-3.5581	-6.1265
59	221	6693	-4.2221	-1.9816	-0.1101	-6.3138
62	185	6705	-2.7221	-0.3463	-3.5581	-6.6265
62	28	6709	-4.2221	1.5541	-3.5581	-6.7261
402	A41	3202	-5.2221	-1.3804	-0.6016	-7.2041
59	290	6696	-5.2221	-2.3824	-0.1101	-7.7146
62	494	6744	-5.2221	-1.0886	-3.5581	-9.8688
62	A82	6163	-2.2221	-4.2064	-3.5581	-9.9866
402	280	3166	-7.2221	-2.5828	-0.6016	-10.4065
6162	6468	185	1.7779	-1.3804	-11.0380	-10.6405
62	A62	6619	-8.2221	-1.7567	-3.5581	-13.5369
62	A82	6164	-7.2221	-4.2064	-3.5581	-14.9866
62	114	6239	-5.2221	-0.3463	-3.5581	-14.9909
6162	6468	186	-5.2221	-1.3804	-11.0380	-17.6405
62	290	6320	-7.6221	-7.0570	-3.5581	-18.2372
62	114	6343	-8.7221	-6.2107	-3.5581	-18.4909
62	290	6319	-8.2221	-7.0570	-3.5581	-18.8372
6162	6297	172	-7.2221	-6.9916	-11.0380	-25.2517
6162	6297	173	-10.2221	-6.9916	-11.0380	-28.2517

Table 10. First lactation milk yield: Combined selection index for females combining information from individual's performance with those of full-sib and half-sib family averages

Sire no:	Dam no:	Daughter no:	$P - \bar{P}$	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_f
58	58	6376	93.3826	26.3953	17.7110	137.4889
S293	63	795	63.7826	30.2884	18.6641	112.7351
6304	6226	41	56.7326	29.3322	16.3942	102.4590
6304	6226	42	50.6326	29.3322	16.3942	96.3590
S293	63	796	47.0826	30.2884	18.6641	96.0351
S293	119	756	64.1426	11.1671	18.6641	93.9738
62	A25	6506	65.7326	30.5970	-6.5504	89.7792
S293	85	714	66.1826	4.9081	18.6641	89.7548
S293	89	689	55.5326	9.3859	18.6641	83.5826
58	A40	6501	30.9826	15.8634	17.7110	64.5570
62	A25	6505	36.6326	30.5970	-6.5504	60.6792
58	A40	6500	27.0826	15.8634	17.7110	60.6570
84	1	969	36.7826	13.7461	-1.7714	48.7573
58	58	6377	3.2326	26.3953	17.7110	47.3389
58	A77	6365	21.6826	6.6293	17.7110	46.0229
62	28	6418	45.0826	0.7070	-6.5504	39.2392
402	68	3242	29.9826	7.8997	-2.0471	35.8352
62	A62	6397	37.9826	-0.9669	-6.5504	30.4653
58	A77	6366	2.5826	6.6293	17.7110	26.9229
S293	58	715	6.2826	0.8812	18.6641	25.8279
84	1	970	13.5326	13.7461	-1.7714	25.5073
402	3027	3178	18.4826	3.8153	-2.0471	20.2508
402	280	3222	19.7326	0.8921	-2.0471	18.5776
S293	58	716	-3.0574	0.8812	18.6641	16.4879
59	249	6288	18.7826	6.2741	-14.8317	10.2250
58	A126	6472	-2.2674	-5.8969	17.7110	9.5467
S293	89	690	-21.1774	9.3859	18.6641	6.8726
S293	119	757	-23.2674	11.1671	18.6641	6.5638
402	68	3241	-1.0674	7.8997	-2.0471	4.7852
6304	6252	34	-8.1174	-9.4349	16.3942	-1.1581
402	3027	3177	-4.5174	3.8153	-2.0471	-2.7492
59	249	6675	4.1826	6.2741	-14.8317	-4.3750
62	28	6710	0.8826	0.7070	-6.5504	-4.9608

Table 10. contd.....

Sire no:	Dam no:	Daughter no:	$P - \bar{P}$	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_f
58	A126	6471	-19.3174	-5.8969	17.7110	-7.5033
62	114	6239	3.7026	-5.0558	-6.5504	-7.9036
59	A24	6185	0.4826	-0.2280	-14.8317	-14.5771
402	280	3166	-16.4674	0.8921	-2.0471	-17.6224
6304	6252	33	-26.4174	-9.4349	16.3942	-19.4581
84	290	949	-12.7174	-7.7137	-1.7714	-22.2025
62	A82	6163	-8.7674	-8.0657	-6.5504	-23.3835
84	A89	921	-12.4174	-9.2573	-1.7714	-23.4461
5293	85	713	-48.2174	4.9081	18.6641	-24.6452
84	290	950	-15.5174	-7.7137	-1.7714	-25.0025
62	114	6343	-20.6174	-5.0558	-6.5504	-32.2236
84	A89	922	-21.4674	-9.2573	-1.7714	-32.4961
402	A41	3202	-12.9174	-17.5762	-2.0471	-32.5407
62	A82	6164	-18.2174	-8.0657	-6.5504	-32.8335
62	185	6195	-16.0174	-11.6177	-6.5504	-34.1855
59	A24	6490	-1.3174	-0.2280	-14.8327	-34.2717
62	185	6704	-16.7674	-11.6177	-6.5504	-34.9355
59	290	6696	-6.7174	-16.6883	-14.8317	-38.2374
62	185	6705	-25.5174	-11.6177	-6.5504	-43.6855
59	161	6012	-12.7174	-16.2376	-14.8317	-43.7867
62	28	6709	-42.4174	0.7070	-6.5504	-48.2608
62	A62	6619	-41.2174	-0.9669	-6.5504	-48.7347
6162	6468	185	-15.0674	-8.5880	-25.6770	-49.3324
6162	6468	135	-16.3674	-8.5880	-25.6770	-50.6324
62	494	6745	-26.9174	-18.4226	-6.5504	-51.8904
59	221	6284	-21.6174	-18.1226	-14.8317	-54.5717
62	290	6320	-29.0674	-20.1861	-6.5504	-55.8039
62	494	6744	-34.7174	-18.4226	-6.5504	-59.6904
62	290	6319	-38.4674	-20.1861	-6.5504	-65.2039
402	A41	3263	-51.4174	-17.5762	-2.0471	-71.0407
59	221	6693	-44.7174	-18.1226	-14.8317	-77.6717
59	161	6180	-46.7174	-16.2376	-14.8317	-77.7867
59	290	6697	-54.3674	-16.6883	-14.8317	-85.8874
6162	6297	172	-40.3174	-22.5758	-25.6770	-88.5702
6162	6297	173	-42.3174	-22.5758	-25.6770	-90.5702

Table 11. Selected female animals with their selection scores for the four characters under study.

Birth Weight:

Sire No:	Dam No:	Daughter No:	I_f	Expected response due to combined selection (%)
S293	58	715	1.9607	
59	249	6675	1.6587	
62	A25	6505	1.1584	
59	161	6196	1.1571	
S293	63	795	1.0597	
S293	80	698	0.9507	
S293	63	796	0.7597	
S293	58	716	0.6607	
S293	119	756	0.6587	
62	A25	6506	0.6584	24.29
84	A09	921	0.6576	
84	A09	922	0.5576	
58	58	6376	0.6568	
62	A62	6397	0.6562	
62	28	6418	0.6551	
S293	119	757	0.4587	
6304	6226	41	0.4569	

Age at first kidding:

Sire No:	Dam No:	Daughter No:	I_f	Expected response due to combined selection (%)
62	28	6710	-506.0299	
62	185	6705	-425.4963	
62	114	6343	-412.9947	
62	494	6745	-412.2519	
6162	6468	186	-388.8951	
62	185	6704	-379.4963	
402	3027	3177	-357.1356	
62	28	6709	-351.0299	
402	280	3166	-324.0178	
84	A89	921	-323.0147	1878.99
84	A89	922	-319.0147	
402	280	3222	-313.0178	
62	290	6320	-313.1195	
62	A82	6164	-311.8143	
59	290	6697	-293.0763	
59	298	6696	-280.0763	
62	114	6239	-262.9947	

Table 11. Contd.....
Body weight at first kidding:

Sire No:	Dam No:	Daughter No:	I_f	Expected response due to combined selection (%)
S293	63	795	25.7974	
58	58	6376	22.0055	
58	A40	6501	21.3091	
58	A40	6500	20.3091	
S293	63	796	16.7974	
S293	119	756	16.1862	
6304	6226	42	16.0398	
6304	6226	41	13.0398	38.45
S293	85	714	12.9226	
58	A77	6365	11.9955	
58	58	6377	11.5055	
59	161	6012	10.6942	
62	A25	6505	10.5349	
58	A126	6471	10.2971	
62	28	6418	10.1739	
S293	80	609	8.5028	
62	A25	6506	7.0349	

First lactation milk yield:

Sire No:	Dam No:	Daughter No:	I_f	Expected response due to combined selection (%)
58	58	6376	137.4889	
S293	63	795	112.7351	
6304	6226	41	102.4590	
6304	6226	42	96.3590	
S293	63	796	96.0351	
S293	119	756	93.9738	
62	A25	6506	89.7792	
S293	85	714	89.7548	543.42
S293	80	609	83.5826	
58	A40	6501	64.5570	
62	A25	6505	60.6792	
58	A40	6500	60.6570	
84	1	969	48.7573	
58	58	6377	47.3389	
58	A77	6365	46.0229	
62	28	6418	39.2392	
402	60	3242	35.8352	

Table 12. Birth weight: Combined selection index for males combining information from full-sib and half-sib family averages.

Sire No:	Dam No:	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_m
S293	58	0.003526	0.002309	0.004835
S293	63	0.002446	0.001309	0.003755
59	249	0.002716	0.000121	0.002837
S293	119	0.001501	0.001309	0.002810
S293	80	0.001501	0.001309	0.002810
62	A25	0.002669	-0.000162	0.002507
S293	85	0.000691	0.001309	0.002000
84	A89	0.001771	-0.000111	0.001660
59	161	0.001096	0.000121	0.001217
6304	6226	0.000901	0.000148	0.001049
58	58	0.001096	-0.000172	0.000924
62	A62	0.000459	-0.000162	0.000298
58	A97	0.000421	-0.000172	0.000249
59	A24	-0.000389	0.000121	-0.000269
6304	6252	-0.000425	0.000148	-0.000277
62	290	-0.000130	-0.000162	-0.000292
62	114	-0.000277	-0.000162	-0.000439
402	280	0.000016	-0.000675	-0.000659
84	290	-0.000659	-0.000111	-0.000770
62	28	-0.000621	-0.000162	-0.000783
59	290	-0.000929	0.000121	-0.000809
58	A40	-0.000929	-0.000172	-0.001101
62	494	-0.001014	-0.000162	-0.001176
62	185	-0.001210	-0.000162	-0.001372
402	60	-0.000794	-0.000675	-0.001470
62	A82	-0.001308	-0.000162	-0.001470
59	221	-0.001604	-0.000121	-0.001484
84	1	-0.001604	-0.000111	-0.001715
58	A126	-0.001604	-0.000172	-0.001776
402	3027	-0.001604	-0.000675	-0.002279
402	A41	-0.001604	-0.000675	-0.002279
6162	6468	-0.001161	-0.001132	-0.002293
6162	6297	-0.002487	-0.001132	-0.003619

Table 13. Age at first kidding: Combined selection index for males combining information from full-sib and half-sib family averages.

Sire No:	Dam No:	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_m
6304	6226	175.2994	282.9493	458.2487
6304	6252	96.1609	282.9493	379.1102
59	161	252.7396	22.3161	275.0557
S293	119	172.9218	88.5896	261.5114
S293	85	67.2907	88.5896	155.8803
S293	80	23.7492	88.5896	112.3388
58	A40	44.8738	59.3825	104.2563
58	A126	39.0997	59.3825	98.4822
S293	58	8.8709	88.5896	97.4605
59	A24	62.5356	22.3161	84.8517
58	A77	19.0604	59.3825	78.4429
58	58	10.9088	59.3825	70.2913
402	60	89.7076	-57.4458	32.2618
S293	63	-59.3988	88.5896	29.1908
84	1	55.7426	-38.1514	17.5912
59	249	-45.1335	22.3161	-22.8174
84	290	3.7761	-38.1514	-34.3753
62	A25	43.1231	-92.3350	-49.2119
62	A62	29.6375	-92.3350	-62.6975
59	221	-91.6655	22.3161	-69.3494
62	290	11.6567	-92.3350	-80.6783
402	A41	-24.7545	-57.4458	-82.2003
59	298	-124.9512	22.3161	-102.6351
402	3027	-69.2486	-57.4458	-126.6944
62	A82	-40.0381	-92.3350	-132.3731
6162	6297	-32.5664	-107.1863	-139.7527
84	A89	-114.4221	-38.1514	-152.5735
402	280	-105.9308	-57.4458	-163.3766
62	28	-72.2537	-92.3350	-164.5887
6162	6468	-70.2676	-107.1863	-177.4539
62	494	-98.4757	-92.3350	-190.8107
62	185	-103.7201	-92.3350	-196.0551
62	114	-105.2185	-92.3350	-197.5535

Table 14. Body weight at first kidding: Combined selection index for males combining information from full-sib and half-sib family averages.

Sire No:	Dam No:	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_m
58	A40	6.2348	6.7964	13.0312
S293	63	7.4372	4.5823	12.0195
58	58	4.4312	6.7964	11.2276
6304	6226	5.0324	2.2295	7.2619
58	A126	0.2228	6.7964	7.0192
S293	119	1.8260	4.5823	6.4083
S293	85	2.0664	4.5823	6.2176
58	A77	-0.5788	6.7964	6.2176
S293	80	0.1426	4.5823	4.7249
62	A25	5.8151	-3.5581	2.2570
59	A24	2.2268	-0.1101	2.1167
59	161	2.0264	-0.1101	1.9163
S293	58	-2.7832	4.5823	1.7993
402	60	2.2268	-0.6016	1.6252
84	1	1.0244	-0.4695	0.5549
402	3027	0.8240	-0.6016	0.2224
6304	6252	-2.5828	2.2295	-0.3533
59	249	-0.2983	-0.1101	-0.4084
84	290	-0.5788	-0.4695	-1.0403
84	A89	-0.9796	-0.4695	-1.4491
402	A41	-1.3804	-0.6016	-1.9820
62	28	1.5541	-3.5581	-2.0040
59	221	-1.9816	-0.1101	-2.0917
59	290	-2.3824	-0.1101	-2.4925
402	280	-2.5828	-0.6016	-3.1844
62	185	-0.3463	-3.5581	-3.9044
62	494	-1.0886	-3.5581	-4.6467
62	A62	-1.7569	-3.5581	-5.3150
62	A82	-4.2064	-3.5581	-7.7645
62	114	-6.2107	-3.5581	-9.7688
62	290	-7.0570	-3.5581	-10.6151
6162	6468	-1.3804	-11.0308	-12.4112
6162	6297	-6.9916	-11.0308	-18.0224

Table 15. <u>First lactation milk yield</u>: Combined selection index for males combining information from full-sib and half-sib family averages.

Sire No:	Dam No:	$b_1(P_{FS} - \bar{P})$	$b_2(P_{HS} - \bar{P})$	I_m
S293	63	30.2884	18.6641	48.9525
6304	6226	29.3322	16.3942	45.7264
58	58	26.3953	17.7110	44.1063
58	A40	15.8634	17.7110	33.5450
S293	119	11.1671	18.6641	29.8312
S293	80	9.3859	18.6641	28.0500
58	A77	6.6293	17.7110	24.3403
62	A25	30.5970	-6.5504	24.0466
S293	85	4.9081	18.6641	23.5722
S293	58	0.8812	18.6641	19.5453
84	1	13.7461	-1.7714	11.9747
58	A126	-5.8969	17.7110	11.8141
6304	6252	-9.4349	16.3942	6.9593
402	60	7.8997	-2.0471	5.8526
402	3027	3.8153	-2.0471	1.7682
402	288	0.8921	-2.0471	-1.1550
62	28	0.7070	-6.5504	-5.8434
62	A62	-0.9669	-6.5504	-7.5173
59	249	6.2741	-14.8317	-8.5576
84	290	-7.7137	-1.7714	-9.4851
84	A89	-9.2573	-1.7714	-11.0287
62	114	-5.0588	-6.5504	-11.6092
62	A82	-8.0657	-6.5504	-14.6161
59	A24	-0.2280	-14.8317	-15.0597
62	185	-11.6177	-6.5504	-18.1681
402	A41	-17.5762	-2.0471	-19.6233
62	494	-18.4226	-6.5504	-24.9730
62	290	-20.1861	-6.5504	-26.7365
59	161	-16.2376	-14.8317	-31.0693
59	298	-16.6883	-14.8317	-31.5200
59	221	-18.1226	-14.8317	-32.9543
6162	6468	-8.5880	-25.6770	-34.2650
6162	6297	-22.5758	-25.6770	-48.2528

Table 16. Selected sire-dam pairs for the four characters under study.

Birth Weight:

Sire No:	Dam No:	I_m	Expected response due to combined selection(%)
S293	58	0.004835	
S293	63	0.003755	
59	249	0.002837	
S293	119	0.002810	49.50
S293	80	0.002810	
62	A25	0.002507	
S293	85	0.002000	

Age at first kidding:

Sire No:	Dam No:	I_m	Expected response due to combined selection(%)
62	114	-197.5535	
62	185	-196.0551	
62	494	-190.8107	
6162	6468	-177.4539	5479.93
62	28	-164.5887	
402	280	-163.3716	
84	A89	-152.5735	

Table 16 contd.....

Body weight at first kidding:

Sire No:	Dam No:	I_m	Expected response due to combined selection(%)
58	A40	13.0312	
S293	63	12.0195	
58	58	11.2276	
6304	6226	7.2619	67.24
58	A126	7.0192	
S293	85	6.2176	
S293	119	6.4083	

First lactation milk yield:

Sire No:	Dam No:	I_m	Expected response due to combined selection(%)
6304	6226	458.2487	
6304	6252	379.1102	
59	161	275.0557	
S293	119	261.5114	868.37
S293	85	155.8803	
S293	80	112.3388	
58	A40	104.2563	

Table 17. Malabari. General selection indices. The coefficients b_1, b_2, multiple correlation R_{AI} and the ranges of $\hat{A}$ for males.

Birth weight:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
101	0.4874	0.2803	0.7466	1.3159 to 1.6571
102	0.4957	0.2168	0.7416	0.8382 to 1.5322
157	0.4898	0.2620	0.7452	0.9277 to 1.6624
364	0.4802	0.3348	0.7509	1.3801 to 1.9083
314	0.4957	0.2168	0.7416	0.7949 to 1.2906
357	0.5039	0.1545	0.7366	1.0520 to 1.5559
402	0.4765	0.3630	0.7532	1.0621 to 1.6339
3174	0.4957	0.2168	0.7416	0.8878 to 1.5818
3179	0.4925	0.2410	0.7435	0.9675 to 1.6570
3182	0.4957	0.2168	0.7416	0.6803 to 0.8290

Age at first kidding:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
101	0.4298	0.2919	0.7091	424.7590 to 626.3352
102	0.4378	0.2226	0.7025	383.4759 to 595.8089
157	0.4321	0.2718	0.7071	439.9220 to 586.8359
364	0.4227	0.3530	0.7148	555.8388 to 1135.7832
314	0.4378	0.2226	0.7025	337.0539 to 597.1071
357	0.4455	0.1565	0.6962	333.5667 to 565.6722
402	0.4190	0.3852	0.7178	421.5444 to 731.1854
3174	0.4378	0.2226	0.7025	372.0116 to 656.5816
3179	0.4348	0.2489	0.7050	309.8731 to 416.3335
3182	0.4378	0.2226	0.7025	383.3502 to 485.7954

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
101	0.4505	0.2885	0.7229	12.9494 to 17.9049
102	0.4587	0.2212	0.7169	9.2706 to 15.2339
157	0.4529	0.2690	0.7212	11.8826 to 19.3554
364	0.4434	0.3472	0.7282	15.9668 to 22.1744
314	0.4587	0.2212	0.7169	9.7833 to 16.3428
357	0.4665	0.1563	0.7110	12.6135 to 15.1793
402	0.4396	0.3780	0.7308	15.6290 to 21.4318
3174	0.4587	0.2212	0.7169	15.9311 to 20.9768
3179	0.4556	0.2468	0.7192	11.2764 to 13.7822
3182	0.4587	0.2212	0.7169	10.8400 to 14.5096

First lactation milk yield:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
101	0.2886	0.2865	0.6002	11.6421 TO 20.3665
102	0.2947	0.2091	0.5891	8.3430 to 16.3744
157	0.2904	0.2633	0.5968	12.2310 to 24.9796
364	0.2829	0.3606	0.6108	15.1376 to 29.7041
314	0.2947	0.2091	0.5891	9.1696 to 20.9783
357	0.2999	0.1413	0.5790	14.0710 to 19.2383
402	0.2796	0.4022	0.6166	19.7498 to 42.7050
3174	0.2947	0.2041	0.5891	8.2234 to 21.0870
3179	0.2924	0.2376	0.5931	6.5234 to 12.3568
3182	0.2947	0.2091	0.5891	6.1080 to 20.7849

Table 18. Breed: SM. General selection indices. The coefficients b_1, b_2, multiple correlation R_{AI} and the ranges of $\hat{A}$ for males.

Birth weight:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
S294	0.5086	0.3325	0.7692	1.0769 to 2.6872
S295	0.5170	0.2719	0.7648	1.1390 to 2.2764
S299	0.5291	0.1845	0.7584	1.9199 to 2.4490
S292	0.5001	0.3936	0.7736	1.5768 to 2.6770
S297	0.5336	0.1519	0.7560	0.8728 to 1.8867
S293	0.4897	0.4036	0.7685	1.9766 to 2.4663
83	0.5291	0.1845	0.7584	1.3078 to 2.0486
84	0.5046	0.3613	0.7713	1.2423 to 1.8983

Age at first kidding:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
S294	0.5940	0.2893	0.8163	368.8005 to 577.8885
S295	0.6018	0.2405	0.8136	364.7403 to 721.6077
S299	0.6135	0.1672	0.8095	307.1609 to 664.8314
S292	0.5864	0.3368	0.8189	494.4178 to 893.1698
S297	0.6181	0.1389	0.8080	459.9273 to 494.7771
S293	0.5859	0.3398	0.8191	537.1127 to 1038.6431
83	0.6135	0.1672	0.8095	311.9339 to 489.2354
84	0.5910	0.3080	0.8173	500.6383 to 870.0133

Body weight at first kidding:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
S294	0.3612	0.3770	0.6749	14.4067 to 21.2695
S295	0.3693	0.2693	0.6659	14.7755 to 19.0225
S299	0.3847	0.4171	0.6482	13.9216 to 17.7686
S292	0.3525	0.4650	0.6846	19.6188 to 27.5478
S297	0.3835	0.1530	0.6496	15.0321 to 16.3743
S293	0.3518	0.4710	0.6852	20.1254 to 27.6891
83	0.3847	0.4171	0.6482	14.7011 to 19.1351
84	0.3579	0.4105	0.6786	18.0106 to 24.2738

Table 18 contd.....
First lactation milk yield:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males		
S294	0.1934	0.3390	0.5274	24.6137	to	40.2308
S295	0.1982	0.2474	0.5099	21.7049	to	42.3871
S299	0.2036	0.1453	0.4898	31.6848	to	45.0715
S292	0.1872	0.4568	0.5490	31.3761	to	48.6547
S297	0.2053	0.1139	0.4835	15.7137	to	28.4751
S293	0.1867	0.4655	0.5505	35.7104	to	57.0689
83	0.2036	0.1453	0.4898	12.0684	to	29.5678
84	0.1912	0.3814	0.5353	26.5198	to	54.3452

Table 19. Breed: AM. General selection indices. The values of b_1, b_2, the multiple correlation R_{AI} and the range of $\hat{A}$ for males.

Birth Weight:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
59	0.3906	0.5106	0.7199	1.3925 to 2.8612
58	0.3923	0.4954	0.7184	1.3336 to 2.1182
63	0.4110	0.3284	0.7022	1.6800 to 2.0507
75	0.4094	0.3432	0.7037	0.9242 to 1.3336
62	0.3895	0.5207	0.7209	1.3954 to 2.2134

Age at first kidding:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
59	0.4542	0.4684	0.7559	455.4780 to 831.1014
58	0.4558	0.4560	0.7549	477.4570 to 710.1194
63	0.4724	0.3265	0.7443	550.3170 to 854.5426
75	0.4724	0.3265	0.7443	416.6019 to 780.3499
62	0.4531	0.4767	0.7565	433.8100 to 748.2614

Body weight at first kidding:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
59	0.4397	0.4785	0.7479	18.9764 to 26.4513
58	0.4413	0.4655	0.7468	18.7090 to 26.6524
63	0.4598	0.3176	0.7343	20.2654 to 30.1511
75	0.4581	0.3310	0.7354	14.3725 to 23.9926
62	0.4338	0.4906	0.7460	17.8605 to 26.1027

First lactation milk yield:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
59	0.2676	0.5685	0.6401	24.9838 to 44.8156
58	0.2693	0.5462	0.6371	34.5123 to 72.0931
63	0.2864	0.3270	0.6067	17.5210 to 48.8675
75	0.2850	0.3446	0.6092	20.2726 to 43.5714
62	0.2664	0.5836	0.6421	29.2005 to 66.2035

Table 20. <u>Breed: F A.</u> General Selection Indices. The values of b_1, b_2, the multiple correlation R_{AI} and the range of $\hat{A}$ for males

Birth Weight:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
6024	0.3923	0.1913	0.6634	0.9280 to 1.1242
6304	0.3710	0.3979	0.6859	1.2038 to 1.5377
6162	0.3747	0.3624	0.6821	0.8506 to 1.3003
6730	0.3652	0.4548	0.6920	1.1046 to 1.7255
6714	0.3761	0.3482	0.6806	1.0345 to 1.7867

Age at first kidding:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
6024	0.4950	0.1888	0.7363	298.7646 to 474.4896
6304	0.4721	0.3649	0.7506	459.4510 to 741.7668
6162	0.4758	0.3364	0.7483	418.6692 to 538.5708
6730	0.4664	0.4091	0.7541	424.3677 to 620.7221
6714	0.4773	0.3248	0.7473	373.9365 to 492.3977

Body weight at first kidding:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
6024	0.4186	0.1961	0.6838	10.7192 to 15.6168
6304	0.3974	0.3916	0.7038	18.4429 to 27.1857
6162	0.4011	0.3579	0.7004	13.5771 to 18.3903
6730	0.3915	0.4450	0.7091	15.4834 to 24.6836
6714	0.4026	0.3444	0.6991	15.9038 to 22.7400

First lactation milk yield:

Sire No:	b_1	b_2	R_{AI}	Range of $\hat{A}$ for males
6024	0.3530	0.1875	0.6324	13.3245 to 21.5494
6304	0.3330	0.4034	0.6587	26.1117 to 64.5898
6162	0.3366	0.3652	0.6541	15.5582 to 36.1750
6730	0.3273	0.4654	0.6661	20.4895 to 51.1739
6714	0.3380	0.3561	0.6523	19.1851 to 37.6399

Discussion

DISCUSSION

To make a comparative study of selection indices for the improvement of dairy goats, selection indices were constructed by different methods using the four characters: birth weight, age at first kidding, body weight at first kidding and first lactation milk yield.

Estimates of heritabilities of lactation yield in dairy goats range from 0.06 to 0.72 (Ronningen, 1967; Singh et al., 1970a; Prakash et al., 1971; Bouillon and Ricardeau, 1975; and Stein, 1976). Estimates of heritabilities of age at first kidding range from 0.10 to 0.68 (Singh et al., 1970a and Bouillon and Ricardeau, 1975). In this study also, estimates of heritability coefficients obtained for these two characters were found to lie in the ranges given above(Table 3).

Simultaneous selection index constructed for each breed incorporating the four economically important traits viz. birth weight, age at first kidding, body weight at first kidding and first lactation milk yield. Relative economic value calculated for each trait, based on the cost of production of each trait helped in improving the efficiency of the index. The expected genetic advance due to the index and that due to straight selection were 5442.7574 and 2561.2345; 769.1024 and 312.3521; 265.7435 and 114.3664 and, 1052.9766 and 817.7718 for the breeds Malabari, SM, AM and F_2A respectively. The percent gain in efficiency in expected genetic advance due to the selection index and that due to straight selection for the above four breeds were found to be 112.51%, 146.23%, 132.36% and 28.76% respectively (Table 4).

Hence from this study, it was concluded that selection based on an index was more efficient than straight selection, when the characters having unequal variances and heritabilities were considered simultaneously. So the result obtained from this study was found to be in perfect agreement with those reported by Hazel and Lush (1942), Panse (1946) and Young (1961).

Seven restricted selection indices were constructed for each breed. The first three of them were constructed by imposing restriction on birth weight, age at first kidding and body weight at first kidding respectively. But in the fourth, fifth and sixth indices, restrictions were imposed simultaneously on the following combinations of characters: birth weight and age at first kidding, birth weight and body weight at first kidding and age at first kidding and body weight at first kidding respectively. The seventh index was constructed by imposing restriction on all the three auxiliary traits simultaneously. The expected genetic advance in individual characters were also calculated in each case (Table 5).

The index obtained for Malabari goats by restricting birth weight was found to maximize the expected genetic advance in the other three traits. The use of this index reduced age at first kidding considerably and increased body weight at first kidding and first lactation milk yield. But the index obtained by restricting birth weight in F_2A goats, increased age at first kidding eventhough this index was useful in improving the genetic advances in the other two characters. Effective restriction of birth weight was possible for SM breed also. But this index also increased age at first kidding, body weight at first kidding and first lactation milk yield. In those cases, the expected genetic advance in the restricted character was equal to zero.

The restriction on body weight at first kidding (body weight kept as a constant) was found maximizing the genetic gain in the other three characters of AM and F_2A goats. The increase in age at first kidding due to selection of F_2A goats based on this index was comparatively less to that obtained by the index with restriction on birth weight. Also the increase in first lactation milk yield due to selection based on this index was less compared to the other one. Selection based on the index constructed by imposing restriction on body weight at first kidding increased age at first kidding and first lactation milk yield of AM goats. In all these cases the expected genetic gains in the restricted character was found to be equal to zero. Restriction on the other characters were found to be of no use with reference to this study.

Seven phenotypic selection indices were constructed between the main trait- first lactation milk yield and the auxiliary traits- birth weight, age at first kidding and body weight at first kidding for each breed. Reletive efficiencies corresponding to these indices were also calculated (Table 6). In the case of the breeds Malabari and F_2A, each of these indices was found to decrease the efficiency of selective breeding. Hence it was concluded that in these breeds, selection on the basis of the main trait- first lactation milk yield alone is the best method rather than using any trait as an auxiliary trait for improving milk production.

It was apparent from the table that I_1, the index between milk yield and birth weight increased the efficiency of selective breeding in AM goats by 23.6 percent. But the increase in efficiency due to I_2, the index when age at first kidding was used as an auxiliary trait was 19.45 percent. But it was found that when these traits were simultaneously used as auxiliary traits (I_4), the increase in efficiency was 16.85 percent. An increase in efficiency of 42.49 percent was noticed for I_3, the index between first lactation milk yield and body weight at first kidding. Birth weight and body weight at first kidding together as auxiliary traits (I_5), for improving the milk production gave an increase in efficiency of 52.16 percent. An increase in efficiency of 42.91 percent was noticed in I_6, the index when age at first kidding and body weight at first kidding were used as auxiliary traits. But when all these characters were simultaneously considered as auxiliary traits(I_7) gave an increase in efficiency of 71.21 percent.

So it was concluded from the study that for the AM breed, I_7, the index between first lactation milk yield and the auxiliary traits- birth weight, age at first kidding and body weight at first kidding was the best.

Also it was apparent from the table that out of the phenotypic indices constructed for SM breed, only the index I_2, was more efficient then selection based on main trait alone. Relative efficiency due to this index was 12.31 percent. All the other indices were found to decrease the efficiency of selective breeding.

Optimum selection indices were constructed by combining information from individual's performance with those of full-sib and half-sib family averages for the selection of females for each character (Table 7 to 10). Also optimum selection indices for males combining information from full-sib and half-sib family averages were also constructed for each character (Table 12 to 15). The first 25% of females selected had selection scores in terms of birth weight, age at first kidding, body weight at first kidding and first lactation milk yield between 0.4569 to 1.9607, -262.9947 to -506.0299, 7.0349 to 25.7974 and 35.8352 to 137.4889 respectively. But the full sisters and the selected male parents had selection scores in terms of the same characters between 0.001660 to 0.004835, -152.5935 to -197.5535, 6.4003 to 13.0312 and 24.3403 to 48.9525 respectively.

The expected response due to selection of females due to birth weight , age at first kidding, body weight at first kidding and first lactation milk yield were found to be 24.29 percent, 1878.99 percent, 38.45 percent and 543.42 percent respectively and that due to selection of males for these characters were 49.50 percent, 5479.91 percent, 67.24 percent and 868.37 percent.

The expected response due to the selection of females and males for the characters- age at first kidding and first lactation milk yield were found to be very high. This may be because of the high phenotypic variances in these characters. This may be because of combining the information on full-sibs of various breeds, which showed a marked difference in the performance of the individuals for these characters.

General selection indices were constructed for selection among males for each character and for each breed. The ranges of multiple correlation R_{AI}, between the index I and the corresponding breeding value $\hat{A}$ for the characters- birth weight, age at first kidding, body weight at first kidding and first lactation milk yield (Table 17 to 20) were found to be 0.7366 to 0.7532, 0.6962 to 0.7178, 0.7110 to 0.7308 and 0.5790 to 0.6166 respectively for Malabari breed; 0.7736 to 0.7784, 0.8080 to 0.8191, 0.6482 to 0.6852 and 0.4835 to 0.5505 respectively for SM breed; 0.7022 to 0.7289, 0.7443 to 0.7565, 0.7343 to 0.7479 and 0.6067 to 0.6427 respectively for AM breed and 0.6634 to 0.6920, 0.7363 to 0.7541, 0.6838 to 0.7091 and 0.6324 to 0.6661 respectively for F_2A breed.

Summary

SUMMARY

Using the data from 71 Malabari goats, mates of 10 sires, 95 Sannen X Malabari (SM) goats, mates of 8 sires, 143 Alpine X Malabari (AM) goats, mates of 5 sires and 64 AM X AM (F_2A) goats, mates of 5 sires located at the farm of AICRP on goats for milk at Mannuthy, birth weight, age at first kidding, body weight at first kidding and first lactation milk yield were combined into different selection indices to make a comparative study of the indices and the breeds.

Simultaneous selection indices were constructed incorporating all the four characters under study, assigning economic values on the basis of cost of production of each trait. Expected genetic advance due to index as well as due to straight selection was calculated for each breed. The percent gain in efficiency due to selection based on index over that due to straight selection was also calculated for each breed. In each case, selection based on index was found to be more efficient than straight selection.

Effect of imposing restriction on birth weight, age at first kidding, body weight at first kidding separately and on combinations of these characters simultaneously were

studied for each breed. Restriction on birth weight was found to be effective for Malabari, SM, and F_2A breeds. All these three indices helped in improving body weight at first kidding and first lactation milk yield. But, only the index constructed for Malabari breed was found reducing the age at first kidding. Imposing restriction on body weight at first kidding was effective only for AM and F_2A breeds. These indices were found improving the birth weight and first lactation milk yield together with an increase in age at first kidding. In the other cases restriction was of no use in improving the genetic advance in the unrestricted characters.

Seven phenotypic selection indices were constructed for each breed, between the main trait- first lactation milk yield and the auxiliary traits viz. birth weight, age at first kidding and body weight at first kidding. In the case of Malabari and F_2A breeds, none of the phenotypic index constructed was found more efficient than selection based on the main trait alone. For SM breed, relative efficiency was more for the index, constructed between main trait- first lactation milk yield and the auxiliary trait- age at first kidding (12.33%). The index between main trait- first lactation milk yield and the auxiliary traits viz. birth weight, age at first kidding and body weight at first kidding simultaneously was found to be the best for improving first lactation milk yield of AM goats. Relative efficiency of this index was 71.21%.

Selection indices for females combining information from individual's own performance with those of full-sib and half-sib family averages were also constructed for individual characters and these indices were arranged in descending order. While selecting the best 25% females, 17 females having the highest scores were selected for each of the characters birth weight, body weight at first kidding and first lactation milk yield and those having the least scores for age at first kidding. Selection indices for males combining information from full-sib and half-sib family averages were also constructed for individual characters and these indices were arranged in descending order. Seven families having the best scores were selected for each of the characters. The expected responses due to both of these indices were also calculated for each character.

General selection indices were also constructed for selection among males for each character and for each breed. The value of R_{AI} were also calculated for each index.

References

REFERENCES

Abplanalp, H. and Asmundson, V.S. (1956). Effectiveness of selection index for the improvement of breast width in New Hampshire Fryers. Poult. Sci. 35 : 1129.

*Acharya, R.M. (1966). Genetic analysis of a closed herd of Indian cattle. Ph.D. Dissertation, Iowa State University of Science and Technology. Ames, Iowa. Anim. Breed. Abstr. 35 : 3467.

*Ahmed, M.S. (1961). Gentic estimates of some characters of economic importance in Haryana cows at Izatnagar and construction of selection indices. M.V.Sc. Dissertation, Post Graduate College of Animal Sciences, Indian Veterinary Institute, Izatnagar, U.P.

Ahuja, S.D.; Prakash Babu, M. and Agrawal, S.K. (1981). Relative efficiency of various criteria of selection for four week body weight in Japanese Quail. Indian J. Poult. Sci. 16 (2) :98-101.

*Akbar, M.K. (1981). Construction of selection indices for commercial egg production. Diss. Abstr. Int., B 42 (6) : 2223-2224.

Bernard,C.S.; Chapman,A.B. and Grummer,R.H. (1954). Selection of pigs under farm conditions: Kind and amount practised and a recommended selection index. J. Anim. Sci. 13 : 389-404.

Binet,F.E. (1965). On the construction of an index for indirect selection. Biometrics. 21 : 291-299.

*Bouillon,J. and Ricordeau,G. (1975). Genetic parameters of growth and milk production in the goats at the testing station. Estimates of direct and indirect resources of selection. Anim. Breed. Abstr. 44 : 3247.

Daya Singh; Acharya,R.M. and Sundaresan,S. (1968). Effectiveness of different selection indices for genetic advancement in Haryana cattle. Indian J. Anim. Sci. 36 (6) : 473-487.

Dev Roy,A.K.; Mohapatra,S.C.; Sharma,B.P. et al (1983). Relative efficiency of index selection for Broiler weight. Indian J. Poult. Sci. 18 : 52-56.

Franz Pierchner. (1968). Population Genetics in Animal Breeding. W.H. Freeman and Company.

*Garcia,B.O. (1971). Heritabilities of milk and butter fat production in goats. Anim. Breed. Abstr. 40 : 2898.

*Hanson,W.D. and Johnson,H.W. (1957). Methods of calculating and evaluating a general selection index obtained by pooling information from two or more experiments. Genetics. 42 : 421-432.

*Hazel,L.N. (1943). Genetic basis of constructing selection indices. Genetics. 28 : 476-490.

*Hazel,L.N. and Lush,J.L. (1942). The efficiency of three methods of selection. J. Heredity. 33 : 393-399.

Jain,J.P. (1982). Statistical Techniques in Quantitative Genetics. Tata McGraw-Hill Publishing Company Limited, New Delhi.

James,J.W. (1968). Index selection with restriction. Biometrics. 24 : 1015-1018.

Kempthorne,O. and Nordskog,A.W. (1959). Restricted selection indices. Biometrics. 15 : 10-19.

Kotaiah,T. and Renganathan,P. (1980). Relative efficiency of part record of egg number and percent production in multiple trait selection. Indian J. Poult. Sci. 15 : 67-68.

Krueger,W.F.; Dickerson,G.E.; Kinder,Q.B. and Kempster,H.L. (1952). The genetic and environmental relationship of total egg production to its components and to body weight in domestic fowl. Poult. Sci. 31 : 922-923.

Lerner,I.M.; Asmundson,V.S. and Cruden,D.M. (1947). The improvement of New Hampshire Fryers. Poult. Sci. 26 (5) : 515-524.

Marutiram,B.; Jain,J.p. and Gopalan,R. (1973a). A selection index for the improvement of poultry. Indian J. Anim. Sci. 43 :524-534.

*Narain,P, and Mishra,A.K. (1975). Efficiency of selective breeding on a phenotypic index. J. Genetics. 62 : 69-76.

Narayanikutty,U. (1983). A comparative study of selection indices for the improvement of Poultry. M.Sc. Thesis, Faculty of Agriculture, Kerala Agricultural University.

Nogsett,M.L. and Nordskog,A.W. (1958). Genetic economic value in selecting for egg production rate, body weight, egg weight. Poult. Sci. 37 : 1404.

*Osborne,R. (1957b). The use of sire and dam family averages in increasing the efficiency of selective breeding under a hierarchical mating system. Heredity. 11 : 93-116.

*Panse,V.G. (1946). An application of discriminent function for selection in Poultry. J. Genetics. 47 : 242-248.

Prakash,C.; Acharya,R.M. and Dhillon,J.S. (1971). Sources of variation in milk production in Beetal goats. Indian J. Anim. Sci. 41 : 356-360.

Prasad,R.J. and Prasad,R.B. (1973). Construction and use of selection indices for improving Tharparkar herd at Patna. Indian Vet. J. 50 (2) : 157-164.

*Rao,C.R. (1962). Problems of selection with restrictions. J. Roy. Stat. Soc. 24 : 401-505.

Renganathan,P.; Mohapetra,S.C.; Ayyagari.V.B.; Venkatramaiah,A. and Chaudhuri,D. (1979). A comparative study on index selection for egg production and egg weight versus selection for egg mass in chickens. Indian Vet. J. 56 (9) : 757-763.

Renganathan,P.; Thiagasundaram,T.S. and Ayyagari,V. et al. (1983). Efficiency of index selection with clutch size as a component. Indian J. Anim. Sci. 53 : 872-879.

*Ronningen,K. (1967). A study of genetic parameters for milk characteristics in goat. Anim. Breed. Abstr. 36 : 3787.

Saxena,S.C.; Mohapetra,S.C. and Mehta,N.T. (1982). Index selection and genetic progress in broiler dams. Indian J. Poult. Sci. 17 (3) : 227-231.

Singh,R.N. and Acharya,R.M. (1980). Beetal Goat: Genetic selection for maximising life time milk production. Int. Goat and Sheep Res. 1 (3) : 226-233.

*Singh,R.N.; Acharya,R.M. and Biswas,D.K. (1970a). Evaluation of genetic and non-genetic factors affecting some economic traits in goat. Acta Agr. Scand. 20 : 10-14.

*Singh,R.N.; Acharya,R.M. and Biswas,D.K. (1970b). Selection index for goats: expected, direct and correlated responses. Acta Agr. Scand. 20 : 61-64.

*Smith,C. (1983). Effects of changes in economic weights on efficiency of index selection. J. Anim. Sci. 56 (5) : 1057-1064.

*Smith,H.F. (1936). A discriminent function for plant selection. Ann. Eugen. 7 : 240-250.

*Steine,T.A. (1976). Genetic and phenotypic parameters for the production characters in goats. Anaim. Breed. Abstr. 44 : 5751.

Tallis,G.M. (1962). A selection index for optimum genotype. Biometrics. 18 :120-122.

Yamada,Y.; Bohren,B.B. and Crittenden,L.B. (1958). Genetic analysis of White Leghorn closed flock apparently plateaued for egg production. Poult. Sci. 37 (3) : 565-580.

*Young.S.S.Y. (1961a). A further examination of the relative efficiency of three methods of selection for genetic gains under less restricted conditions. Genet. Res. Camb. 2 : 106-121.

---

* Originals were not referred.

SELECTION INDICES ON GOATS- A COMPARATIVE STUDY

BY

REMA T. P.

ABSTRACT

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF

Master of Science (Agricultural Statistics)

FACULTY OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF STATISTICS

COLLEGE OF VETERINARY AND ANIMAL SCIENCES

MANNUTHY - TRICHUR

1985

ABSTRACT

Records on birth weight, age at first kidding, body weight at first kidding and first lactation milk yield of Malabari, Sannen X Malabari (SM), Alpine X Malabari (AM) and AM X AM (F_2A) goats from 1974- 1984 were examined to make a comparative study of selection indices constructed by employing different methods.

The relative economic value of each trait in rupees was calculated as 29.96 for birth weight, 0.67 for age at first kidding, 20.83 for body weight at first kidding and 18 for first lactation milk yield.

Simultaneous selection indices were constructed by incorporating all the traits together for each breed and on finding the percent gain in efficiency of each index over that due to straight selection, the efficiency of index selection was proved.

Out of the seven restricted selection indices constructed for each breed, imposing restriction on birth weight was found effective for Malabari, SM and F_2A breeds and restriction on body weight at first kidding was effective for both F_2A and AM breeds. But all these effective restricted selection indices, except the one for

Malabari breed (when birth weight was restricted) were increasing the age at first kidding.

Seven phenotypic selection indices were constructed for each breed. But none of them was found improving the first lactation milk yield of Malabari and F_2A goats. For SM breed, the best index was the one constructed between the main trait first lactation milk yield and the auxiliary trait age at first kidding. Relative efficiency was the largest, when all the auxiliary traits were considered simultaneously for improving the first lactation milk yield of AM goats.

Combined selection indices for females combining information from individual's own performance with those of full-sib and half-sib family averages were constructed for each character and these indices were arranged in descending order to choose the best females. Also combined selection indices combining information from full-sib and half-sib family averages were constructed for each character and these indices were arranged in descending order to choose the best parents. The expected response due to selection of females and males were also calculated.

General selection indices were also constructed for selection among males and the value of R_{AI} was calculated in each case.