Theor Appl Genet (1985) 70: 166–171

Efficiency of one- and two-stage selection indexes for improvement of net economic merit in White Leghorns *

V. Ayyagari, S. C. Mohapatra, G. S. Bisht, T. S. Thiyagasundaram and D. C. Johari
Central Avian Research Institute, Izatnagar, U.P.-243 122, India

Received May 4, 1984; Accepted October 20, 1984
Communicated by H. Abplanalp

Summary. The effects of varying intensities of selection at first and second stages, for a given final intensity, on the efficiency of two-stage index selection are described. Data collected on four White Leghorn strains for part and residual egg number, body weights at 20 and 40 weeks and egg weight at 39 to 40 weeks were utilised. Four of the five traits were used in the first stage and all five traits were used in the second stage for the construction of two-stage selection indexes. The index that utilised all five traits had the maximum efficiency for one-stage selection. The relative efficiency of the two-stage index increased with increase in proportion selected at the first stage. A practical breeding schedule that adds the advantage of reduced generation interval by utilising a two-stage index selection is suggested for egg type chickens.

Key words: One- and two-stage selection indexes – Relative efficiency – Proportion selected – White Leghorns

Introduction

Selective breeding in layer stocks on part record instead of total egg production has the advantage of reduced generation interval. This can be expected to more than offset losses in accuracy of selection by increasing the genetic gains per unit of time (Lerner and Cruden 1948). Morris (1964) contended that selection on early record was ineffective in improving the full record. The kind of unsatisfactory correlated responses observed in the residual records and other relevent parameters led Gowe et al. (1973); Flock (1977) and Gowe (1977) to suggest that the length of the part period be extended to maximize the progress in annual egg production per year, despite the likely increase in generation interval.

Since continued genetic improvement of economically important traits is the main emphasis in commercial breeding, selection for part period egg production by itself would not seem to be of much use. Gowe and Fairfull (1980) reported satisfactory genetic gains with selection on part record egg production when supplemented with selection for several other commercially important traits. To make satisfactory progress in the net economic merit there appears to be a need to include such traits of economic importance as egg weight, body weights, etc., in addition to egg production, which itself may be included as part, residual and full year record in a selection index.

Cunningham (1975) examined the efficiency of two-stage index selection compared to selection in one-stage and illustrated the method of computation along with a numerical example with data on pigs. Abdou and Kolstad (1979) utilised body weight at 4 weeks of age, energy utilisation and feed efficiency in the first stage and egg number in 90 days after sexual maturity, and egg weight in the second stage, to compute the relative efficiency of one- and two-stage index selection in White Leghorns.

The possibility of selecting layer type chickens at two stages in order to improve their annual egg production does not seem to have been explored. The objective of this study, therefore, was to examine statistically the effect of two-stage selection utilising part and residual egg production and other traits of economic importance that are available during the laying cycle, and to compare its efficiency with one-stage selection.

Materials and methods

Data used in the present study were obtained from 1,813 White Leghorn hens, progeny of 421 dams mated to 113 sires, belonging to four different strains. All the hens included

* C.A.R.I. Publication No. 26/83

survived until the end of the laying cycle and contributed data to all traits considered. The data were corrected both for hatch and strain effects by fitting least square constants (Harvey 1966) before computing estimates of genetic and phenotypic variance covariances. Variance components were used to obtain genetic variances as $\sigma^2_g = 2(\sigma^2_s + \sigma^2_d)$ and phenotypic variances as $\sigma^2_p = \sigma^2_s + \sigma^2_d + \sigma^2_e$. Similarly, the corresponding covariance components were used to obtain genetic and phenotypic covariances.

The economic values in rupees of the various traits were computed as partial regression coefficients of the income over feed cost of the individual entry on the separate component traits by utilising the data of the third Random Sample Laying Test (1980–81) of Bombay unit. The traits used for index construction and their economic values in rupees were as follows:

X_1 Body weight at 20 weeks of age in grams ($a_1 = 0.0075$)
X_2 Body weight at 40 weeks of age in grams ($a_2 = -0.0113$)
X_3 Egg weight at 39 to 40 weeks in grams ($a_3 = 0.1194$)
X_4 Part period egg production as the number of eggs laid up to 40 weeks of age ($a_4 = 0.2578$)
X_5 Residual egg production as the number of eggs laid from 40 to 72 weeks of age ($a_5 = 0.2570$)

Index construction

The procedure as described by Cunningham (1975) was followed for constructing one- and two-stage indexes and to arrive at their relative efficiencies. The important steps involved are briefly given below.

With the genetic and phenotypic variance covariances among the traits (X_1 to X_5), a super matrix M (10×10) was set up whose upper five rows has the P matrix in the first five columns and the G matrix in the remaining columns. The lower five rows included the G' in the first five columns and a C matrix in the remaining columns. This super matrix M was partitioned to give the in-put matrices appropriate to each index where

P = a phenotypic variance and covariance matrix of 4×4 or 5×5 traits;
G = a genetic variance and covariance matrix of 4×4 or 4×5 or 5×5 traits;
C = a genotypic covariance matrix between traits included in the aggregate genotype (4×4 or 5×5).

The weight given to each of the component traits for a given index was obtained by the general index equation which maximizes the r_{TI} as shown below:

$$Pb = Gv$$

which was solved to give

$$b = P^{-1} Gv \tag{1}$$

where b = an unknown vector of index coefficients, with four or five columns; V = a column vector of relative economic weights for the traits involved, with four or five rows.

$$\sigma^2_I = b'Pb \tag{2}$$

is the variance of the index

$$\sigma^2_T = v'C\,v \tag{3}$$

is the variance of the aggregate genotype.

The covariance between index and the true breeding value (r_{TI}) was obtained in the ratio of σ_I/σ_T which measured the accuracy of predicting T from I. When selection is on I, the genetic gain in T is given by $H = \bar{i}\,\sigma_I$ where $\bar{i}$ is the selection intensity obtained from proportion selected and σ_I is the standard deviation of the index.

One-stage selection

Selection takes place in a single operation only after all the traits are measured. The proportion selected was considered to be 15%. An index (I_1) was constructed utilizing all five traits.

Alternatively, another index (I_2), that included all five traits in the aggregate genotype but excluded from its P matrix the phenotypic variance of the residual egg number (X_5) and its phenotypic covariance with the other four traits (X_1 X_2 X_3 and X_4), was also constructed by ignoring the 5th row and column in the super matrix (M). For I_1 and I_2, the index coefficients b, $\sigma_I\,\sigma_T$, r_{TI} and ΔH were obtained.

Two-stage selection

The variables available at first stage selection when the birds were 40 weeks old were

$X_1 = X_1, X_2, X_3$ and X_4.

Their corresponding b values obtained after solving the equation 1 were

$b_1 = b_1, b_2, b_3$ and b_4.

An additional variable, X_5, which was available only when the birds were 72 weeks old, was added at the second stage:

$X_2 = X_1, X_2, X_3, X_4$ and X_5.

The corresponding b_2 comprised of

$b_2 = b_1, b_2, b_3, b_4$ and b_5.

It was assumed that the first stage selection took place when variables X_1 were available at the age of 40 weeks. An index (I_3) was constructed for selection at the first stage by ignoring the 5th and 10th rows and columns of the super matrix M which gave the required b_1 and the variance of the index.

Second stage selection, amongst those individuals that are retained in first stage selection, was assumed to have taken place when all the variables of X_2 were available at the age of 72 weeks. Different combinations of proportions selected at first and second stages to give a final proportion of 15% selection were also considered, as shown in Table 1. A single selection parameter denoted by S was arrived at for each first stage truncation selection by combining the truncation point (t) and the standardised selection differential ($\bar{i}$) as shown in equation 4 (Table 1).

$$S = \bar{i}\,(\bar{i} - t) \tag{4}$$

The adjustment needed in the super matrix M to take care of the effect of first stage selection was achieved by equation (5) and this adjusted supermatrix denoted by

$$M^* = M - T'T\,w \tag{5}$$

gave the necessary input matrices to calculate second stage indexes where T = a vector which is the product of b_1 and the first four rows of the supermatrix M and w = a scalar which is the ratio of the selection parameter (S), to the variance of the first stage index. Since the value of w is dependent on the proportion selected at first stage (Table 1), the original supermatrix was adjusted to yield six adjusted supermatrices M^*. The partitioning of each of such adjusted supermatrices M^* gave the input matrices to yield the second stage index coefficients b_2 and their index variances. Each of such second stage indexes was denoted by an additional subscript that varied from 1 to 6, as shown in Table 1. The net effect in the case of two-stage selection was obtained by adding the effect of index selection at the first stage to that of the index used at the second stage.

Table 1. Second stage indexes for two-stage selection

Index	Proportion selected (%)		Strandardized selection differential ($\bar{i}$)		Truncation point (t)	Selection parameter $S=\bar{i}\,(\bar{i}-t)$
	First stage	Second stage	First stage	Second stage		
I_{31}	20	75.00	1.400	0.424	0.841	0.78260
I_{32}	25	60.00	1.271	0.644	0.675	0.75752
I_{33}	30	50.00	1.159	0.798	0.524	0.73596
I_{34}	35	42.80	1.058	0.917	0.385	0.71203
I_{35}	40	37.50	0.966	1.011	0.253	0.68876
I_{36}	45	33.33	0.880	1.091	0.121	0.66792

Table 2. Variance – covariance matrix of different traits in White Leghorn[a]

Traits	X_1	X_2	X_3	X_4	X_5
Body wt at 20 weeks (x_1)	11,539.9198 6,367.0230	10,997.8860	103.5284	537.7449	201.3287
Body wt at 40 weeks (x_2)	 8,565.8168	31,814.6708 20,620.6996	245.4851	202.6502	−88.7815
Egg wt at 39 to 40 weeks (x_3)	 97.1462	 184.8436	11.6860 7.3158	−3.9306	−6.7076
Part period egg no. (x_4)	 255.4451	 88.8920	 −3.6327	152.2293 49.5264	87.9034
Residual egg no. (x_5)	 46.1000	 −173.9267	 −10.6432	 58.5744	730.4770 218.0450

[a] Phenotypic covariances are shown above the diagonal and genetic covariances below the diagonal

Thus, the net effect of two-stage selection $=\bar{i}_f \sigma I_f + \bar{i}_s \sigma I_s$ where, σ_{I_f} and σ_{I_s} are the standard deviations of indexes used at first and second stages, respectively. Since both one- and two-stage indexes were all assumed to have the same final intensity of selection (15%) their relative effectiveness was obtained by comparing their $\bar{i}\,\sigma I$, which is the net effect of selection for any given index.

Results and discussion

Phenotypic and genetic variance and covariances for all five traits are given in Table 2. Both phenotypic and genetic covariances of body weight at 20 weeks (X_1) with all other traits were positive. Except for residual egg number, the body weight at 40 weeks (X_2) also had positive covariances with the other three traits. Phenotypic and genetic covariances of egg weight (X_3) with the two body weights were positive and with the part and residual egg number were negative. Covariances of body weight at 40 weeks with part period egg number and with residual egg number in the opposite direction is a point of interest.

One-stage index selection

Three indexes (I_1, I_2 and I_3) were investigated for one stage index selection. The I_1 index included all five traits (X_2) as a single operation for selection and when practically applied would lead to longer generation intervals because the residual egg number (X_5) would be available only when the birds are 72 weeks old. On the other hand, the I_2 and I_3 indexes utilize in their P matrix only X_1, traits that become available early in the laying cycle (when the birds are only 40 weeks old) and when practically applied would lessen the generation interval required for the I_1 index.

The index coefficients (b values), the expected genetic changes, the r_{TI} values, the net effect of each of the index and their relative efficiencies are shown in Table 3. Index coefficients for egg weight and body weight at 40 weeks were consistently negative, while part period egg number and residual egg number, when included, received a positive emphasis. Body weight at 20 weeks, unlike that of at 40 weeks, had a positive b value.

The expected genetic gains included a sizable decline in body weight at 40 weeks and a slight decline in body weight at 20 weeks. Of the three indexes, the decline in egg weight was least in the I_3 index in which the residual egg number was not included. The gains in part period egg number were more or less the same in different indexes. The gain in residual egg number, which ultimately decides the gain in annual egg num-

Table 3. Index coefficients (b) expected genetic change per trait from one standardized selection with different indexes for one-stage selection

Traits	I_1	I_2[a]	I_3
	Index coefficients		
Body wt at 20 weeks (x_1)	0.3610	0.3063	0.5967
Body wt at 40 weeks (x_2)	− 0.7362	− 0.7647	− 0.7795
Egg wt at 39 to 40 weeks (x_3)	−23.1096	−26.0138	− 1.6249
Part period egg no. (x_4)	17.7516	24.0508	10.4879
Residual egg no. (x_5)	10.6381	0	−
	Expected genetic changes		
Δ Body wt at 20 weeks (g)	− 2.741	− 2.793	− 1.936
Δ Body wt at 40 weeks (g)	−37.130	−44.913	−56.063
Δ Egg wt at 39 to 40 weeks (g)	− 0.999	− 1.105	− 0.739
Δ Part period egg no. (No)	3.601	3.680	3.301
Δ Residual egg no. (No)	8.371	5.205	4.312
σ_I	447.953	352.139	184.279
r_{TI}	63.999	50.310	62.715
$\bar{i}\,\sigma_I$ Net effect or genetic change in economic units	696.118	547.224	286.369
Relative effectivenes (%)	100.0	78.6	41.1

[a] In this index, genetic variance of residual egg number (x_5) and its genetic covariance with x_1, x_2, x_3 and x_4 were also utilised in the *G* matrix while computing the index coefficients (b values)

$\bar{i}$ was taken as 1.554 σ_P because of 15% selection

ber, was found to be maximum in the index where the residual egg number itself was a component trait. The next best gain in residual egg number was seen in I_2, where the genetic covariances of this trait with the other traits were included in the *G* matrix.

A comparison of the three indexes in terms of genetic changes in economic units ($\bar{i}\,\sigma_I$) revealed that the I_2 index which excluded the phenotypic information on residual egg number was only 22% less efficient than the best index (I_1) that utilised all five traits. It must also be pointed out, however, that the I_2 index will involve a shorter generation interval there by doubling the relative efficiency when considered per unit of time. The I_3 index, which utilized only X_1 traits, although required a shorter generation interval although it was found to be least efficient among the three one stage indexes considered.

It may, therefore, be concluded that if efficiency is evaluated per unit of time, the I_2 index is the best, provided one knows the genetic covariances of residual egg number with other X_1 traits to construct the required index.

Two-stage indexes

How to partition a given final intensity between the two-stages is an important question in two-stage index selection. This partitioning of the 15% final intensity was achieved in six combinations of proportions selected at first and second stages, as shown in Table 1.

The truncation points (t) on the actual distribution of index values and the selection parameters (S) obtained by using equation 5 also appear in Table 1. First stage selection was assumed to have taken place on X_1 traits. Thus, the I_3 index was utilised for first stage selection. For each combination of proportions selected at first and second stages, a second stage selection index was computed. All second stage indexes utilised X_2 traits. The weighting factors for these second stage indexes were the same as those where no prior selection has taken place (I_1). However, the variances of these indexes were reduced proportionally to the correction imposed in the variance covariance matrix (*M*). Total genetic gains and efficiencies of different two stage indexes relative to one stage index (I_1) are presented in Table 4. It must be pointed out that the method followed assumed an initial multivariate normal distribution. Although the derivation of index coefficients at first and second stage are not distribution dependent, the estimated gains from second stage selection tend to be overestimated because the distribution of index values at second stage may depart from normality which may affect the accuracy of the selection differentials used for predicting the gains at second stage. However, Cunningham (1975) expressed the view that with an array of traits, the normality of their multivariate distribution is better protected than in the case of a single trait. Since in the present study as many as five traits were considered in the second stage, it was reasonable to assume that the overestimation of gains in the second stage may not be very large. Even if some overestimation persists, the comparison of relative efficiencies should not be markedly affected.

The relative efficiency of the six two stage indexes varied from 57% to 79%. As the proportion selected at first stage increased, the efficiency of the two stage index, relative to the one stage index, also increased. It can be seen from Table 4 that the standard deviation of the selection index at first stage was less than that of the index at second stage. Because of the higher standard deviation of the second stage index, its contribution to the net effect ($\bar{i}\,\sigma I$) increased as the intensity of selection at second stage increased, which in turn improved the relative efficiency of the two stage index selection.

In the numerical example given by Cunningham (1975), as well as in the results presented by Abdou and Kolstad (1979), the standard deviation of the first stage index was larger than that of the second stage index, leading to relative efficiencies exceeding 90%. Contrary to this, Sharma and Mohapatra (1982) observed that the traits included in the first stage index gave a considerably lower index variance than the index at second stage, resulting in an efficiency of 63%.

Table 4. The effect of selection intensity at the first stage on the relative efficiency of two-stage indexes. F = first stage; S = second stage

Index used in the first (F) and second (S) stages	Proportion selected (%)	$\bar{i}$	SD of the index	Total genetic gain	
				Absolute	Relative (%)
One-stage index					
– I_1	15.00	1.554	447.953	696.118	100
Two-stage indexes					
F I_3	20.00	1.400	184.279		
S I_{31}	75.00	0.424	338.178	401.377	57.6
F I_3	25.00	1.271	184.279		
S I_{32}	60.00	0.644	342.243	454.622	65.3
F I_3	30.00	1.159	184.279		
S I_{33}	50.00	0.798	345.697	489.445	70.3
F I_3	35.00	1.058	184.279		
S I_{34}	42.80	0.917	349.493	515.452	74.0
F I_3	40.00	0.966	184.279		
S I_{35}	37.50	1.011	353.146	535.043	76.8
F I_3	45.00	0.880	184.279		
S I_{36}	33.33	1.091	356.385	550.981	79.1

The best two stage index (I_{36}) was about 20% less efficient than the one stage selection but has the advantage of discarding as much as 55% of the flock after first stage selection at the age of 40 weeks which would avoid expenditure in maintaining inferior birds for long and decrease the amount of record keeping.

If the birds are bred only after second stage selection, the generation interval with the two stage index selection will be same as for one stage selection. The alternative approach – to combine the advantage of decreasing the generation interval with that of imposing some selection pressure on residual egg number, as suggested by Flock (1979) – is to breed all the selected chickens at first stage selection itself. Thereafter, while the progeny are growing, the parents may be maintained until the age of 72 weeks and can then be subjected to second stage index selection. The growing progeny of those birds that are unselected at second stage can then be discarded. This way, by the time second stage selection is completed, the progeny of the selected birds will be ready for housing in cages. A practical schedule would be to select the birds (about 20% to 25%) at the age of 300 days at first stage. With 60 days devoted for taking the required number of hatches (3–4 at 10 day intervals), the progeny would be 140 days old by the time their parents are subjected to second stage selection, (i.e. at 72 weeks of age) and would be ready to lay. Two generations can than be raised with two-stage index selection in the time taken for one stage selection. If genetic gains are to be evaluated per unit of time, the relative efficiencies are doubled when the above programme is followed. While 75% to 80% of the adult birds are discarded at first stage selection, about 5 to 10% extra progeny are to be raised and reared for a period of 20 weeks within a reasonable breeding cost. The prerequisite for such a procedure would be to maintain the entire flock in the base generation until the age of 72 weeks in order to generate the required variance and covariances for construction of first and second stage selection indexes. Thereafter, it is necessary to maintain the entire flock only once in few generations because the indexes may need servicing as the variance and covariances may change due to earlier selection.

References

Abdou FH, Kolstad N (1979) Two stage selection in White Leghorn hens. Acta Agric Scand 29:93–97

Cunningham EP (1975) Multi-stage index selection. Theor Appl Genet 46:55–61

Flock DK (1977) Genetic analysis of part period egg production in a population of White Leghorns under long-term RRS. Z Tierz Züchtungsbiol 94:89–103

Gowe RS (1977) Multiple-trait selection in egg stocks. 1. Performance of six selected lines derived from three base populations. 2. Changes in genetic parameters over time in the six selected strains. In: Proc 26th Annu Nat Breed Roundtable Poultry Breed America. Kansas City Mo, pp 68–91

Gowe RS, Fairfull RW (1980) Performance of six long-term multitrait selected Leghorn strains and three control strains and a strain cross evaluation of the selected strains. In: Proc 1980 South Pac Poultry Sci Conv. World's Poultry Science Association, New Zealand Branch, Auckland, pp 141–161

Gowe RS, Lentz WE, Strain JH (1973) Long-term selection for egg production in several strains of White Leghorns. Performance of selected and control strains including genetic parameters of two control strains. In: Proc 4th Eur Poultry Conf. British Poultry Science Ltd, London, pp 225–245

Harvey WR (1966) Least squares analysis of data with unequal subclass numbers. USDA-ARS 20: 1–157

Lerner IM, Cruden DM (1948) The heritability of accumulative monthly and annual egg production. Poultry Sci 27:57–78

Morris JA (1964) The usefulness of early records as selection criteria. In: Proc 1964 Australian Poultry Sci Conv. Suffer's Paradise, Queensland, pp 7–11

Sharma RP, Mohapatra SC (1982) Efficiency of two-stage index selection for selection of broiler parents. Indian J Poult Sci 17:157–163