OPTIMUM ECONOMIC WEIGHTS FOR AN INTEGRATED DYNAMIC CROSSBREEDING SYSTEM IN SHEEP USING EVOLUTIONARY STRATEGIES

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SUMMARY

The optimum selection direction for breeds contributing to an integrated three-breed terminal crossing system depends upon future trait means in the crossbred individuals and upon the dynamic nature of the production tiers. An evolutionary strategy (ES) was used to find the optimal economic weights for each breed using a production model, and compared to those obtained as partial first derivatives (AN) of the profit function. In addition, use of a single index throughout the time horizon or an updated index each generation (3 years) was evaluated. ES indices result in higher profit than AN indices (5 % to 18 %), and updating each generation resulted in higher profit than not updating, although the difference was negligible using ES. ES placed less emphasis on the optimum trait (*fat*) and more emphasis on reproduction in maternal breeds, resulting in higher profit per lamb because a larger proportion of production occurred in the commercial tier. ES allowed the simultaneous optimisation of economic weights for each breed and found optimal indices by "looking ahead" at the effects of selection on profit, selecting solutions that maximised cumulative system profit. This paper illustrates the use of evolutionary algorithms for optimisation of breeding program design.
Keywords: Breeding objective, crossbreeding, evolutionary algorithms

INTRODUCTION

Livestock production systems can have many interacting factors that make the decision-making process difficult. A computer model of the system can assist in examining the consequences of decisions that are made, but even finding an optimal solution can become complicated when the number of variables is large. Optimal selection within each breed contributing to an integrated crossbreeding system when profit is a non-linear function of trait means depends upon future trait means in the crossbred tiers. If the relative size of the tiers depends upon reproductive rate, and reproductive rate is a trait in the breeding objective, then the economic value of reproductive rate depends upon the improvement in economic efficiency associated with changes in the relative size of each of the tiers. Iterative procedures are required to find the economic weights for each breed. Evolutionary algorithms can be used to find the optimum values of the variables of complex systems, simplifying the decision-making process.

The production system modelled in this study is the commonly used three-breed terminal crossing system in meat sheep. The variables to be optimised are the economic weights (a) for each of the breeds with the objective of maximising profit in the multiplier and commercial tiers.

MATERIALS AND METHODS

System model. The breeding and production system is composed of three tiers. The purebred tier (Pt) is comprised of a nucleus for each of the breeds contributing to the crossing system; maternal dam (MD), maternal sire (MS) and terminal sire (TS). The multiplier tier (Mt) is comprised of MD females and MS males, producing F1 progeny; males are for slaughter and all females are used as dams in the commercial tier (Ct). Ct dams are mated with TS males to produce slaughter male and female progeny. The total number of slaughter progeny is fixed at 10,000 (Mt and Ct slaughter progeny). If an insufficient number of slaughter progeny are produced, additional Mt replacements are sourced from MD, and if a surplus is produced then the oldest Ct dams are culled.

Profit is due to three traits; *days* to slaughter (all progeny, *np*), carcase *fat* depth (slaughter progeny, *ns*) and number of lambs per ewe (*nlw*, all dams, *nd*). System profit is the sum over time (t=0-15 years) of annual and replacement costs for dams in Mt (T=1), annual costs for dams in Ct (T=2) and costs and income for all progeny:

$$\sum_{t=0}^{15}\sum_{T=1}^{2} ns_T 80.0 - np_T 0.5 days_T + ns_T\left(62.96 fat - 3.70 fat^2 - 259.26\right) - nd_T 40.0/nlw_T - 50.0 nd_{T=1,1}$$

Trait means for *days*, *fat* and *nlw* in TS are 60 days, 10 mm and 1 lamb, in MS are 100 days, 10 mm and 2 lambs, and in MD are 100 days, 7 mm and 1 lamb. The optimum for *fat* is 8.5 mm.

Genetic model. An infinitesimal genetic model is assumed, with one observation for each purebred animal for each trait measured before slaughter age (Table 1). In the case of *nlw*, the trait measured in juveniles is assumed to have equal genetic (G) and phenotypic (P) (co)variances as *nlw* in adult females. Selection of progeny in each nucleus is using an index of phenotypes ($b=P^{-1}Ga$) (Hazel 1943). The superiority of progeny over parents is equal to $ib'G/\sqrt{b'Pb}$ (i=selection intensity). Progeny are selected proportionately equally from across parental age groups. Reduction of variance due to selection in progeny from each dam age class is accounted for (Bulmer 1971). Dams are distributed across six age classes and sires are used only once.

Evolutionary algorithm. An evolutionary strategy (ES) (Back 1993) was used to find the optimal economic weights (**a**) for each of the breeds. Each candidate solution was represented by a string containing the economic weights (length = 9 or 45), and another string of equal length containing mutation step sizes. Each generation, the mutation string (*m*) of each parent is mutated using $m_i' = m \cdot \exp\left(\left(\sqrt{10N}\right)^{-1} ran_1 + \left(\sqrt{10\sqrt{N}}\right)^{-1} ran_2\right)$. Five progeny variable strings (a') are produced from each parent using $a_i' = a_i + m_i' ran_3$, ran_k is a random normal deviate (0,1). Rank selection among all progeny produced is used to replace parents with progeny. This is repeated for 200 generations. ES is naturally suited to unbounded problems and requires little parameterisation.

Two strategies were examined for the use of economic weights; a single set of economic weights per breed for the time horizon (15 years of selection), or five sets of economic weights per breed for the time horizon (one set per generation, approx. 3 years). For the former, ES string length was equal to 9 (3 breeds X 3 economic weights) and parent population size was 15. For the latter, ES string length was equal to 45 (3 breeds X 3 economic weights X 5 generations) and parent population size was 45. Results from ES are compared to those obtained using partial first derivatives (AN) of the system profit function.

Table 1. Heritability (diagonal), genetic (below) and phenotypic (above) correlations and phenotypic variance for *days*, *fat* and *nlw*

	Days	Fat	Nlw
Days	**0.4**	0.0	0.05
Fat	0.07	**0.25**	0.0
Nlw	0.01	0.0	**0.1**
V_p	20.0	1.0	0.5

Table 2. Change in number of dams and lambs in multiplier and commercial tiers from selection (deviation from AN1)

	AN5	ES1	ES5
Mt Dams	-47[1]	-922	-911
Mt Lambs	-19	-477	-482
Ct Dams	-335	-2102	-1751
Ct Lambs	9	237	240

RESULTS AND DISCUSSION

System profit (per lamb) from selection (cumulative system profit less 16 * base year profit) is highest with ES5 ($11.35), ES1 ($11.31), AN5 ($10.77) and least with AN1 ($9.55). The difference in profit between optimal (ES) single or multiple-generation strategies is minimal, however between first derivative single or multiple-generation strategies is considerable. ES resulted in a large improvement of profit over that obtained with AN.

ES strategies result in greater increases of *nlw* than AN (Figure 1), resulting in fewer dams in Mt and Ct, fewer progeny in Mt and more progeny in Ct than from AN (Table 2). ES causes a larger shift in production from Mt to Ct and this is favourable. The cost of Mt dams is recovered only through the sale of male slaughter progeny, and through the productivity of F1 dams in the commercial tier. Minimising the size of Mt, and maximising the productivity of Ct, is most profitable.

Use of ES allowed for simultaneous optimisation of the breeding objectives for the three breeds. A reduction in emphasis on *days* in the maternal breeds is compensated by a small increase in emphasis on *days* in TS (Figure 1). Maternal breeds have greater emphasis on *nlw* causing the reduction in costs (dams) and increase in income (Ct lambs).

The ES can "look ahead" and find optimal solutions while AN relies on current trait means. The fitness function ES selection is based upon is cumulative selection profit. As such, all factors contributing to fitness are simultaneously selected for, resulting in individual variable values that have high fitness, but also the combinations of variable values that have highest fitness. For more complex systems where an analytical approach necessarily means the problem must be simplified, evolutionary algorithms offer a means by which to simplify the process, not the problem.

REFERENCES

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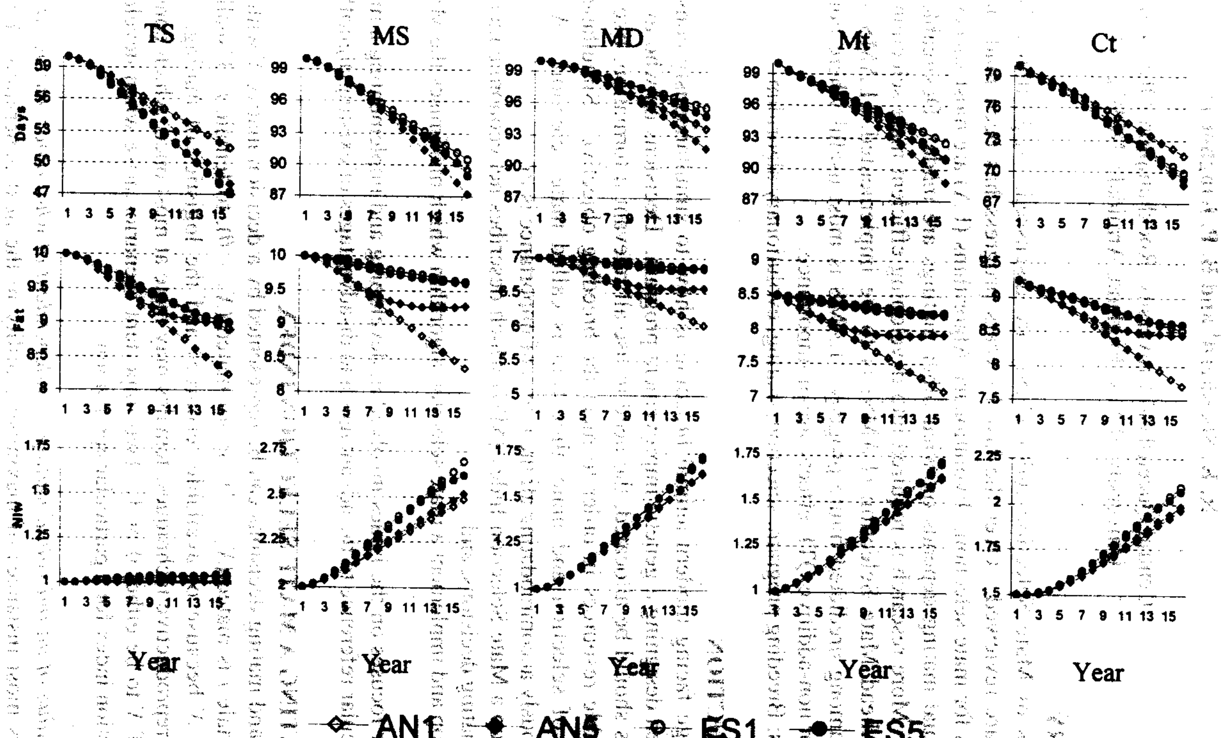

Figure 1. Mean days, fat and nlw in terminal sire (TS), maternal sire (MS), maternal dam (MD), multiplier tier (Mt) and commercial tier (Ct) arising from selection on an index with economic weights derived using evolutionary strategies (ES) or first derivatives (AN).