PROGENY TESTING FOR BEEF CHARACTERISTICS

Epreuve de la descendance pour les caractères de la production de viande bovine

Überprüfung der Nachkommenschaft in Hinblick auf Merkmale der Rindfleischproduktion

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Beef production has, over recent years, received a boost in terms of its relative importance as a result of shortages of meat and excesses of milk products (at least in Europe). In this context efforts to increase beef production have received relatively more attention and, naturally, methods of genetic improvement have been assessed together with the short term management improvements which can be made. Not unexpectedly, performance testing of beef cattle has developed throughout Europe. In recent years progeny testing has also increased although probably not to the same extent as performance testing.

The European situation regarding both performance and progeny testing was reviewed by Prof. H. Kräusslich (1971) and this indicates quite large differences in the types of progeny test which are practised. Whilst the advantages and disadvantages of progeny testing are well known, it is worth repeating some of them since they should have a bearing on the type of test adopted in any specific set of circumstances. Firstly, progeny testing is most useful for characteristics which cannot be measured on the live animal — e. g. most carcass characteristics. Yet many tests measure characteristics which can be measured on the live individual (growth rate, feed conversion) and fail to measure objectively carcass characteristics. Secondly, progeny testing can enable a more precise estimate of breeding value to be made — this is dependent upon the heritability of the trait and the number of progeny involved in the test. Thirdly, progeny testing is usually relatively expensive to carry out and fourthly, results in a longer generation interval than performance testing.

It must be pointed out that some of these points, e. g. long generation interval,

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assume that breed improvements is involved i. e. additive gene effects cumulating over successive generations. This assumption is not valid in all situations since an A. I. centre may progeny test simply to identify superior sires which are used solely to sire slaughter progeny.

In adition, progeny testing enables an A. I. centre to create an impression of a level of accuracy which is acceptable to the producer — this having little or nothing to do with accuracies of estimated breeding values.

The progeny test itself can be carried out in numerous ways but basically there is a convenient split into two categories — station and field testing. Station testing means any test which uses facilities specifically committed to the purpose of testing animals as opposed to a field test which uses commercial producers' facilities i. e. their housing, management and, in most cases, their normal slaughter procedures. There are often discussions on which of these two basic approaches is best. The station test normally enables greater precision of measurement and more types of measurements but usually costs more and may involve considerable initial capital investment whereas the field test is relatively cheap but normally is less accurate and restricted in the traits which can be measured. However, accuracy of measurement is not necessarily synonymous with accuracy of test since the aim of the progeny test is to identify bulls which will sire better commercial progeny. In this context, whilst a field test carried out using several farms may be less precise in its measurement, the correlation between such results and commercial practice could well be higher than that between practice and a station test on a single location (how ever it attempts to copy commercial production). Other than for the accuracy of selection aspect, any exaggeration of the variability of performance of progeny will tend to mislead commercial producers into expecting more improvement than is realistic.

One of the main justifications for progeny testing has always been that it enables measurements to be taken which are not possible on the individual candidate for selection — in particular, carcass traits. However, it is also true that there may be correlated traits which can be measured on the live individual which will allow selection to take place at a lower level of accuracy but with considerable savings in costs. The two organisations (Milk Marketing Board and Meat and Livestock Commission) concerned with beef progeny testing in Britain have both carried out tests which measured carcass traits as part of the test but now use carcass classification i. e subjective assessment.

These two organisations have adopted different approaches to progeny testing — the M. M. B. purchased a farm and developed it as a progeny test station whereas M. L. C. has organised «field» progeny testing using commercial beef producers of high calibre. Basically M. M. B. purchase calves, transport them to Warren Farm (the «station») and test on an 18 month beef system purchasing about 25 animals per sire with the intention of having a test based on at least 20 records per sire. Normally losses are lower than provided for, thus giving slightly better accuracy. A test normally involves 10-20 sires and takes in calves every other month of the year. This raises one of the problems of a station test — once it has been established the aim must be to operate at full capacity and this means operating seasonal production systems on a non-seasonal basis.

M. I. C., on the other hand, purchases calves and delivers them to about 10 producers (3-4 calves per bull per producer) who rear them in 18 month beef production avoiding further mixing of groups after the initial balanced allocation of calves. About 40 calves per bull are purchased with the intention of obtaining a test based on 30 progeny per sire. Losses in this context include animals for which a weighing was missed or which was not retained in its original grouping. Tests normally involve 5-10 sires and since tests use commercial producers' facilities, operate on a seasonal basis but this raises problems in organising inseminations where a large number of sires are involved.

A report by M. M. B. (1972) pointed out that a problem experienced in a field test which it organised was the re-grouping of cattle by farmers i. e. re-distribution of steers among pens to ensure even batches of animals at all stages, whereas present M. L. C. experience is that this is a minor problem. This is probably due to the fact that M. L. C. uses selected producers of known ability whereas the M. M. B. test (some years ago) simply attempted to get information on many farms (in a similar manner to the milk progeny tests). The M. M. B. report also points out that errors due to the re-grouping problem altered the estimate of heritability considerably. Whilst this is so, except in the planning stage of a programme, such errors are of no significance assuming the same bull is selected since the realised response will be the same. Nevertheless the benefits of being able to adjust data for various components obviously allows greater accuracy in terms of establishing real differences at testing station level.

There appears to be no data which will allow the different tests to be evaluated and, in any case, decisions would depend on the precise circumstances — the availability of capital, the co-operation of able producers for a field test, the potential for organisation of collection of data and carcass information, the structure of the industry etc. all bear upon the problem.

It must be stated, however, that a considerable drawback to the field test is the absence of feed intake and feed conversion data. Whilst several station tests do not, in fact, take such measurements they can be taken without much effort by the use of electronically operated gates. It would appear that a major criterion for selection in the present feed situation is that of efficiency — at least in any country where a significant part of the feeding period is indoors. Selection on such a basis may also mean that the problem of increased mature body size and consequent increased calving problems may be allayed to some degree. If efficiency is the major criterion, station tests would be preferable to field tests. The genetic correlation between growth rate and feed conversion is probably the key to this decision.

With regard to M. M. B. and M. L. C. testing procedures the actual operating costs are very similar both being around £ 900 per sire tested excluding carcass costs. The costs do not take into acount the capital invested in a station by M. M. B. but this, it could be argued, is a good investment in its own right. The M. L. C.'s costs include the support which is given by providing the calf, at Friesian calf price, to the feeder.

Carcasses have been dissected but this is not now done. However, the M. L. C. has been investigating the prediction of beef carcass composition by sample joint dissection (KEMPSTER *et al.*, 1974) — the following table summarises some of the results:

Joint dissected	Correlation		Cost of dissection per progeny
	Lean % in side	Lean/Bone ratio	
Coast	0.94	0.79	£ 10
Pony	0.94	0.82	£ 12
Full side	1.00	1.00	£ 85

This information is the starting point for assessing the value of the inclusion of sample joint dissection in progeny tests compared to other methods e. g. the subjective assessment used by M. L. C. in its national carcass classification scheme scores subcutaneous fat and conformation and costs very much less. The correlation between fat score and % lean in side is – 0.62.

Obviously cost of information together with any relevant correlations must be considered in evaluating the relevance of progeny testing for beef characteristics. Returns as well as costs must be estimated but since returns will be different not only in size but also in time scale these need evaluating on a common basis. In addition there are other factors which must be considered —

I) what are the alternatives and their costs and returns (if any)?
II) is the scheme part of an overall breed improvement programme or simply a «once and for all» slaughter generation programme?
III) what is the effect on other traits not under direct selection? — for example, effect of increased size on calving problems
IV) what is likely to occur in the industry if nothing is done?
V) what are the ways in which the returns will be made?

One of the ways which can be used to evaluate the usefulness, in cost benefit terms, of a programme is the use of the «discounted gene flow» technique as described by MCCLINTOCK and CUNNINGHAM (1974). The method was evolved to express the *present* economic value of the total genetic consequences over a period of years of one insemination. It takes into account the likely outcome of one insemination and evaluates the returns using the discounted cash flow technique having first established the economic merit due to the genetic contribution of that insemination.

In the U. K., 60 % of beef produced is derived from the dairy herd and each year 20-25 % of the 3 million dairy cows are inseminated with a beef breed.

A beef insemination can be either into a dairy cow which is the most common type or into a beef cow and the consequences are somewhat different. A beef bull insemination into a dairy cow will provide, with a known probability, a calf which, if it is male will be slaughtered as a beef animal but if it is a female, will normally become a crossbred beef suckler cow and produce slaughter progeny for, on average, five seasons, whereas the same insemination into a beef cow will normally result in slaughter progeny only.

The consequence of one beef insemination can be outlined as follows:

A. Probability of a calf from 1 dose of semen $(C) = 0.6$
Probability of a male calf $(P) = 0.5$
Additional economic merit of the calf M

Discounted cash flow factor $\left(\frac{100}{100 + r}\right)^y$

where r is discount rate (10 % for all examples) and y is the year from the insemination in which the value is expressed i. e. slaughter point.

Thus, a steer calf has the probability and an economic merit:

$$C\,P\,M\left(\frac{100}{100 + r}\right)^y$$

where $y = 3$ since a steer calf is 2 years old at slaughter.

This, using the figures given gives a figure of 0.2250 M.

B. A female calf has the same probability and conception rate as the steer but is then used for breeding, therefore contributing 1/2 M to its progeny — all of which are slaughtered. The female calves first at 3 years old thus producing its first slaughtered progeny in year 6 (from time of insemination) and produces slaughter progeny for 5 successive years i. e. 6, 7, 8, 9 and 10. The value can be summarised

$$\sum_{1}^{n} C\,P\frac{M}{2}\left(\frac{100}{100 + r}\right)^y$$

Where n is the number of calves produced in a lifetime.

For the values assumed, the figure summates to *0.35307 M*
Therefore the total value for 1 insemination is *0.57846 M*

Alternatively, if the insemination was into a beef cow the total value would be twice that of the steer value *0.45078 M*

The value has so far been calculated from the time of insemination but when attempting to evaluate different testing programmes, each of which has its own time scale before semen is produced, this must be further discounted by the necessary time factor. For the purpose of this paper, the systems being compared are Performance testing : Progeny testing : Performance testing followed by progeny testing. The time scales can, therefore, be taken as follows:

	Performance tested Months	Progeny tested Months
Purchased	0	0
Inseminations	6	6
Progeny born	15	15
Progeny slaughtered	33	33
Progeny test result analysed		40
1 year semen		40-52
Progeny born		55
Progeny slaughtered		73

Thus, progeny from the first year's semen of a progeny tested bull are slaughtered in Year 7. This means that the original 0.57846 *M* which still applies for Performance tested bulls progeny has to be discounted and becomes 0.39510 *M*.

Two situations have been considered — firstly that where semen is simply used for the one year (as outlined) and secondly where semen is used for 4 years. The pattern of discounting then allows the merit to be summarised:

	Discounted values of M	
	Performance test sires	Progeny test sires
1st year of semen production	0.57846	0.39510
2nd year of semen production	0.52588	0.35919
3rd year of semen production	0.47808	0.32654
4th year of semen production	0.43462	0.29685
Total for 4 years	2.01704	1.37768

Against the values of economic merit has to be put the costs involved basically these are the purchase price of bulls, cost of semen collection (for 3 extra years in 4 year assessment), cost of lay-off (for progeny test bulls), cost of progeny test (dependent upon numbers in the test).

The figures used in this exercise are those which appear to be incurred by those involved in A. I. but the costs do not consider other operational costs since these would be incurred even if no selection programme was practised. The costs have to be discounted for the time at which they are incurred — thus semen collection charges for the 3 years for a performance test bull amount to £ 1,700 whereas for a progeny test bull they become £ 1,275 due to the delay in incurring the cost. The basic costs used can be found in Appendix 1.

The method in which the example was calculated to indicate the relative cost benefit was to calculate *M* in terms of increased daily gain, to transfer such gain into increased weight at slaughter (by multiplying by 540 days) and to assume a value of 18.23 p per Kg liveweight as net margin over production costs. The calculation then was to find the number of doses of semen needed (on a per annum basis for 1 or 4 years) to give a financial return equal to the costs involved. Obviously the lower the number of doses the better the returns from a specific scheme.

The schemes are studied and the results discussed — not as precise conclusions but as an indication of the type of evaluation which can be made and the way in which such evaluation can assist decision making.

The three cases are:

A. Either performance tested bulls selected at 1 in 5 (actually 2 in 10)
   or progeny tested bulls selected at 1 in 2
   or combination of the above — 1 in 5 on performance followed by 1 in 2 on progeny tests

B. Either performance tested — selected 1 in 10
or progeny tested — selected 1 in 4
or combination of the above — 1 in 10 on performance followed by 1 in 4 on progeny test

C. Either performance tested — selection 1 in 20
or progeny tested — selection 1 in 8
or combination of the above — 1 in 20 on performance followed by 1 in 8 on progeny test

In calculating responses the heritability of 18 month beef daily gain has been taken either as 0.3 or 0.5 although it must be pointed out that at the moment, the «heritability» of performance test 400 day weight in terms of 18 month beef production is unknown in U.K. conditions — a basic omission in the planning of an overall national programme.

The value for M has been calculated using the genetic response calculation based on the correlation between estimated and actual breeding value (r_{IA}) since this method allows assessment of the various schemes to be more easily studied in relation to each other.

$$M = i\, r_{IA}\, \sigma_A\, V$$

where i is selection intensity in standard deviations.

r_{IA} = is the correlation between estimated and actual breeding value i. e. accuracy.
σ_A = genetic standard deviation.
V = monetary value of 1 unit of progress.

Response in terms of daily gain was calculated using the following normal genetic formulae:

Performance test. A)

$$R = i\, r_{IA}\, \sigma_A \quad \text{where } r_{IA} \text{ is } \sqrt{h^2}$$

Progeny test. B)

$$R = i\, r_{IA}\, \sigma_A \quad \text{where } r_{IA} = \sqrt{\frac{nh^2}{4 + (n-1)\, h^2}}$$

Performance test followed by progeny test. C)

(I) Initial response as (A)

(II) As (B) but using $r'_{IA}\, \sigma'_A$, where $r'_{IA} = \sqrt{\frac{nh'^2}{4 + (n-1)\, h'^2}}$

$$\sigma'^2_A = \sigma^2_A\ [1 - h^2\, i\, (i - x)] \text{ and } h'^2 = \frac{\sigma'^2_A}{\sigma'^2_A + \sigma^2_E}$$

and assuming that σ^2_E is the same before and after the performance test selection has been made.

An example of the detailed calculation is given in Appendix 2 and the results indicating the number of doses of semen required per annum to cover the costs involved are shown in Tables 1, 2 and 3. In these tables the actual improvement in the progeny (in Kg) is shown in brackets below the selection intensity applicable. The comparisons show that the use of performance tested bulls is the most cost effective — within the assumptions made regarding the heritability of the test and correlation with commercial production. In the U. K., bulls are normally worked for 4 years and it is interesting that for all cases the doses required are between 4500 and 9000 for progeny tested bulls. These requirements are similar to the level achieved by some smaller A. I. centres and indeed by the M. M. B. until 2 or 3 years ago. The M. M. B. now achieve production of approximately 30,000 doses per bull per annum which is 3-6 times the level to break even in terms of national returns. Tables 1 and 2 indicate the advantages of using the combined performance and progeny tested bull and of using the performance tested bulls before they are progeny tested. Table 3 indicates that this conclusion is not valid at high selection intensity. However, Table 3 indicates that at the higher selection intensities the doses required are higher, indicating the effect of diminishing returns. Actual improvement is obviously higher and, in some circumstances, this additional gain may be of paramount importance — e. g. if values used were in terms of «savings of imports» as opposed to «net margin to producer».

It is obvious that the arbitrarily chosen levels of selection intensity need changing to maximise the cost effectiveness i. e. reducing the doses of semen required per annum.

TABLE 1

BREAK EVEN POINT IN DOSES OF SEMEN *per annum* PER BULL SELECTED FOR GROWTH RATE

Type of test	Selection intensity *	Number of progeny tested per bull	No. of semen doses per bull *per annum*			
			$h^2 = 0.5$		$h^2 = 0.3$	
			BULL	USED	BULL	USED
			1 year	4 years	1 year	4 years
Performance...	1 in 5 (7.8-4.7)	—	3060	1470	5090	2450
Progeny	1 in 2 (5.1 to 3.1)	30	13520	4870	18670	6270
		20	13020	4770	18300	6700
		10	12960	4870	18410	6920
Performance preceeding progeny...	1 in 5 then 1 in 2 (12.0 — 7.3)	30	8870	2970	13390	4480
		20	8570	2890	13080	4410
		10	8330	2840	13020	4430
Performance using selected bulls until progeny tested ...	1 in 5 then 1 in 2	30	2770	1880	4480	2950
		20	2650	1820	4310	2880
		10	2520	1770	4130	2840

TABLE 2

Type of test	Selection intensity *	Number of progeny tested per bull	No. of semen doses per bull per annum			
			$h^2 = 0.5$		$h^2 = 0.3$	
			BULL	USED	BULL	USED
			1 year	4 years	1 year	4 years
Performance...	1 in 10 (10.0-6.0)	—	3550	1480	5910	2490
Progeny	1 in 4 (8.9 to 5.3)	30 20 10	14090 13440 13180	4610 4470 4460	19460 18890 18720	6370 6280 6340
Performance preceeding progeny...	1 in 10 then 1 in 4 (17.3 — 10.4)	30 20 10	10230 9800 9460	3620 3520 3460	15120 14690 14550	5350 5270 5320
Performance using selected bulls until progeny tested ...	1 in 10 then 1 in 5	30 20 10	3300 3130 2930	2300 2220 2140	5300 5040 4770	3560 3470 3410

TABLE 3

Type of test	Selection intensity *	Number of progeny tested per bull	No. of semen doses per bull per annum			
			$h^2 = 0.5$		$h^2 = 0.3$	
			BULL	USED	BULL	USED
			1 year	4 years	1 year	4 years
Performance...	1 in 20 (11.9-6.9)	—	4560	1710	7610	2860
Progeny	1 in 8 (11.0 to 6.7)	30 20 10	21490 20400 19840	6620 6310 6210	29680 28660 28180	9150 8870 8810
Performance preceeding progeny...	1 in 20 then (21.1 — 12.6)	30 20 10	34330 34040 34520	10090 10010 10160	50930 51230 53380	14960 15060 15710
Performance using selected bulls until progeny tested ...	1 in 20 1 in 8	30 20 10	11010 10760 10510	6320 6220 6180	17670 17350 17120	9790 9730 9850

* Figures in brackets below selection intensity are the equivalent of progeny in Kgs.

The returns used were for growth since this character is common to all tests but it is obvious that these calculations need doing for other individual characters, for correlated characters and for situations where selection is based on an index. The value of progeny testing for % lean in the side (assuming $h^2 = 0.5$ and $\sigma_p = 3.5$ %) would result in a marked reduction in the doses required — to a level some 40-50 % below those in the tables, clearly indicating the real value of such a test. Such figures need evaluating using different carcass criteria for the test and comparing them with performance tests using echo sounding with or without scanning equipment. Since theoretically index selection maximises progress the doses required could be reduced even below 40 % of the figures shown in the tables.

Another conclusion from this type of approach is probably more specific to the U. K. but it is interesting to note that testing and selection of bulls which are to sire slaughter generation animals only, requires 28 % more semen per annum to break even compared to those used to inseminate dairy cows to produce some of the suckler cows.

It is clear that, in most circumstances, the progeny testing of beef bulls for beef characteristics has a significant and valuable role to play even where such programmes are not directly linked to breed improvement programmes.

Programmes which are linked to purebreed improvement as well require evaluation but should be even more cost effective than the examples studied so far.

SUMMARY

Some of the advantages and disadvantages of progeny testing are reviewed together with a brief discussion of the logic and methods of «station» and «field» progeny testing in Britain. The «discounted gene flow» method of cost benefit analysis is briefly outlined and used to evaluate and compare performance testing, progeny testing and a combined system using performance testing, followed by a progeny test for the provision of an A. I. stud. The three procedures are evaluated for three levels of selection intensity for growth, two values of h^2 and for different periods of semen usage. The cost benefit analysis is calculated and results given in terms of the number of doses of semen required annually to covr the costs of the testing programme involved.

In general, it would appear that progeny testing can be cost effective if more than 4500-9000 doses are used annually where bulls are used for 4 years and that performance testing followed by progeny testing reduces the doses required except at high selection intensity.

RESUME

Certains avantages et certains desavantages du contrôle de la descendance sont revisées avec une discussion brêve de la logique et des méthodes du contrôle en «station» et en «ferme» en Grande Bretagne. La méthode du «courant génétique escompté» pour l'analyse du coût et du profit est brêvement exposée et utilisée à évaluer et comparer le contrôle de performance, le contrôle de la descendance et une système combinée se servant du contrôle de performance suivi par un contrôle de la descendance dans le but de fournir un haras d'A. I. (insémination

artificielle). Les trois méthodes sont évaluées en trois niveaux de la sélection d'intensité de croissance, deux valeurs de h^2 et des périodes différentes d'usage de semence. L'analyse du coût et du profit est calculée et les résultats sont présentés en termes de nombre de doses de semence réquises annuellement pour couvrir les frais du programme de ces contrôles.

En général, il apparerait que le contrôle de la descendance pourrait être viable pourvu que 4500-9000 doses soient servies annuellement tandis que les taureaux sont employés pendant 4 années et que le contrôle de performance suivi par un controle de la descendance dimunerait les doses nécessaires à l'exception de la haute selection d'intensité.

ZUSAMMENFASSUNG

Einige der Vor -und Nachteile der Nachkommenschaftsprüfung sind hier überprüft mit einer anschließenden kurzen Diskussion über die Logik und Methode von Nachkommenschaftsprüfstationen in Groß Britanien. Die «nicht mitzählende Gen-Strom» Methode, einer kostenvorteile bringende Analyse ist kurz erörtert und wird dazu verwendet, den Testvorgang zu entwickeln und zu vergleichen. Nachkommenschaftsprüfung und ein kombiniertes System, die den Testvorgang ausführen und den darauffolgenden Nachkommenschaftstest, stehen den A. I. Studenten zur Verfügung. Die drei Vorgänge sind für drei verschiedene Arten, eine Auswahl von dem Grad des Wachstums, entwickelt. Zwei Werte von h^2 und ein Wert für verschiedene Perioden von Samengebrauch. Die kostenvorteile bringende Analyse ist kalkuliert und ihre Resultate werden in Form von der Anzahl des Samenquantums die jährlich benötigt werden, gegeben um die Kosten des in Frage kommenden Prüfprogramms zu decken.

Im Allgemeinen scheint es, daß die Kosten für Nachkommenschaftsprüfung sich rentieren wenn mehr als 4500-9000 Dosierungen jährlich verwendet werden und Bullen, die auf diese Weise 4 Jahre lang behandelt werden, benötigen für den Testvorgang eine verminderte Dosierung, außer bei einer hohen Auswahl der Intensität.

APPENDIX 1

Basic costs used in examples of cost benefit analysis

Performance test bulls	— Purchase price £ 1,500	
Other bull	— Purchase price £ 1,000	
Collection of semen	— £ 750/year	
Lay off charge	— £ 350/year	
Progeny test charge:	30 progeny	£ 900 per bull tested
	20 progeny	£ 700 per bull tested
	10 progeny	£ 450 per bull tested

«Subsidy» ie cost to MLC per performance tested bull £ 200.
This was included since it is part of the National investment although, obviously not a cost to the A. I. organisation purchasing such bulls.

APPENDIX 2

The following is an example of the calculation used in assessing the cost effectiveness of the various alternatives considered. This calculation is for a performance test selection of 1 in 5 followed by a progeny test selection of 1 in 2.

Assumptions: (I) Selection is on males only.
(II) $h^2 = 0.5$ $\sigma_P = 0.045249$ Kg/day.
(III) Semen is used for one year.

Performance test

Actually 2 out of 10 selected was used ($1.27\,\sigma$). $r = \sqrt{h^2}$.

$$\text{Response} = i\, r_{IA}\, \sigma_A = \frac{1.27}{2} \times 0.7071 \times 0.031996 \text{ Kg/day.}$$

This is multiplied by 540 days giving 7.7579 Kg.

Progeny test

Selection was 2 out of 4 ($0.66\,\sigma$). The test was based on 30 progeny.

$$r_{IA} = \sqrt{\frac{nh^2}{4 + (n-1)\,h^2}} = 0.9$$

$$\text{Response} = i\, r_{IA}\, \sigma_A = \frac{0.66}{2} \times 0.9 \times 0.031996$$ which, over 540 days gives 5.1315 Kg.

Progeny test after performance test

The selection of the bulls to be progeny tested on the basis of their performance test will reduce the additive genetic variation and the actual additive genetic variance after selection is given by $\sigma'^2_A = \sigma_A^2\,[1 - h^2\, i\,(i - x)]$.

$$\sigma_A'^2 = 0.00102373\,[1 - 0.5 \times 1.27\,(1.27 - 0.84)] = 0.000744201$$

Assuming σ_E^2 is the same as before i. e. remains constant then

$$h'^2 = \frac{\sigma'^2_A}{\sigma'^2_A + \sigma_E^2} = \frac{0.000744201}{0.000744201 + 0.00102373} = 0.4209$$

Then

$$r'_{IA} = \sqrt{\frac{nh'^2}{4 + (n-1)\,h'^2}} = 0.8827$$

$$\text{Response} = \frac{0.66}{2} \times 0.8827 \times 0.02728$$

which is 4.291 Kg over 540 days.

Therefore total response is $7.7579 + 4.291 = 12.0488$ Kg.

Value is response × value per unit of response × discounted gene factor for 1 year semen of progeny tested bull

$$12.0488 \times £\,0.182325 \times 0.3951 = 0.867958$$

Costs (per bull used)

Cost of testing 10 bulls + Purchase of 2 bulls + Progeny testing 2 bulls + 3 yr lay off period for 2 bulls

2000 + 3000 + 1800 + 900 = £ 7,700

Doses required per annum $\dfrac{7700}{0.867958} = 8872$

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