The Genetic Improvement of the Irish Cattle Population

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The dominant position of the cattle industry in the national economy does not need to be stressed. The 1.5 million cows and 14,000 bulls in the country and their progeny are both the raw material for much of the output of our farms, and the agency through which much further raw material is processed into marketable products. The output of meat, dairy produce and livestock which derives from this population of animals makes up a half of the total output of agriculture, and two-thirds of all agricultural exports. This relative dominance of cattle has remained fairly constant over the last 10 years (Fig. 1). The pattern is likely to be substantially the same for many years to come. At the level of the individual farmer, output from cattle is also the major source of income. In a recent survey (Attwood, 1965) of 884 farms of varied size and system of farming, it was found that output from cattle and dairy produce comprised on average 54 per cent of total output (Table 1). With the exception of tillage farms, where a quarter of the output derived from cattle, dairy produce and cattle consistently accounted for half to three-quarters of the total output for farms of all sizes and types. It is therefore evident that improvements in the efficiency and productive capacity of the cattle industry must play a large part in the progress of both the individual farmer and the nation.

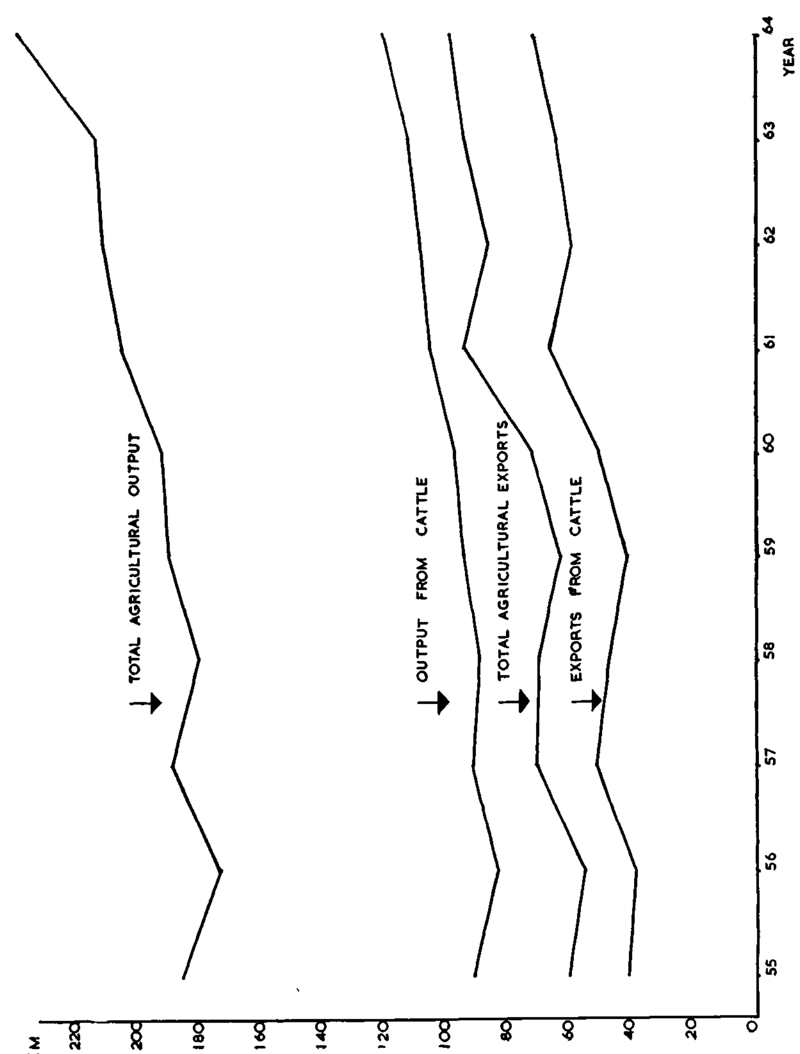
TABLE 1

CATTLE AND DAIRY PRODUCE AS PER CENT OF TOTAL OUTPUT ON A SAMPLE OF 884 FARMS, 1963–64

	Farm size (acres) Under 50	50-100	Over 100	All Farms
Creamery milk—better soils ...	62.5	65.3	72.7	68.0
Creamery milk—poor soils ...	68.5	72.0	61.5	67.1
Creamery and tillage	44.9	49.5	46.9	47.4
Liquid milk	78.9	75.5	68.6	70.9
Dry stock—better soils	49.9	48.3	54.0	52.5
Dry stock—poor soils	54.2	46.9	43.0	48.8
Tillage	25.5	29.1	29.8	27.4
All farms	55.7	55.4	52.4	53.7

These improvements can be brought about in two ways: we may improve the inherent genetic capacity of the animals themselves, or we may improve the environment in which they perform. There is a difference between these two sources of improvement, which it is important to note. Efforts to provide better feeding and management will undoubtedly bring about rapid improvement. However, the effort must be repeated year after year if the initial gains are to be maintained. Genetic improvement, on the other hand, is cumulative from one generation to the next: the gains made in each generation are permanent, and provide the starting point for future progress. Genetic gains, therefore, though harder won,

FIGURE 1. TOTAL AGRICULTURAL OUTPUT AND EXPORTS, AND OUTPUT AND EXPORTS DERIVED FROM CATTLE, 1955-'64



are inherently more valuable, and are worth a correspondingly greater effort to achieve.

DEVELOPMENT OF GENETIC IMPROVEMENT METHODS

Planned improvement for productive traits is a surprisingly recent innovation in the history of man's domestication of cattle. Until comparatively recent times, the number rather than the merit of his stock was the breeder's aim. The stimuli of scientific enquiry, growing demand for farm products, and stable agricultural conditions led to considerable efforts at stock improvement in Britain in the eighteenth century, and it is to these efforts that we owe most of our present breeds. The need for documentation of this work led to the establishment of herd books (Coates' Herd Book was first published in 1822) and with the growth of the herd book developed the idea of "pure breeds", whose purity was protected by rules for registration. The herd books were the only documentary evidence of an animal's worth, and over the years excessive reliance came to be placed on pedigree registration. The development of agricultural shows in the last century and the prominence that was given to show winnings in the breeding world led to a gradual shift away from the evaluation of animals on their productive merit towards a greater emphasis on points of type, whose relationship to productive capacity was often extremely tenuous. Thus, by the beginning of the twentieth century, the methods employed in many breeds for the evaluation and improvement of stock had strayed a long way from those used so successfully by the pioneer breeders of two centuries ago.

In 1864 Gregor Mendal demonstrated that for some traits in peas, inheritance is particulate; that these units of heredity occur in pairs; and that they segregate at gametogenesis and recombine at fertilization according to predictable patterns. In 1901 his work was rediscovered, and in the subsequent decade his conclusions were confirmed for many traits in plants and animals. Within a further decade, it had been shown that Mendel's units of heredity were identifiable physical segments (now called genes) occurring in the chromosomes in the nuclei of plant and animals cells. In 1918, R. A. Fisher demonstrated that variation in continuously varying (or quantitative) traits, such as height, weight, milk yield, could be analysed in Mendelian terms. The science of genetics, then, has given us within the last 50 years a proven rational basis for the study and exploitation of genetic variation in animals.

Early efforts to apply genetics to animal improvement were largely restricted by the inadequacy of mathematical theory. Computing procedures for extracting the necessary genetic information from large populations of animals did not exist. The work of Fisher, Wright and Lush has helped to bridge this gap, and the development within the past decade of powerful electronic computers has made it possible to use the elegant statistics of these pioneers on problems of genetic improvement. The two sciences of genetics and statistics are the basis from which the modern animal geneticist works. They enable us to understand why the efforts of the eighteenth century breeders were so successful, and to plan improvement programmes in the light of knowledge which they never had.

The fruitful application of scientific theory to breeding programmes can already be seen in the tremendous improvements which have taken place in our domestic poultry. The physical structure of our cattle populations, however, has been an obstacle to the use of genetic theory in that species in the years since it has become available. The long generation interval, the low reproductive rate, and the fragmentation of the population into separate herds all make effective selection extremely difficult. However, within the last 20 years a revolutionary structural change has occurred, which has radically altered the importance of these factors—that is the widespread use of artificial insemination (AI).

At this particular point in time, therefore, circumstances are ripe for the exploitation of planned genetic improvement in cattle on a scale and level of effectiveness which was never before possible. In the last 10 years a start has been made in several countries, including our own, which have serious ambitions for their cattle industry. This movement has been gathering momentum abroad, most notably in America, Britain, New Zealand and Scandinavia, and is already producing substantial gains for dairy traits. Suitably harnessed to a practical programme genetic theory it can give us the kind of cattle we need.

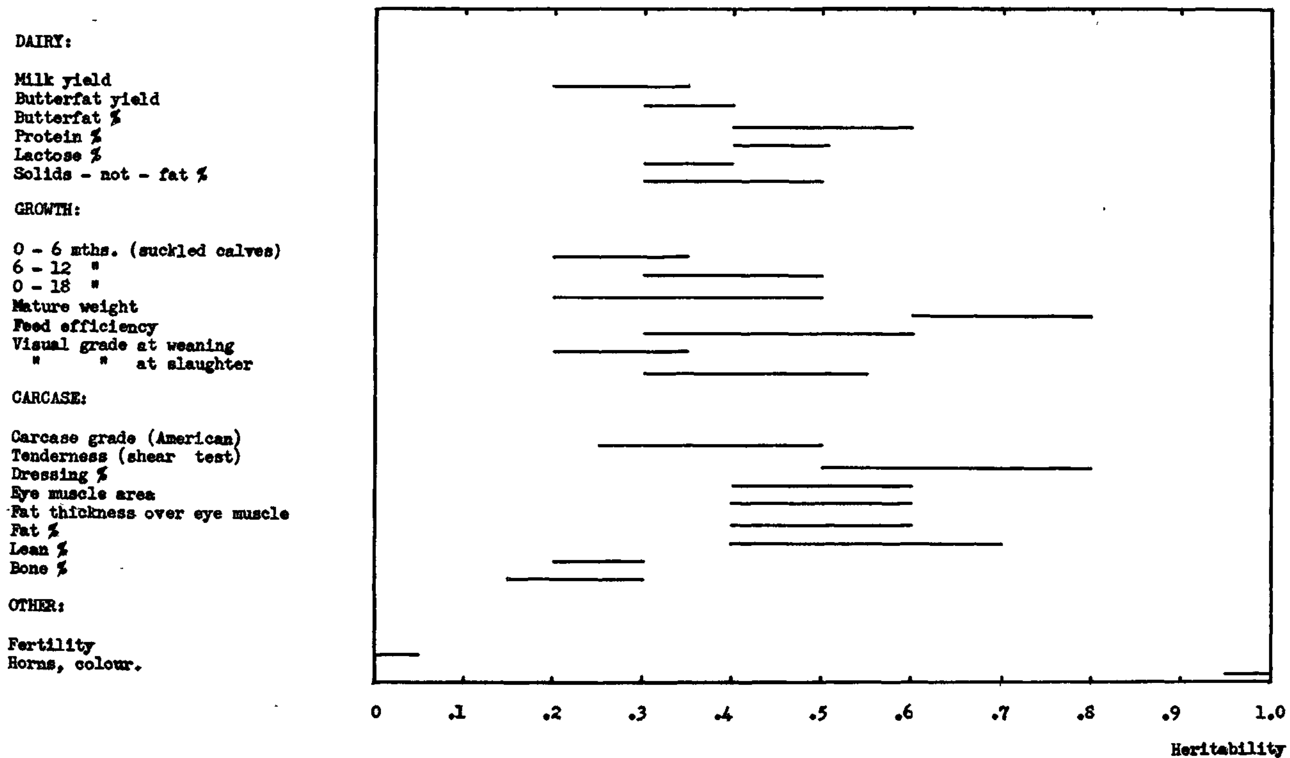
PRINCIPLES OF SELECTION

Basically, genetic improvement is brought about by means of selection, that is, by arranging that superior animals leave more progeny than inferior ones. Mutation, migration and random drift can also produce genetic changes. With the exception of migration, they cannot contribute to an improvement programme. Migration, in the form of importation, has probably been the major factor determining genetic movements in our cattle population in the past: our present stock are largely the descendants of Shorthorns imported between 1800 and 1850. We now appear to be in the process of replacing this stock with Friesians. Importation, though not a substitute for planned improvement within our own population of cattle, will undoubtedly continue to make an important contribution.

The progress which we can hope to bring about in a selection programme depends on (1) the length of the generation interval, (2) the degree to which the trait in which we are interested is heritable, (3) the intensity of selection, and (4) the accuracy with which we can identify the genetic value of the animals. The first two of these are more or less beyond our control. It is by manipulating the third and fourth, the intensity and accuracy of selection, that we can determine the rate of genetic advance.

The degree to which a trait is heritable can be expressed by an index which is called the "heritability" of the trait and which runs from 0 to 1. The heritability of different traits can be measured experimentally in a population. Figure 2 lists approximate heritability values for a range of traits in cattle, based on actual estimates obtained by various research

FIGURE 2 RANGE OF HERITABILITY VALUES FOR DIFFERENT TRAITS IN CATTLE



workers. It is evident from these values that it would be futile to breed for fertility, whereas coat colour is readily changed by breeding. Most economic traits, however, have heritabilities in the range of 0.2 to 0.4 which means that they are only partially controlled by heredity. Our breeding plans must take this into account.

For any particular trait, the genetic progress will be the product of the accuracy and intensity of selection. The accuracy with which we can identify the genetic merit of an individual will depend on how we go about measuring that merit. For instance, we can measure the genetic merit of a cow for milk yielding by observing how much milk she gives in a lactation, by observing her dam's yield, by judging her appearance as a dairy animal or by innumerable other criteria. Obviously some of these criteria are better than others, and in general we will prefer to use a direct measure of the trait where possible. The animal must then be evaluated using information on this trait observed in the individual itself or in its relatives. From genetic theory we can calculate the accuracy of these different sources of information. The accuracy can be expressed as a percentage of complete knowledge of the genetic value of the animal being evaluated for selection. Table 2 lists the relative accuracy of the more common types of information available to us in selecting cattle, for two levels of heritability which span the range within which most economic traits fall. It can be seen that in each case a single record on the individual itself is worth more than all the information available from all the relatives in the pedigree. It is also evident that records on sufficient progeny are better than any other source of information. We can use this background information to decide what proportion of our resources to devote to tapping the different sources of information available in our selection programme.

TABLE 2

RELATIVE ACCURACIES OF PRODUCTION RECORDS USED FOR SELECTION. ACCURACIES ARE EXPRESSED AS PER CENT OF FULL KNOWLEDGE OF THE GENOTYPE OF THE INDIVIDUAL BEING SELSCTED

Heritability	Relative accuracy of production records on:					
	Complete pedigree	Self	20 half-sibs	Progeny 5	Progeny 20	Progeny 40
	%	%	%	%	%	%
0.2	39	45	36	46	72	82
0.4	50	63	41	60	83	90

Intensity of selection is the most important single determinant of progress and is measured as the ratio of animals selected to those available for selection. If, for instance, a farmer rears five heifers, and after observing their first lactation, retains two, his selection intensity is two-fifths.

The effect of intensity of selection on the gains made is illustrated in Table 3 for selection among recorded cows and progeny tested bulls for milk yield. The actual intensity of selection operated by most breeders is in fact surprisingly poor, and recent evidence from Britain suggests that it tends to be poorer in the top herds at the apex of the breed structure than in ordinary commercial herds. In any planned improvement programme it will be necessary to ensure above all an adequate intensity of selection.

TABLE 3

GENETIC SUPERIORITY FOR MILK YIELD (GALLONS) OF INDIVIDUALS SELECTED FROM AMONG (*a*) COWS ON THE BASIS OF ONE MILK RECORD EACH AND (*b*) BULLS, ON THE BASIS OF 40 PROGENY RECORDS EACH, AT DIFFERENT INTENSITIES OF SELCTION

	Selection intensity								
	3/4	2/3	1/2	1/3	y	1/10	1/20	1/50	1/100
Cows	5.3	6.8	10.0	13.7	17.5	22.0	26.0	30.5	33.0
Bulls	15.5	19.7	29.1	40.0	51.2	64.2	75.9	89.0	96.4

THE IRISH CATTLE POPULATION

The Irish cattle population consists of 1.5 million cows, 14,000 natural service and 400 AI bulls and their progeny. The geneticist interested in improving the productive capacity of our cattle must first look to the national stud of AI bulls. At present, close to one million of our cows are being bred artificially, and each bull in AI is siring anything from one to 10,000 progeny per annum. The extent to which this use of AI has revolutionized the breeding structure of our cattle population is not generally appreciated. The problem of stock improvement in present-day conditions is an entirely different one from that which our livestock policy makers faced even 20 years ago, and calls for a fundamentally different breeding programme.

There are several different reasons why our interest centres on AI as the main avenue of stock improvement. The most obvious one is the greater usage possible with an AI bull: on average, AI bulls breed over 2,000 cows per year, against 40 for each natural service bull. Potentially, an AI bull can breed over 100,000 cows in a year. AI bulls may also be selected much more intensely than those in natural service, since so many less of them are needed. Because of their large-scale use, greater effort and expenditure in seeking good bulls for AI is justified. Furthermore, AI use enables us to estimate a bull's breeding value more accurately. It makes possible a comprehensive progeny test for a wide range of traits, and the test can be taken to any degree of accuracy by increasing the number of progeny. All these advantages mean that the potential for genetic improvement of the national herd through the selection and testing of bulls for the AI stud far outstrips the combined potential of all other avenues of stock improvement.

DEVELOPMENT OF ARTIFICIAL INSEMINATION

It is interesting to follow the development of AI in this country. From the start made by Mr. Nagle in Mallow in 1946, the growth of AI has been a steady expansion to the present position where we have nine AI stations bringing the service to every farmer in the country and breeding more than 60 per cent of the national cow herd. This growth is illustrated in Fig. 3. There is no indication as yet that the growth from year to year

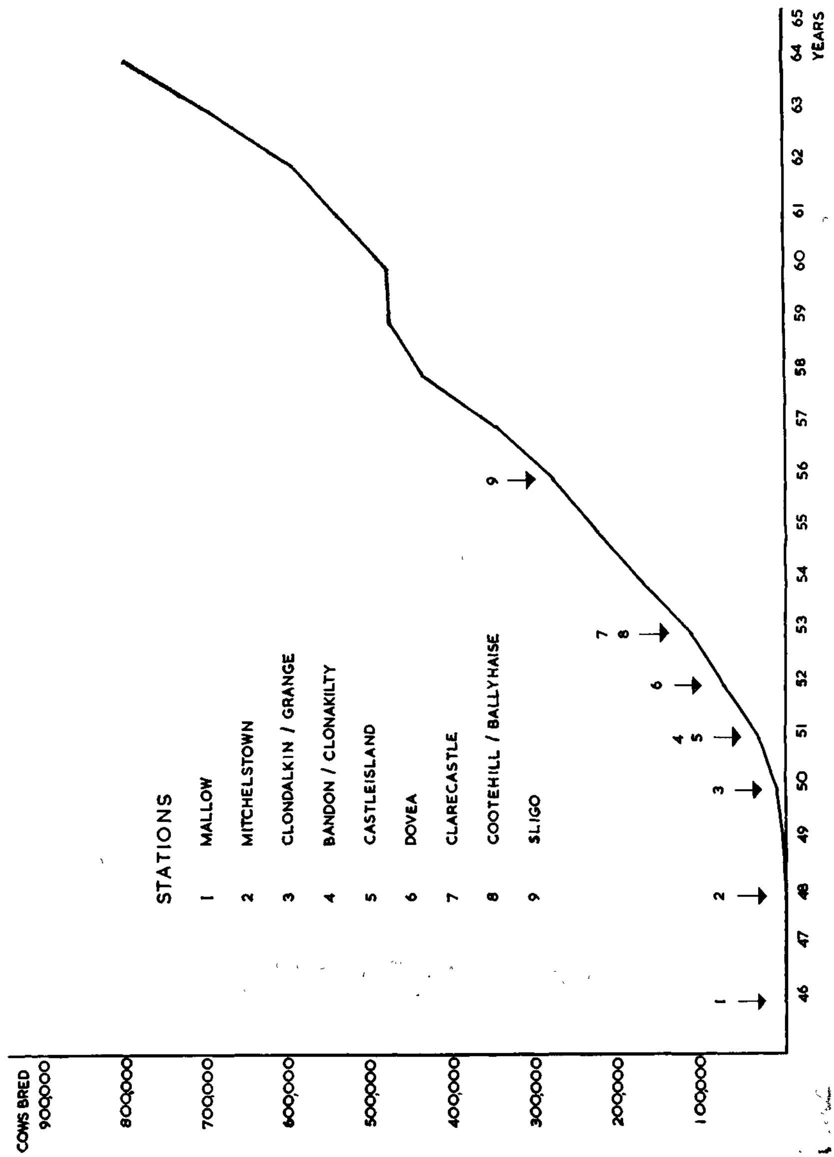


FIGURE 3. GROWTH OF AI, SHOWING DATE OF COMMENCEMENT FOR EACH STATION

is tapering off. If we are to judge by the experience of other countries with a similar herd structure to our own, we may be breeding over 90 per cent AI in a few years' time. In one aspect of this development we have been particularly fortunate: we have avoided the proliferation of small stations which is a feature of AI structure in, say, Holland, and which makes the rational exploitation of the advantages offered by AI extremely difficult. Figure 4 shows the present structure of the AI service. Each of the nine stations serves a wide area and breeds a substantial proportion of the cows in its area. With a rising cow population and greater usage of AI on the present herd, there is room for further growth of the service in all areas.

The pattern of breed use in AI has been dominated by the Hereford, Angus, Shorthorn and Friesian, with all other breeds coming to about 1 per cent of inseminations each year. One consistent trend has been the increase in Friesian inseminations from the introduction of the first Friesian bull in 1948 to the present position where over 40 per cent of all services are from Friesian sires. The use of the four main breeds of bull in AI over the last 11 years is illustrated in Fig. 5.

Before the opening of the first AI station, the genetic potential of this method of cattle-breeding had been clearly recognized and cogently stated by Dr. Henry Kennedy (1945). He proposed the systematic testing of bulls so that the normal service could be provided by proven sires. He further suggested that positive steps be taken to ensure that bulls for testing would be available, by the establishment of special herds of bull mothers. Twenty years later we can report that while the technical development of the AI service has been thorough and satisfactory, its genetic potential has barely been touched. The bulk of the service is being provided by unproven bulls, and the systematic provision of bulls for testing has yet to begin. Were it not that many farmers are grading up to Friesians, the shortage of bulls of proven merit would be far more evident.

RESEARCH RESULTS

It will be evident from what I have said that the primary point at which the science of genetics can be applied to the benefit of the Gross National Product of this country is in the selection of the bulls which enter AI. Our research has therefore been directed to several aspects of this problem. The dual-purpose sires are obviously the more important part of the national AI stud, since their progeny are retained in the cow herd, whereas beef-cross progeny are not. In Ireland it is not necessary to justify the goal of dual-purpose cattle, and we can be encouraged by the fact that the weight of contemporary evidence indicates no genetic antagonism between beef and dairy traits—in other words that true dual-purpose cattle can be bred.

The general structure of a programme for the selection of dual-purpose bulls for use in AI derives from the structure of our cattle industry, the biology of cattle, and the genetic nature of the traits in which we are

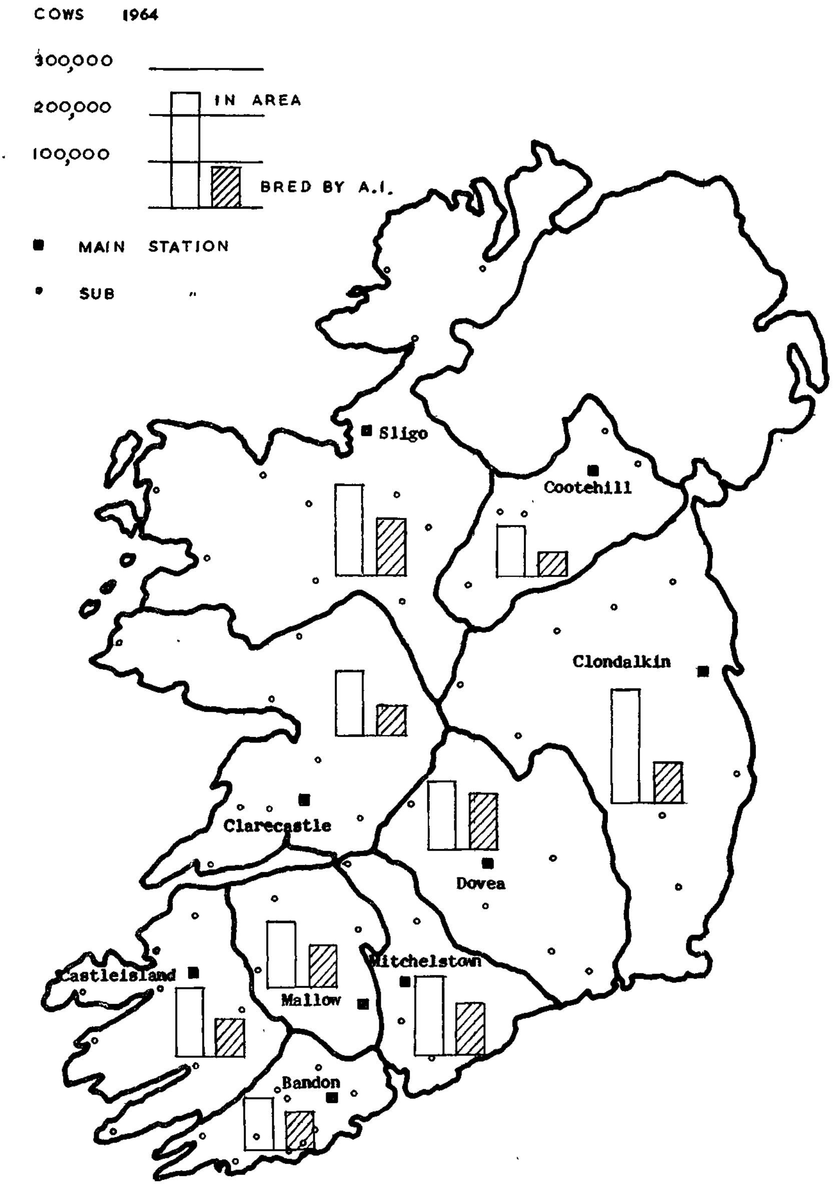
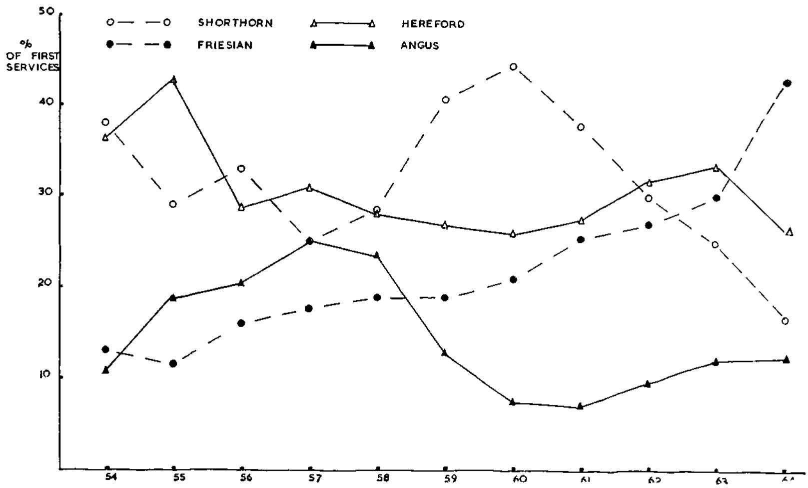


FIGURE 4 A.I. STATION AREAS, SHOWING MAIN AND SUBSTATIONS

AND 1964 TOTAL AND A.I. BRED COW POPULATIONS.

FIGURE 5. PERCENTAGE OF INSEMINATIONS BY BREED OF BULL 1954-'64.



interested. In the first place, we know (Table 2) that the only way to evaluate an animal with high accuracy for traits of low heritability is by means of a progeny test. A progeny test for dairy traits is therefore required. Many aspects of beef performance can be observed in the bull himself, and are moreover fairly highly inherited. This suggests that we should screen all young bulls in a performance test. In providing the young bulls for testing, it is nothing more than common sense to arrange the matings from which they are produced, so as to have for their parents the best animals in the population.

The more detailed construction of the programme however, requires a great deal of research. For instance, in deciding the scope of the progeny test for milk yield alone, we must balance 14 different variables, all of which can be adjusted to alter the rate of genetic progress and economic returns. The decisions involved in setting up the performance test and arranging the planned matings are equally complex. The solution of these problems involves the use of a kind of genetic operations research. We have carried out such a project (Cunningham and Cleaves, 1965) for the problems connected with the choice of factors in a milk progeny test.

We selected 3,000 of the huge number of alternative programmes which can be constructed from various combinations of the 14 controlling factors. We then programmed our computer to simulate what would happen if each of these schemes were operated over a 20-year period. With help from our economists, we costed each scheme and priced the returns. Among other factors, we looked at the effects of different levels of proven bull usage, costs of proving bulls, types of milk recording service, proportions of cows bred by young untested bulls and number of progeny per bull tested. The computer calculated the year-by-year genetic gains in the national cow herd, the accumulated gains over 20 years, and the net returns on the costs. In some cases, schemes which maximized genetic gains lost money, that is, the cost of the scheme was not covered by the net return. Some of the results of this study are presented in Tables 5 and 6, which are discussed in more detail in a later section. They indicate that a feasible programme which would give near-maximum net returns over a 20-year period would have the following structure: 80 per cent of all cows would be bred to proven sires, 20 per cent to young sires; 20 per cent of the 200 bulls in the proven stud would be replaced annually by 40 young sires chosen from 160 progeny tested each year; 80 per cent of the young bulls would be alive when their progeny were recorded, and each bull would be evaluated on 40 progeny records; the milk recording system would be such as to give eight progeny records for every 100 first inseminations carried out by a young bull. The encouraging thing about these results is that they indicate an optimum programme which in scope and structure could be readily organized.

The reason why we have concentrated our operations on the progeny test end of the programme is that the costs of progeny testing dwarf the costs of the other components. The programme would therefore have to be constructed around the decisions reached on progeny testing. The provision of recorders is the major cost in progeny testing. Improving the yield of information per recorder is therefore a promising way of reducing the overall costs of the programme. With this in mind we have investigated (Cunningham, 1965a) the possibility of having the recorders visit each herd less frequently than in the present monthly system. Using daily milk records on 333 spring-calving cows, we measured the loss in accuracy in estimating total yield when one moves from monthly to bi-monthly testing. We also tried 17 different methods of combining these periodic tests into an estimate of total yield, in order to see if there was a more efficient method than that currently in use. The results of this investigation indicate that for sire-proving purposes bi-monthly cow recording is fully adequate—the trifling loss in accuracy is easily compensated for by a marginal increase in the number of progeny per bull. It also emerged that even with bi-monthly testing, the present stepwise method of calculating total lactation yields is the best method.

Whatever the procedure used for testing the cows on the farm, the people who must choose between the bulls on test are finally faced with the problem of evaluating each bull on the basis of a mass of progeny records collected in a large number of herds. Since the differences between bulls will account for a mere 7 per cent of the variation in these records, considerable statistical refinement of the data is needed. Furthermore, the large amount of money which it has cost to acquire these records in the first instance, justifies the devoting of considerable resources to the extraction of the maximum amount of useful information which they contain. A great deal of research has been done in different countries to devise efficient methods of bull evaluation from progeny test data. Most of the methods in current use are in fact highly refined and adjusted averages of progeny records. This use of averages as the basis of evaluation was made necessary in the past because it was not feasible to attempt more difficult computations. In recent years, however, the availability of extremely large electronic computers has made more sophisticated computations possible. We therefore went back to basic genetic and statistical theory in an attempt to devise a method which could be proved "optimum" by reasonable criteria of optimality. We believe we have succeeded in doing this and the results have been published (Cunningham, 1965b).

We discovered in the course of this work that rather similar methods have been developed independently for the computation of ballistic missile trajectories from photogrammatic data. This rather interesting similarity in development becomes understandable when one considers the similarity of the problem. The missile people spend vast amounts of money to make a test launching, and this large investment in the operation justifies the use of sophisticated mathematical analysis to extract the maximum amount of information from the test. Our method of sire evaluation has been tried on sample data in our own computer and we are at present programming a very large machine in Britain to handle it.

We made a second approach to this problem on a more prosaic level. We took 16,000 dairy records in which there were represented 25 sires with at least 100 progeny each. We then randomly divided the progeny of each sire into groups of 20 and for each of seven different procedures evaluated each sire on each group of his progeny. This exercise was then repeated with random groups of 40 progeny. The point was to see which method gave the best concordance of estimates of the same sire from separate samples of his progeny. This experiment is practically complete, and the results indicate that of the seven methods tested the so-called stablemate comparison method is the best.

In a further study we are looking at the level of young sire usage necessary to give a specified number of progeny records with a predetermined probability of obtaining at least the number required. It is rather important to keep this probability high, otherwise we might find too frequently that having gone to the expense of maintaining a laid-off bull to five years of age, we were unable to evaluate him. We can use the fact that the number of progeny records per bull follows the Poisson distribution to construct tables which will help in deciding how many first inseminations to make with each young sire.

These studies provide some guidance to us in the construction of a genetic improvement programme geared to AI. There are, of course, still a great many unanswered questions, which must be investigated in the future. However, our own results and computer predictions, and the experience of colleagues who are seeking answers to similar problems overseas suggest that a programme can be constructed which would make the best use of the opportunities now offered by AI. Such a programme is outlined in Fig. 6.

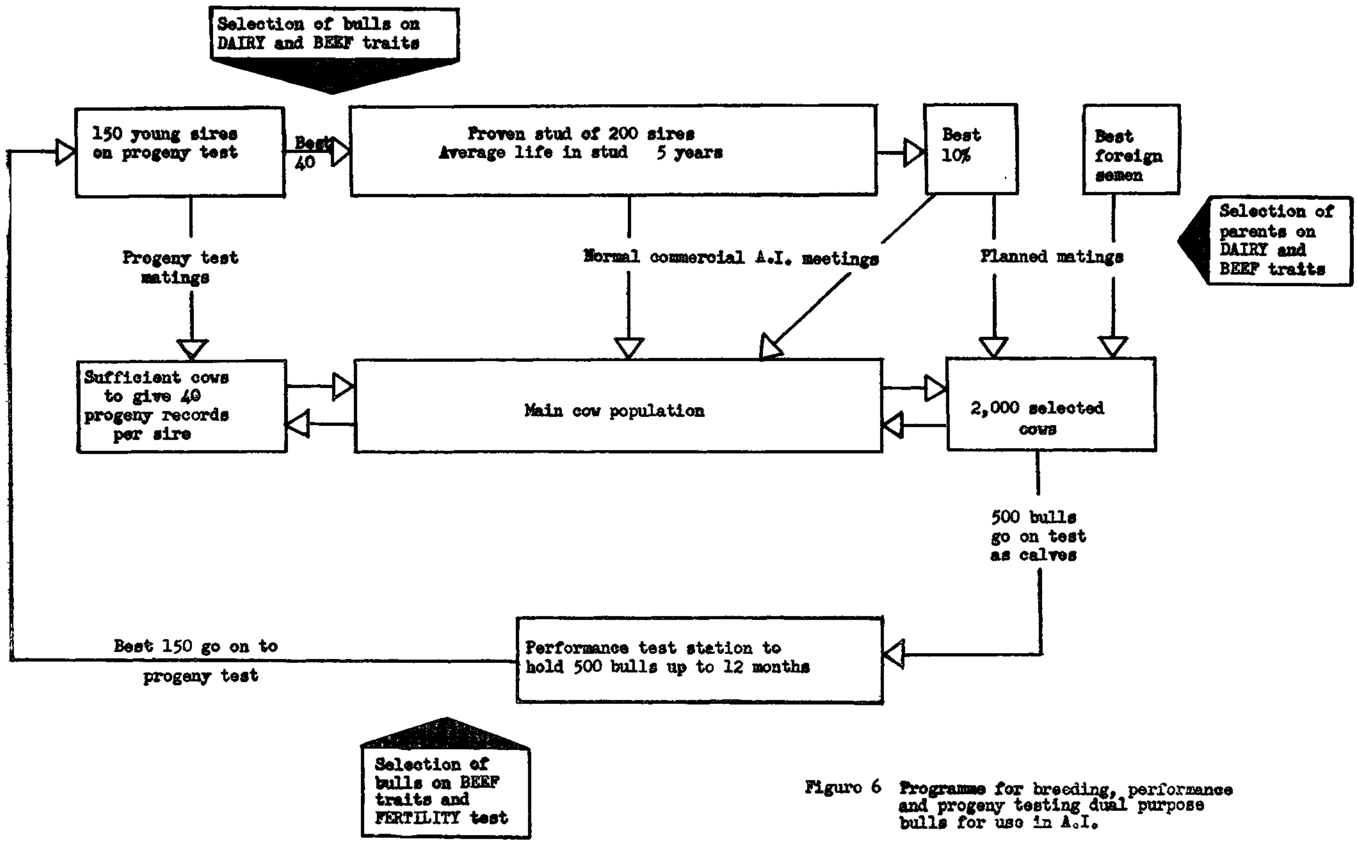


Figure 6 Programme for breeding, performance and progeny testing dual purpose bulls for use in A.I.

A SELECTION PROGRAMME FOR DUAL PURPOSE BULLS FOR USE IN AI

The organisation and execution of such a selection programme would require the resources and co-operation of all the nine AI stations in the country. The activities which would be undertaken are as follows:

Planned matings

Arrangements would be made for 2,000 planned matings per year. The first stage of this operation is to locate the top sires and dams available. The sires would, of course, be the best proven sires standing in AI both here and abroad. In the national AI stud of some 200 Friesian and Shorthorn bulls in February, 1965, there were 16 Friesian and six Shorthorn bulls which on their progeny test results could be regarded as candidates for this honour. We can also take advantage of the extensive testing programmes in operation in Britain and America by using semen from the top bulls in their studs. Increasingly, the top bulls in European studs will have beef as well as dairy progeny figures, so that for the future we can expect to be able, within veterinary requirements, to choose the kind of bulls we want for bull fathers.

The location of 2,000 potential bull mothers presents a more difficult problem. These cows should be chosen on their own performance for milk production and composition, on their sire's progeny test, if such is available, and on inspection for suitability of type. The type inspection should probably emphasize beef potential. However, the main criterion for selection of these cows must remain their production figures. The shortage of recorded cows limits the population in which one can look for them. This is, perhaps, less of a problem in the Shorthorns, where non-pedigree cows can qualify as bull mothers, than in the Friesians, where the dam must be registered before the bull bred out of her becomes eligible for licensing. However, approximately 2,500 registered Friesian cows are being recorded at the moment, and those undoubtedly contain some potential bull mothers. At any rate, the AI authorities should begin the compilation of a register of elite cows, and from this register the planned matings would be made.

The planned mating of the top AI bulls to elite cows, by arrangement between the AI authorities and individual breeders, is already becoming a common feature in other countries. Once a policy of systematic acquisition and testing of bulls for AI use is undertaken, it is only common sense for the bulls to be acquired in this way. Methods of payment to breeders would have to be worked out for our conditions, but the experience in other countries indicates that suitable arrangements can be made. With contract matings of this kind, it will become necessary to have more than the usual pedigree guarantees of an animal's identity and parentage. This guarantee can be provided by blood typing the parents and the progeny, and such a blood typing service is now available in this country.

Performance test

Working back from an estimate of 150 young bulls per year as the required number to put on progeny test, we find that we must performance test about 500 per year to allow room to select with reasonable intensity on the results of the performance test. This permits a selection of about one in three, allowing for some rejects on fertility. The planned matings should be arranged to ensure that all calves are born within a three-month period in spring. The 500 male calves required would then be selected from among those born, and would be collected in to a central performance testing station. Here they would all be put on a standard rearing programme and would be carried through to about one year of age. Records of feed consumption and growth rate would be kept during this period. At the end of the period, they would be evaluated for overall performance and also for body type. It may become feasible to include at this stage some estimate of carcase quality, using ultrasonic measurements of back-fat and loin eye muscle depth. Those bulls judged best would be tested for fertility and in the future, for freezability of their semen. The final batch of 150 would then move on to the progeny test stage.

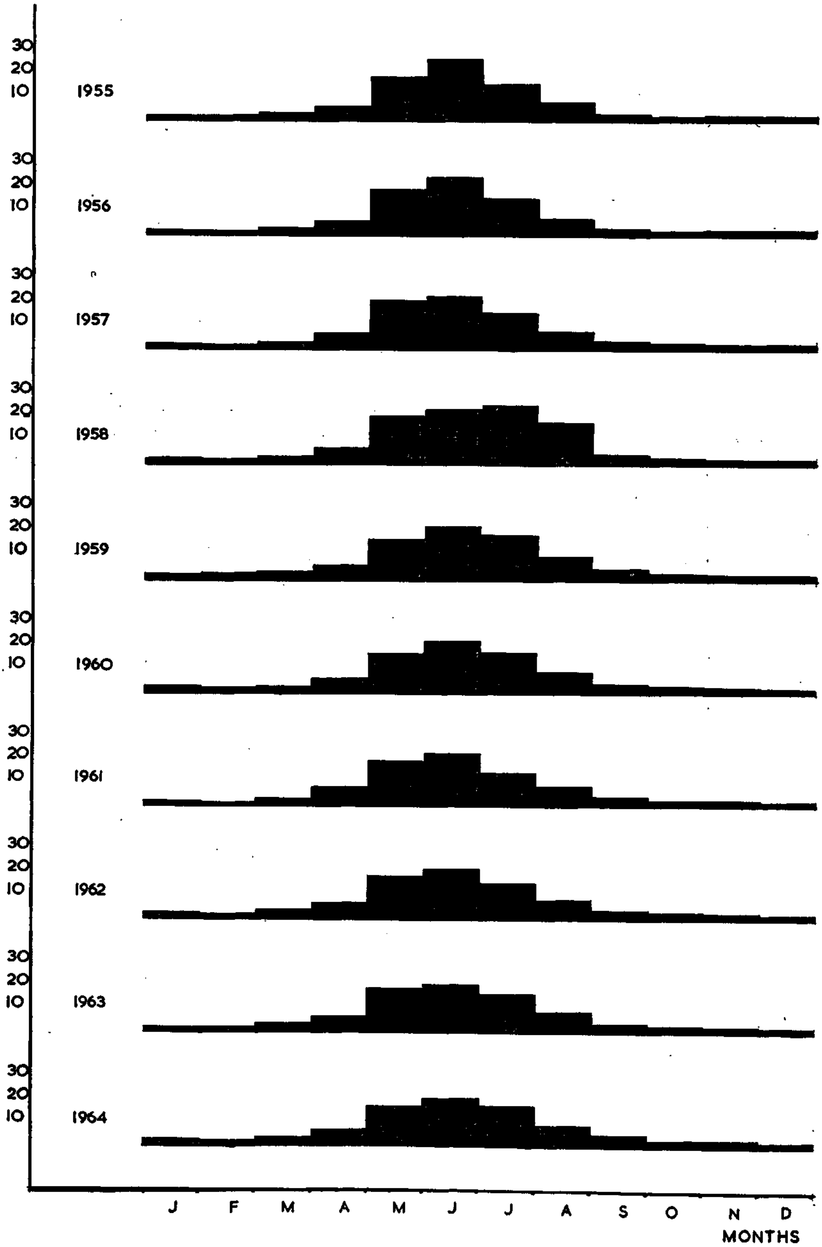
The arguments in favour of carrying out the performance test at one location are overwhelming. Most obviously, there is the fact that it is impossible to maintain a standard environment at several places. The detailed supervision of the growth and health of the bulls on test can be better provided for in a large unit, since this justifies the skilled staff needed. Furthermore, the station will in effect be an experimental AI station, since there will be the need for fertility testing of many animals per year. Further advantages emerge when we consider the requirements for a progeny test.

Progeny test

If we estimate that at least 500 first inseminations per young bull are needed to ensure sufficient progeny for testing, then we will have to make more than 75,000 services per year from young bulls. These services should be concentrated as far as possible in the May, June, July period so that the progeny will be born over as small a period of time as possible. These three months are the peak insemination season here, and this seasonality in our cattle breeding (Fig. 7) if properly used, can be quite an advantage. The young sire services should moreover be used randomly over the whole country, so that all bulls are tested on the same cow population and the same range of farms. This widespread distribution of semen could best be handled from a suitably located central station. Using frozen semen, of course, simplifies the operation considerably.

Progeny testing tends to be very inefficient if a high proportion of the progeny concerned are located in small herds. The reason for this is that herd-to-herd differences make up more than a third of the variation in dairy records, and that it is difficult to eliminate this variation if the average herd size is small. In herds in the liquid milk trade, the cows tend to calve in two groups—in Spring and Autumn. The systematic

FIGURE 7. SEASONAL DISTRIBUTION OF AI, 1955-'64



differences between the management of these two groups means that the herd must effectively be treated as two herds. This reduces the useful size of the herd by a half. The net result of these considerations is that the bulk of the progeny testing will be done in creamery supply herds of moderate to large size. Table 4 (compiled from Agricultural Statistics, C.S.O. 1960) shows the distribution of herds and cows by province and herd size. Since a high proportion of the herds in Leinster are in the liquid milk business and have two calving seasons, we find that the bulk of the useful herds will occur in Munster. In fact, one-third of the cows in the country are to be found in herds of ten or more cows in Munster.

TABLE 4

NUMBERS (IN THOUSANDS) AND PERCENTAGES OF COWS AND HERDS BY HERD SIZE IN EACH PROVINCE (1960)

Herd size (cows)	Leinster		Munster		Connacht		Ulster		State	
	Herds	Cows	Herds	Cows	Herds	Cows	Herds	Cows	Herds	Cows
1–3 No.	25.2	50.3	16.5	33.0	55.5	117.9	21.8	44.0	119.0	245.2
%	48.2	16.6	22.7	5.2	76.1	54.8	64.3	37.0	51.3	19.2
4–9 No.	19.0	103.7	30.3	169.9	16.4	82.9	11.1	60.6	76.8	417.1
%	36.3	34.2	41.7	26.7	22.5	38.6	32.7	50.9	33.1	32.8
10 and over No.	8.1	149.0	25.9	433.8	1.0	14.2	1.0	14.4	36.0	611.4
%	15.5	49.2	35.6	68.1	1.4	6.6	3.0	12.1	15.6	48.0
Total No.	52.3	303.0	72.7	636.7	72.9	215.0	33.9	119.0	231.8	1273.0

After an intensive period of use, the young bulls should be laid off for three and a half years, until the first records on their daughters become available. The number of bulls laid ofi at any one time would not exceed 600. Similar numbers of bulls are successfully maintained during the layoff period in New Zealand and Britain and should prove no problem here. It is possible that individual farmers may be prepared to lease some bulls for the layoff period, thus reducing the number to be maintained by the AI authorities.

An interesting suggestion has recently come from Norway on the problem of laying off bulls. Dr. Skjervold has calculated that it may cost less to freeze, say, 50,000 inseminations from each young bull, and then shoot him, than to keep him until his progeny test is complete. The bank of semen is then used or discarded when the progeny test results come in. This scheme has the added advantage that it is possible to do a carcase evaluation on each young bull. Since most carcase characteristics are relatively highly inherited, this information would be quite valuable (Table 2), and might greatly reduce the need for a progeny test for carcase traits. As semen-freezing technology improves, this scheme becomes more attractive, and it is quite likely to be a serious alternative for us within a few years.

When the daughters come into milk it will be necessary to collect about 40 records per young bull on test. It will be possible to do a preliminary ranking within each batch of young bulls after the first few months of their daughters' production, so as to get the most promising of them back into service in time for the peak of the season, thus in effect, shortening the test period by one year. At the end of the season, the best 40 surviving young bulls graduate to the permanent stud as proven bulls. Of course, the figures used are not absolute, and it might be that in some years only 30 are judged good enough. The advantage of a large programme is that the average merit of this selected group can, in effect, be guaranteed in advance.

The annual draft of proven sires would go into regular service in the different AI stations. There are, however, bound to appear some outstanding bulls, whose services it would be a pity to limit to one station area. If the distribution of semen from the central performance testing station is an established practice, then it will not be difficult to arrange that the top sires be made available to all farmers. With the more extensive use of frozen semen, this becomes even simpler. Indeed, if liquid nitrogen freezing becomes widespread, the central station could very we l act as a clearing house for semen of all kinds and a central depot for liquid nitrogen. With centralized milk testing and data handling, a rationalized and very simple transport scheme could service all phases of the operation.

The question of whether a beef progeny test is required has still to be decided. Since it is so difficult to get an agreed and measurable criterion of carcase quality, perhaps we should concentrate on growth rate, with safeguards to ensure that we are not selecting for undesirable body conformation. However, with a programme of this scope and complexity we should probably include some carcase assessments. Many hundreds of steer progeny of our present AI stud have been reared to slaughter at the AI stations and evaluated by Department of Agriculture and Fisheries personnel. Perhaps an extension of this practice will suffice. On the other hand, it might be possible to assemble groups of bull calves, with many young sires represented in each group and to have farmers rear these groups on contract. The groups would then go to slaughter in the usual way and records would be collected at the meat factory. Such a system could be a very efficient source of genetic information, and with close technical advice for co-operating farmers it might even be made self-supporting.

Milk recording

When the daughters of the young sires begin their first lactation in herds all over the country, there arises the important question of what is the most economical and efficient way to record their performance and evaluate their sires. This question is closely linked with the whole problem of milk recording. The present procedure is that each AI station carries out monthly milk recording in herds in its own area. These herds are chosen to maximize the amount of progeny test information collected. No charge is made to the farmer and the cost of the scheme is borne jointly by the AI station and the Department of Agriculture and Fisheries. Approximately 10,000 cows are recorded under this scheme by about 30 recorders. A further 30,000 cows are recorded under cow testing association (25,000) and pedigree herd (5,000) schemes. If 150 young bulls are to be fully tested each year, a large increase in progeny test recording will be needed. This might provide a good opportunity for a thorough re-organization of milk recording services on a national scale.

Recent developments may mean that the nature as well as the scope of milk recording should be changed. There is growing need for more detailed information on milk composition. New and improved methods of milk analysis are now becoming available, which can handle huge volumes of fat tests at less cost and with greater accuracy than the Gerber method. Mass methods for simultaneous estimation of fat, protein, solids-not-fat and lactose will soon be available. To take advantage of these developments we will have to organize large-scale centralized milk testing. It may also be possible to greatly reduce the cost of the operation on the farm. After extensive trials, Sweden has now gone over to a system where the farmer does the recording himself. A similar scheme is being tested in Britain. With occasional supervision and advice and the backing of efficient centralized milk analysis and data processing, these schemes have proved very satisfactory. We should be testing a variety of alternatives ourselves, because it is only on the basis of competently conducted field tests of this kind that we can make sound decisions.

All these testing and recording operations are for the purpose of collecting information on which decisions can be made. The whole reason for the existence of the complex of operations is to enable us to decide which bulls to shoot and which to use. The whole process converges on these selection decisions. In compiling the information on elite cows, breeding schedules, station performance, progeny tests for dairy and carcase traits, and above all, in the evaluation of the young sires, speedy and efficient handling of large volumes of information will therefore be necessary. Furthermore, since an operation of this scope will need to constantly review and reappraise its progress and procedures, it must be in a position to assemble data rapidly and efficiently. These requirements mean that mechanized data processing must be used. One of the reasons why we have, perhaps, been less responsive to the need for change in the past has been precisely this inability to carry out constant and thorough reappraisal of our operations. The task of checking and correcting the flight path of a selection programme of this scope will also require personnel of a high level of technical competence.

BEEF BULLS

The systematic acquisition, testing and use of beef-breed bulls in AI should be considerably easier to plan and carry out than in the case of dual-purpose bulls, if only because we have less traits to consider. There are, however, some special problems involved. Our two beef-breed societies wish to protect the market for young bulls in their members' interest, and therefore effectively refuse to register the progeny of AI bulls. This means that the top bulls identified through AI cannot be used as the sires of the next generation of young bulls, and thus breaks the cycle of improvement at its most critical point. It also prevents us from capitalizing on the existence of proven superior bulls of these breeds in foreign studs. The difficulty can be overcome by a change in breed society policy or by the licensing of superior non-registered bulls of these breeds. It is expected that the rules for herd book registration of Charolais calves will permit AI parentage and this example may influence the other beef breed societies.

This difficulty aside, the problem of testing beef breed bulls for AI should be fairly straightforward and would consist of the same three stages as for dual-purpose bulls. The best sires and dams would be chosen (on recorded performance figures together with some visual screening rather than on show winnings or the sale price of individual ancestors) and mated. The resulting bull calves would be evaluated in a common environment for growth, conformation, such carcase characteristics as can be measured in the live animal, and fertility. The best would be selected for use in the regular stud. Samples of their progeny could be evaluated for carcase traits after rearing in batches on commercial farms or in special rearing units. This progeny test of the bulls would then be used mainly for the identification of the sires of the next generation of bulls for testing. It would not be necessary to arrange the laying off of beef bulls, for two reasons. In the first place, they are being judged solely for beef performance and the selection on the planned matings and performance test will be an adequate guarantee of superiority in this respect. Secondly, all their progeny are destined for the butcher's block, and not for the breeding herd. The effect of a sire of poor merit is therefore limited and transitory—very different from the situation with a poor dual-purpose bull. This means that less precision in testing the beef bulls can be tolerated.

We have not gone into the requirements of a programme for beef bulls in the same detail as for dual-purpose bulls, because it is less important from a genetic point of view, and also because it would be nothing more than an academic exercise while the ban on the use of sons of AI bulls persists. The potential for rapid improvement of the beef bulls in AI, however, is very great. It would certainly be in the interest of the two beef breeds to exploit this potential—in spite of the short-term danger to the young bull market. The room for selection which exists in the Angus and Hereford breeding herds in this country is extremely small since about 60 per cent of the herds in each breed consist of either one or two cows. Even in the remaining herds, there is seldom sufficient scope for systematic progressive selection. By co-operating in the identification of superior bulls for AI and by making the fullest use of the best of them in pedigree herds, these breeds could make steady progress. It is also likely that overseas buyers of beef breeding stock will increasingly demand that the cattle be backed by authenticated growth and production figures (our own buyers of Charolais in France have done just this). By putting themselves in a position to supply such stock, Irish beef breeders might well capture much of the trade which is now being done by English and Scottish breeders.

GENERAL AND FINANCIAL CONSIDERATIONS

There are some very real dangers in centralised planning of a breeding operation on this scale. The first is the obvious danger for any centralised operation: that the plan may be leading in the wrong direction. It is possible that the selection objectives we aim for today may become outdated in a few years, as has undoubtedly happened in the past. The emphasis on small blocky beef cattle so pronounced 15 years ago, is now being reversed. High butterfat yields are now desirable in Ireland, but in 20 years' time the bulk of our milk may be going for liquid consumption in Britain and Europe, and high fat content may be an embarrassment. The danger then is that a fast-moving improvement programme will move our cattle farther along the wrong road, if in fact its aims are in the wrong direction. The answer, of course, is that with competent planning, the danger will be negligible. The corresponding advantage of being geared for rapid progess is, of course, that we can quickly respond to changes in demand.

The chief biological danger inherent in large and efficient selection programmes is that of inbreeding. It is known, for instance, that a 1 per cent increase in the coefficient of inbreeding causes on average a drop of 1 lb. of butterfat per lactation. Associated decreases in fertility and viability might be expected. If followed blindly, a highly efficient selection scheme might produce an undesirable increase in inbreeding. The question of whether special precautions against this need to be taken, is being actively debated by geneticists at the present time, and is so far unresolved. The precautions would probably take the form of subdividing the whole population into several groups and planning the allocation of the different bulls to each group in such a way as to have a lag of several generations between the use of related bulls within any one group. An alternative is merely to extend the present system of heifer tagging to avoid not alone sire–daughter matings but also other close matings. At any rate, the nature of inbreeding depression is such that any dangers from it can be seen and calculated in advance, and precautionary measures taken if necessary.

Calculating the genetic progress to be expected from a breeding programme of this kind is fairly straightforward. Making economic predictions of costs and returns is rather more difficult, because of the extra assumptions involved. However, we have made some elementary estimates of cost and return for the dairy progeny testing aspects of the dual-purpose bull programme. Some of the results obtained are given in Tables 5 and 6 and the assumptions involved are discussed below.

When we began this work, the nine AI studs were breeding about 800,000 cows per year, with approximately half of these inseminations being to dairy or dual-purpose bulls. We therefore chose a figure of 400,000 cows as a basic population size. There were 200 dual purpose bulls in the national stud. Since the trend is towards greater usage of the bulls, predictions were also made on the assumption that the same cow population is served by a stud of 100 and of 50 bulls. We assumed that 80 per cent of the young bulls are alive when their proofs are complete (at five years of age) and that 20 per cent of the old bulls in the proven stud die each year. The number of young sires to be selected is determined by the size and mortality rate of the proven stud.

An important factor in these predictions is the record recovery rate, that is, the proportion of first services which result in a progeny record. The record recovery rate depends on the number of live calves per first insemination (c), the proportion of heifers born (f), the proportion of these which are tagged or identified at birth (t), the proportion reared and completing a lactation (r), and the proportion of these which are recorded (p). The factors c and f will be relatively unchangeable at 0.65 and 0.5. The two situations considered in the present study correspond to a contract rearing and recording system in which r = 6, f = 1.0 and p = 1.0, and an efficient field recording system in which r = 0.4, t = 0.8 and p = 0.8. The record recovery rates for these two systems are 0.20 and 0.08.

In computing the economic returns, the marginal value of milk was taken to be 1.6 shillings/gallon and the cost per young sire tested was given five different values ranging from £750 to £3,000. The basic calculations were carried out by two computer programmes, the first calculating the cumulative gains over 20 years for any combination of the controlling parameters, and the second giving the detailed year-by-year gains in proven bull and young bull merit. In all, we examined the results of five combinations of bull cost with three stud sizes with two levels of record recovery rate with 10 levels of proven bull usage with 10 levels of progeny per sire tested. The programmes giving maximum economic returns for the 30 cases given by five bull costs by three stud sizes by two record recovery rates were found and are given in Table 5. It can be seen that in the situation most immediately relevant to the present structure of our AI stud (200 bulls, 8 per cent record recovery rate, £750 to £1,000 cost per bull tested) maximum gains are obtained by testing 267 bulls per year, and that the net return to farmers over a 20-year period averages about a million pounds, or £2 10s. per cow per year. It is also evident that at any particular size of stud, the gain from using a contract testing system (changing the record recovery rate from 8 per cent to 20 per cent) is not great. On the other hand, by increasing the usage of proven bulls from 1,500 services per bull (200 bull stud) to 6,400 (50 bull stud) the net gains can be increased by 60 per cent.

It is interesting to compare the economically optimum programmes with those giving maximum genetic gains, and also to see how sensitive the economic returns are to arbitrary alteration of the parameters. Table 6 gives the net annual economic gains for programmes which maximize

TABLE 5

PROGENY TESTING PROGRAMMES FOR MILK YIELD WHICH MAXIMIZE ECONOMIC RETURNS OVER 20 YEARS.
(For assumptions involved, see Txet)

	Percent of 1st services resulting in a progeny record									
	20%					8%				
Cost per bull tested (£)	750	1,000	1,500	2,000	3,000	750	1,000	1,500	2,000	3,000
200 Bull stud—										
Bulls tested annually	400	320	240	240	160	267	267	214	214	160
Percent of services to proven bulls	80	80	85	85	90	75	75	80	80	80
Number of services per young bull	200	250	250	250	250	375	375	375	375	500
Annual net return (£1,000)	1,260	1,180	1,028	908	696	1,044	980	856	748	576
100 Bull stud—										
Bulls tested annually	240	240	200	200	160	214	214	160	160	100
Percent of services to proven bulls	85	85	85	85	90	80	80	80	80	85
Number of services per young bull	250	250	300	300	250	375	375	500	500	500
Annual net return (£1,000)	1,568	1,508	1,404	1,306	1,132	1,360	1,308	1,220	1,140	988
50 Bull stud—										
Bulls tested annually	240	240	240	150	100	160	160	120	120	107
Percent of services to proven bulls	85	85	85	85	90	80	80	85	85	80
Number of services per young bull	250	250	250	400	400	500	500	500	500	750
Annual net return (£1,000)	1,904	1,844	1,724	1,636	1,508	1,644	1,604	1,524	1,464	1,364

TABLE 6

ANNUAL NET RETURNS OVER 20 YEARS FROM PROGENY TESTING PROGRAMMES FOR MILK YIELD WHICH MAXIMIZE GENETIC GAINS (*) AND REQUIRE 160 AND 100 BULLS TESTED PER YEAR

(For assumptions involved, see text)

Bulls tested annually	% of services to proven bulls	Services per young bull	Cost per bull tested (£) 750	1,000	1,500	2,000	3,000
200 Bull stud, 20% record recovery			Annual net return (£1,000)				
*1,000	75	100	904	656	156	−344	−1,344
160	90	250	1,056	1,016	936	856	696
100	95	200	756	732	684	632	532
200 Bull stud, 8% record recovery							
*534	75	187	944	808	544	272	—256
160	80	500	936	896	612	736	576
100	90	375	748	720	668	616	508
100 Bull stud, 20% record recovery							
*667	75	150	1,428	1,260	928	592	—72
160	90	250	1,492	1,452	1,372	1,292	1,132
100	95	200	1,252	1,228	1,176	1,128	1,028
100 Bull stud, 8% record recovery							
*400	75	250	1,276	1,176	976	776	376
160	80	500	1,340	1,300	1,200	1,140	735
100	90	375	1,204	1,180	1,124	1,072	964
50 Bull stud, 20% record recovery							
*400	80	200	1,848	1,748	1,548	1,348	948
160	90	250	1,820	1,780	1,700	1,620	1,460
100	95	200	1,656	1,632	1,584	1,532	1,072
50 Bull stud, 8% record recovery							
*267	75	375	1,628	1,560	1,428	1,296	1,028
160	80	500	1,644	1,604	1,524	1,444	1,284
100	90	375	1,556	1,528	1,472	1,420	1,312

genetic gain, and require 160 and 100 bulls tested per year for the same 30 basic situations as in Table 5. It can be seen that the genetically optimum programmes required the testing of very large numbers of bulls per year, and at higher bull costs lost money in some cases.

The complexity of the testing operation increases rapidly with the number of bulls tested, and the problems of accommodation, layoff arrangements and farmer acceptance of so many young bulls, seemed formidable at a level of 267 per year. We therefore looked at the effect of an arbitrary reduction in this figure. At a level of 160 and 100 bulls tested per year, the net ecnomic gains were approximately 10 per cent and 30 per cent short of the maximum possible for the 200 bulls, 8 per cent record recovery, £750 to £1,000 bull cost case. In the detailed programme described earlier, a somewhat arbitrary figure of 150 bulls for testing each year was chosen, on the grounds that it gives near-optimum economic gains and brings the scale of the operation down to a level that is immediately feasible for our AI organizations.

It should be pointed out that exercises of this kind may overestimate or underestimate the real progress which can be achieved. The assumption has been made here that the bulls are selected solely on the milk yield of their progeny. In practice, butterfat, solids-not-fat and protein, will also need to be considered, and in our circumstances growth rate, feed efficiency and beef quality. Attempts to select simultaneously for several of these traits will reduce the rate of progress to a slower pace than that predicted here. On the other hand, no account is taken of supporting selection in the form of initial sire and dam selections and planned matings which could augment the gains from progeny testing to give a rate of progress up to double that predicted, and at little extra cost. Furthermore, the structure of AI will undoubtedly change in a way which favours faster progress: the number of cows served by dual-purpose bulls will be much greater than the 400,000 estimated here, and the number of cows served by each proven bull will increase greatly as the use of frozen semen spreads. In addition, the costs of the beef performance test will be largely covered in the figure of £750 to £1,000 per bull tested, while the economic gains to farmers resulting from the performance test might well equal the returns for selection on dairy traits. On balance, we believe that our predictions give an extremely conservative estimate of the gains to be drived from a planned selection programme.

The programme is good business in another sense. There is no other area in agriculture where technical developments can be more rapidly and effectively brought to work on every farm in the country. With most innovations, each individual farmer must be convinced of its merits and persuaded to adopt it. The natural conservatism of many farmers can and does therefore slow down the introduction of the new technique. In this case, however, the benefits of having more productive cattle are delivered on to the farm every time an insemination is carried out. From the point of view of national growth and productivity, there can be few programmes with this attraction to the same degree.

How would such a scheme be financed? The most obvious, and probably the most satisfactory way would be to finance it out of insemination fees. In this way the benefits would be directly paid for by those who availed of them. At the present level, a shilling per insemination would give £50,000. A charge of 2/6d. per insemination would, therefore, carry an effective programme. A possible alternative would be to replace the present scale of fees (Shorthorn 15/-, Friesian 20/-, beef breeds 25/-) with a uniform fee of 25/-. Since the programme is designed to improve the dual-purpose bulls, the cost would then fall appropriately on the users of these bulls.

The major cost in the programme would be that involved in milk recording. Cows are recorded for several purposes: for bull proving, for cow culling, for feeding to yield. Recording is considered desirable as a management aid and as a stimulus to better husbandry. For these reasons, it is officially encouraged in most countries, including our own, by Government subsidies. If a unified recording scheme were to be operated by the AI authorities in conjunction with a sire-proving programme, then it would seem fair that Government support for milk recording should continue, and in this way help the breeding scheme. The detailed partitioning of costs between the Government and the AI authorities would have to be worked out.

Apart from the recurrent costs, such a programme would need some initial capital, primarily in order to set up the performance test station. This burden might be eased if some land, already in public hands, could be made available on a long lease. Several of the operations involved in the breeding programme might well be better done by specialist bodies who could provide services on contract. Such services might be the centralised testing of milk, the blood typing of parents and progeny and the screening of progeny for deleterious recessive genes.

CONCLUSIONS

Cattle breeding nowadays is a matter of genetic theory and matrix algebra, of massive production recording and electronic computers, of artificial insemination and liquid nitrogen storage of semen. Times have changed, and our techniques must change too. The decisions of a dozen AI station managers and livestock inspectors can now transform the cattle stocks of the country in less than a decade. It is essential that their selection decision have all the backing that science can give them.

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DISCUSSION

Dr. J. C. McCarthy: I should like to thank the Society for inviting me to speak on Dr. Cunningham's paper. Dr. Cunningham began by mentioning the importance of cattle as milk and beef producers to our economy. It is useful to remind ourselves of how milk production and beef production are tied in our system. The consequences of this tie-up in agricultural planning are apparent. Any national breeding programme, particularly a dual-purpose one, has to be evaluated in this background. As Dr. Cunningham has stated there seems to be little genetic connection between dairy and beef characters within existing breeds; thus in very broad terms one may breed independently for milk-yield or beef production or both, as Dr. Cunningham chooses. I shall refer again to these alternatives.

The next part of the paper deals with the development of genetic improvment methods and the principles of selection. Here, the principles of the potential genetic improvement of cattle by selection are dealt with in a theoretical manner. I don't want to obscure the picture too much but since Dr. Cunningham referred to poultry as an example of the power of selection I would like to point out that improved strains of commercial poultry have in their recent history a large number of generations of breeding involving hybridization and genetic reassortment more comparable to plants or laboratory animals than cattle. The length of the generation interval defines the genetic progress per unit of time; progeny testing has the effect of lengthening the generation interval and, of course, slows down genetic progress. For milk, one is forced (for reasons stated in the paper) into progeny testing which is both expensive and slow. The point I am trying to make is that breeding for milk is a slow, expensive task relative to other traits such as growth rate. For the same reasons emphasis in animal breeding schemes, such as P.I.D.A.'s new Pig Accreditation scheme, has shifted from progeny testing to performance tests wherever possible; this allows rapid turn-over of generations, allowing more selection to be done in a shorter time.

In the context of selection, there are a couple of important addenda which are relevant to a selection scheme such as the one proposed. These relate to the effects on selection gains of including a number of different traits in an index for selection. (1) In general, the more traits one takes account of in selection the less will be the progress in any one; this is a consequence of the lessened intensity of selection for single traits (or more correctly the reduction in the selection differentials). (2) Genetic correlations (as we express the genetic connection between different characters) tend to reduce on simultaneous selection for several characters, for example, with a dual-purpose selection programme although no genetic antagonism exists between beef and milk at the beginning, one will build up slowly over time. (3) There exist such things as selection limits. I do not think Dr. Cunningham need worry overmuch about (2) and (3) but nevertheless there is no point in ignoring what is learnt from work in other species such as poultry where selection limits seem to have been reached. I don't want to be interpreted as saying that one cannot breed for milk and beef simultaneously—what I am saying is that it is easier in the short and long run to breed for milk separately or beef separately. It follows from what I said that genetic predictions tend to be more modest and difficult when simultaneous selection is practised.

Dr. Cunningham then dealt with the more familiar topic of AI developments. In this context he mentions "grading-up" to Friesians. It is as well to remember that the most rapid way of changing a population genetically is by such top-crossing. Dr. Cunningham argues sensibly that we can have the best of both worlds. If there is a lesson from the poultry breeders it is: to succeed you need to get, by fair means or foul, the best of your competitor's stock and start your breeding from there.

I don't intend to comment on Dr. Cunningham's personal research. I am aware of what it involves, but to my mind the more technical aspects of progeny testing are a side-issue in the context of a national breeding programme. Admittedly one could not embark on the proposed schemes without considerable technical know-how, but Dr. Cunningham's programme must be judged according to the criteria implicit in the following questions:

(1) Is a dual-purpose selection programme genetically possible?

(2) Is it economically desirable?

The questions are not independent, of course, but if I can clear the air with regard to the first, then those of you who are more enlightened than I on agricultural economics may tackle the more controversial second question. I have no doubt that the scheme proposed in the paper would work. However, I have mentioned certain genetical difficulties which arise in simultaneous selection (which is what the scheme entails). Other geneticists will concur with this view. This implies a modicum of conservatism with respect to projected genetic progress. The paper is unsatisfactory in that only one trait, milk-yield, has been used to work out economic returns. I do, however, appreciate the difficulty of such computations particularly in the light of the long-term nature of the programme—and it is a long-term! I should like to ask in this regard: what are the predicted and actual economic returns from milk-breeding schemes of similar magnitude in other countries? I think that some reference should have been made to these for comparison at least.

Putting forward a scheme of this nature is, to make a crude analogy, like selling an insurance policy; let us look briefly at financial aspects in an attempt to examine the critical question: is it economically desirable? Supposing the scheme got the "go-ahead" in the morning, it would be about 10 years before the first batch of heifers from proven bulls would be milking in commercial herds. Now capital input over the period would, taking the figures of £1,000 for bull tested, 150 bulls per year over seven to eight years of the nine to 10 period would be over £1,200,000. This is a conservative estimate taking no account of capital costs of ancillary equipment. The scheme would be made to finance itself by raising the insemination fees appropriately after nine to 10 years. Getting down to practical terms we ask:

(1) What sort of cattle do we want 20 years from now? If we want higher yielding cows which are larger in size, then this is the programme to do it.
Do we want larger cows in our milking herds?
(2) Are we willing to invest a million or more to this end?

The unfortunate feature of this dual-purpose scheme is that the beef selection is tied to the slow cycle of milk selection. It cannot be otherwise if we want better dual-purpose cattle. I do not want to get into details of alternative schemes. In general, I feel that concentration on beef breeding is more attractive nationally (1) because of the relative ease of breeding in comparison to milk (2) because I am not at all sure that markets will open up for the extra milk or milk-products won in a dual-purpose programme and (3) changing demands for milk could be easier accommodated by management alterations than changing demands for beef characters. I admit being out of my depth here. I discussed this proposed dual-prupose scheme with several people in the hope of getting some clues on the milk-versus-beef angle. I have been informed that farmers want higher milk yielding stock but that at national level this could be disastrous. I am sorry that I wind up sitting on the fence with regard to the desirability of dual-purpose breeding; this is to some extent a failure of the paper to provide me with a more enlightening breakdown of projected gains in genetical and financial terms, but also because I am not a competent crystal-gazer.

I think this proposal of a dual-purposes cheme by Dr. Cunningham must be given serious attention both by you and by our policy-makers.

Dr. M. D. McCarthy: In supporting the vote of thanks to Dr. Cunningham, welcomed the paper both because he believed it was the first paper on a genetic subject presented to the Society and because it was an important exercise in Operations Research. He proposed to speak about the second aspect and to say that, in this regard, he was not fully convinced by the arguments in the paper. He did believe that some method of quantitative objective assessment was essential in the selection of bulls for the AI centres but the paper set out to determine the strategy and tactics of such an operation and, in his view, the arguments were not quite convincing. He would make the following criticisms:

(*a*) Since the evaluation of a scheme was made to depend on economic factors it was essential that it should be perfectly clear how the economic gains were derived. He did not find it possible to understand exactly how the "Annual Net Return" given in the tables was calculated and he felt that this should be made perfectly clear to begin with.

(*b*) In making this assessment the author had apparently evaluated his figures for each of 20 years and had averaged them over that period. In doing this he had, of course, taken advantage of the "compound interest" nature of the genetic gains but he had not allowed for the fact that these returns were future ones. It would appear more appropriate that in making this evaluation the method of "discounted cash flows" should be used.

(*c*) The evaluation of returns in the paper were confined solely to the increases to be expected in milk yields and thus did not take into account at all the effect on the importance of store cattle and dead meat trades. Thus, to base a decision on the milk element only could at best provide a "sub-optimal" solution of the problem and it would appear essential that if a final decision were to be based on such an approach a different objective function should be defined which took both the milk and meat aspects of the problem into consideration.

Dr. Cunningham: Dr. John McCarthy has clearly stated a number of caveats which must attend any selection programme—in particular the problems of multiple-trait selection, of genetic antagonisms between traits, and of possible selection limits. I am encouraged by the fact that on balance he concludes that a meat and milk selection scheme such as that outlined is workable. We must be aware of these possible problems, and of that raised by Mr. Mescall about the efficiency of cattle selected for high production, but to my mind we must not let the existence of potential difficulties mesmerise us into inaction.

Dr. McCarthy's conclusions regarding the economic costs and returns in the first ten years of a selection programme are unnecessarily gloomy. In the first place, the costs would not be uniform over these years, but would build up gradually to the levels stated. The principal cost item—the progeny test for dairy traits, would not be involved until 5-6 years after the programme began. In fact, when the first batch of daughters of bulls fully tested under the scheme came into milk, only three annual batches of young bulls would have incurred the full testing cost. In addition, the early investment can bring quick returns from the beef performance test end of the programme. Furthermore, in the early stages of such a programme, the young bulls bred by planned matings should be better than the existing stud for dairy traits and so should be improving the population from within two years of the start. These factors are difficult to quantify, but nevertheless offer substantial returns from an early stage.

The desirability or otherwise of dual-purpose cattle is a perennial chestnut. There can be no doubt that increased productivity for meat and milk is good business for the individual farmer—and it is he, after all, who is asked to pay for an improvement scheme. It is also true that many studies have shown that higher producing cattle are biologically more efficient than lower producers. Bord Bainne are optimistic about the market prospects for dairy produce. All of our future competitors for the British and European markets are trying to increase output per cow, and we must follow suit if we are to survive in these markets. Control of output in future is more likely to be effected through cow numbers than through cow yields. In short, I believe we must try to breed for higher productivity in our cattle for both beef and dairy traits.

The "annual net return" figures given in Tables 5 and 6 are, as Dr.

M. D. McCarthy has surmised, merely the average annual marginal (i.e. after deducting feed cost) value of the extra milk produced by the population over a 20-year period after the introduction of a bull testing scheme. He makes the valid point that we could have used a more sophisticated accounting system to allow for the deferment of the gains. However, as I have indicated in reply to Dr. John McCarthy, the initial capital outlay is not great, the buildup in annual expenditure is gradual, and the delivery of returns from performance testing and young bull breeding begins almost immediately.

The reasons why our operations research studies are solely in terms of milk yield are chiefly two: (1) evaluating bulls for milk yield is likely to be the most expensive aspect of an integrated dual-purpose selection scheme, and (2) this reduces the problem to mathematically tractable proportions. We would dearly like to do a textbook OR study of all the factors involved, but this does not appear to be feasible. One disadvantage of the present exercise is that it seriously underplays the potential gains from the improvement in beef traits, whereas the cost of this improvement is included in the overall cost of bull acquisition and testing.