

**Breeding methods for cattle, pigs, and poultry in the United States :
including inter-state co-operation project no. 253.**

Contributors

European Productivity Agency.

Publication/Creation

Paris : The European Productivity Agency of the Organisation for European Economic Co-operation, [1957]

Persistent URL

<https://wellcomecollection.org/works/dxyjqwh2>

License and attribution

You have permission to make copies of this work under a Creative Commons, Attribution, Non-commercial, No-derivatives license.

Non-commercial use includes private study, academic research, teaching, and other activities that are not primarily intended for, or directed towards, commercial advantage or private monetary compensation. See the Legal Code for further information.

Image source should be attributed as specified in the full catalogue record. If no source is given the image should be attributed to Wellcome Collection.

Altering, adapting, modifying or translating the work is prohibited.



Wellcome Collection
183 Euston Road
London NW1 2BE UK
T +44 (0)20 7611 8722
E library@wellcomecollection.org
<https://wellcomecollection.org>

~~PAMPHLET~~

~~BJU~~

~~ORG~~

BREEDING METHODS



for **cattle**

pigs

and **poultry**

IN THE UNITED STATES

OEEC

PUBLISHED BY

THE EUROPEAN PRODUCTIVITY AGENCY OF

THE ORGANISATION FOR EUROPEAN ECONOMIC CO-OPERATION

PARIS

X
BJU

ORG

PRICE 14/- \$ 2.00 700 Fr. fr.

X

MINISTRY OF
AGRICULTURE, FISHERIES AND FOOD

CENTRAL VETERINARY LABORATORY
NEW HAW, WEYBRIDGE, SURREY

LIBRARY

Class No.

BJU/ORG

Accession No.

L67/138

62G.43



22500590893

RETURN TO
VETERINARY LABORATORY
NEW HAW, WEYBRIDGE, SURREY

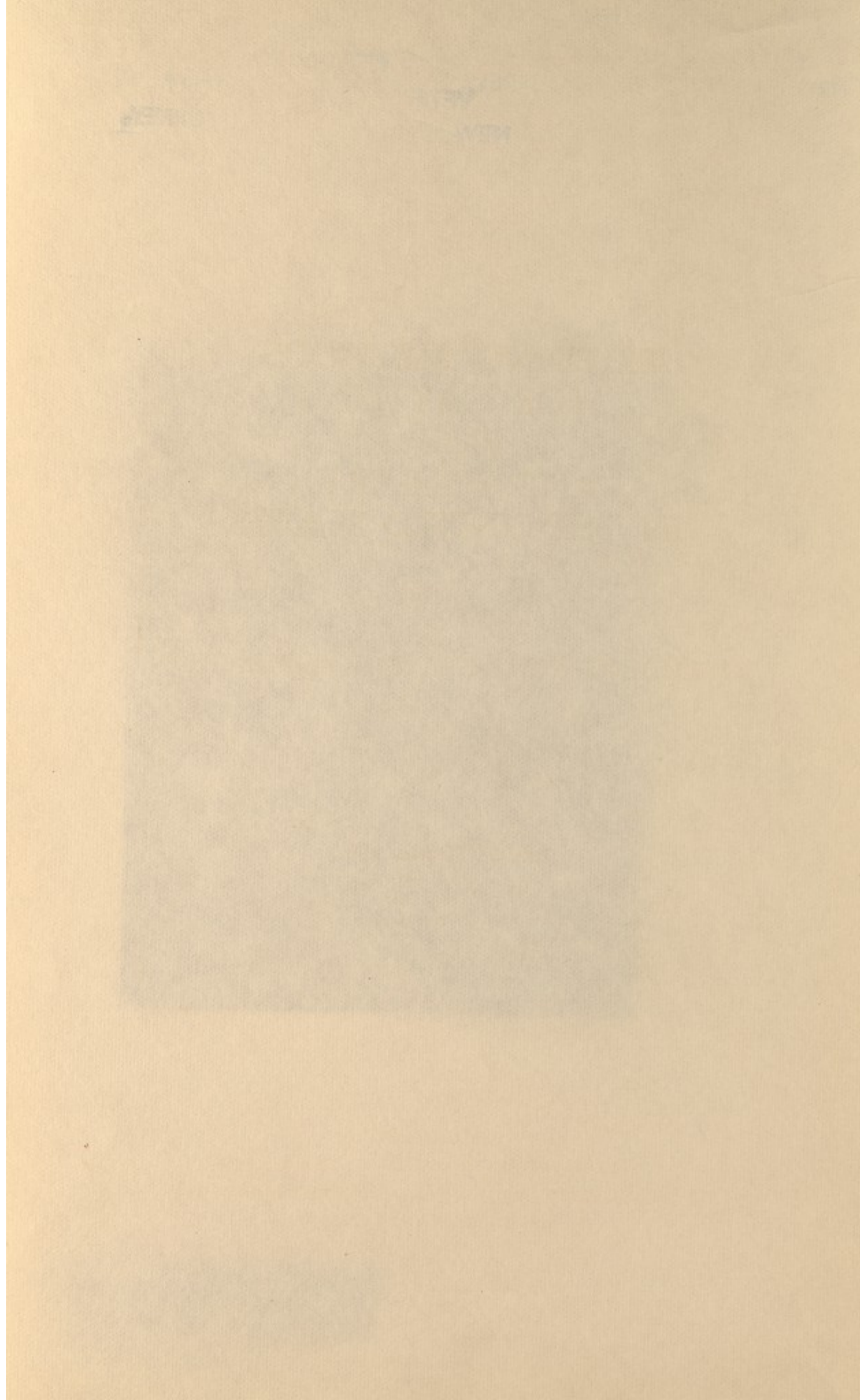
RETURN TO
VETERINARY LABORATORY
NEW HAW, WEYBRIDGE, SURREY

BREEDING METHODS
FOR CATTLE
PIGS
AND POULTRY
IN THE UNITED STATES

INCLUDING INTER-STATE CO-OPERATION

PROJECT No. 253

PUBLISHED BY
THE EUROPEAN PRODUCTIVITY AGENCY OF
THE ORGANIZATION FOR EUROPEAN ECONOMIC CO-OPERATION
2, rue d'Alsace-Lorraine, PARIS-17



**BREEDING METHODS
FOR CATTLE
PIGS
AND POULTRY
IN THE UNITED STATES**

INCLUDING INTER-STATE CO-OPERATION

PROJECT No. 253

**PUBLISHED BY
THE EUROPEAN PRODUCTIVITY AGENCY OF
THE ORGANISATION FOR EUROPEAN ECONOMIC CO-OPERATION
2, RUE ANDRÉ-PASCAL, PARIS-XVI^e**

Ministry of Agriculture,
Fisheries and Food,
Veterinary Laboratory
Library

Class No. B54
Auth. Mk. ORG
Access No. L67/138
Demand No.

The Organisation for European Economic Co-operation comprises the following Member countries : Austria, Belgium, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Sweden, Switzerland, Turkey and the United Kingdom. The Organisation came into being with the signing of the Convention for European Economic Co-operation on 16th April 1948, when Member Governments pledged themselves "to combine their economic strength, to join together to make the fullest collective use of their individual capacities and potentialities, to increase their production, develop and modernise their industrial and agricultural equipment, expand their commerce, reduce progressively barriers to trade among themselves, promote full employment and restore or maintain the stability of their economies and general confidence in their national currencies". Representatives of each of the Member countries meet daily at OEEC's headquarters, the Château de la Muette, Paris, to discuss their economic problems and work out common solutions. The United States and Canada, although not members of the Organisation, participate in its work and Yugoslavia is represented by an observer. Spain participates as a full member in the work of the agricultural bodies of the Organisation, which are directed by the Ministerial Committee for Agriculture and Food set up by the Council on 14th January 1955.

The European Productivity Agency, which is responsible for the publication of the present report, was set up as a new branch of the OEEC in May, 1953. Its task is to stimulate productivity, and thereby raise European standards of living, by influencing not only Governments but also industrial, agricultural and research organisations, private and collective enterprises and public services. One of its primary aims is to convince management and workers alike of the benefits of productivity and to enlist their co-operation.

4359 454

WELLCOME INSTITUTE LIBRARY	
Coll.	WelMcmec
Coll.	
No.	V

Published in May 1957

FOREWORD

1. In January 1954, proposals were put forward by the European Association for Animal Production (E.A.A.P.) and by the Danish delegation to the O.E.E.C. to organise a mission to the United States to study modern breeding methods for cattle, pigs and poultry, and also to study American methods of ensuring adequate and efficient inter-State co-operation in the animal production field. These proposals were subsequently merged into one and approved by the Director of the European Productivity Agency and by the Foreign Operations Administration (F.O.A.) for implementation. A Mission was therefore formed comprising twenty-one leading experts on animal production from eight European countries, as follows: Austria (1), Belgium (2), Denmark (4), France (2), Netherlands (4), Norway (3), Sweden (3), United Kingdom (2). Mr. Jacques Delage, Associate Professor for Animal Husbandry at the Institut National Agronomique, in Paris, was Mission Secretary.

2. The Mission left for the United States on 19th April 1955 for a six weeks' visit, during which it studied at the main Federal and State institutions for cattle, pigs and poultry production. The names of the members of the Mission are given in Annex I attached, and an outline of the itinerary will be found in Annex II.

3. On its return to Europe, the Mission met at O.E.E.C. Headquarters to prepare its report, which was finalised at a further meeting held on 8th and 9th November 1955. The text as finally adopted by the Mission is attached hereto.

4. During its tour, the Mission had an excellent opportunity of studying and discussing with the best United States experts the modern trends in animal breeding, the organisation of practical breeding work and inter-State co-operation in this field.

5. Throughout this report, liberal use has been made of publications handed out to the Mission during its tour.

6. The European Productivity Agency, in publishing this report, would like to place on record its indebtedness to the United States authorities for the excellent facilities provided to the Mission and also to the many research workers, officials and

TABLE OF CONTENTS

Chapter	I. Introduction	9
	II. Breeding methods in general	15
	III. Genetics and reproduction	23
	IV. Report of the Poultry Section	31
	V. Report of the Pig Section	67
	VI. Report of the Cattle Section	107
	VII. Inter-State co-operation	211
	VIII. Summary	215
Annex	I. Members of the Mission	221
	II. Itinerary of the Mission	225

TABLE OF CONTENTS

Chapter I. Introduction	8
II. Breeding methods in general	15
III. Genetics and reproduction	23
IV. Report of the Poultry Section	31
V. Report of the Pig Section	87
VI. Report of the Cattle Section	107
VII. Inter-State co-operation	211
VIII. Summary	215
Annex I. Members of the Mission	321
II. Itinerary of the Mission	325

I

INTRODUCTION

PURPOSE OF THE MISSION

1. In its efforts to co-ordinate the agricultural productivity programmes of the various countries and to promote the exchange of technical agricultural information, the European Productivity Agency of the Organisation for European Economic Co-operation encouraged the organisation of a mission to study the modern breeding methods for cattle, pigs and poultry applied in the United States and the methods of inter-State co-operation used there.
2. The success achieved in the production of hybrid maize by using inbreeding and crossbreeding has led American breeders to try using similar techniques for improving animal breeds. More generally, the methods used, which entail frequent resort to crossing, are a priori contrary to those used in Europe, which are based more particularly on pure line breeding. It was therefore felt that a mission should be appointed to study how far American methods could be applied in Europe.
3. Furthermore, in the sphere of animal production, there are in the United States programmes providing for co-ordination both between the States and the Federal Government and between the States themselves. This presupposes some co-operation between the various organisations at State and Federal level.
4. In view of the need to promote such co-operation in Europe, it was felt that the Mission should be instructed to ascertain how such co-operation had been achieved in this field.
5. To facilitate discussions and possibly lighten the programme, the members of the Mission were divided into 3 sections specialising in the study of poultry, pigs and cattle respectively. With a few exceptions, the 3 sections usually followed the same itinerary, but they did occasionally do different work in one and the same university. This report does

not propose to review in detail the numerous observations made in the various sectors or the great amount of information compiled ; it seeks rather to identify the guiding principles which gradually emerged during this trip. Accordingly, it contains general chapters on the principles of breeding, genetics and reproduction and inter-State co-operation in the United States, and special chapters on poultry, pigs and cattle, prepared by the members of the respective sections.

6. As will be seen from the various parts of this report, this study tour was particularly successful and it is to be hoped that it will facilitate the subsequent introduction of co-ordination plans between various European countries designed to solve similar problems.

7. The Mission would like to place on record its indebtedness to the European Productivity Agency and to the United States authorities for the opportunity offered it to visit the United States to study this important question. The information and assistance given to the Mission throughout its tour by research workers, administrative officers and others who contributed so much to the success of the visit, were of the highest order. The Mission also wishes to express its appreciation and thanks to those who provided it with hospitality and made the members feel so much at home during their brief stay in the American continent.

8. Further, such missions have the merit not only of revealing new methods and techniques, but also of establishing human contacts which should serve to encourage further exchanges of experience.

9. The problems to be solved and the solutions recommended may differ depending on the special conditions in the various countries, but common methods of study are evolved and new fields of investigation opened up in the course of such exchanges. Research is being conducted in the United States in the field studied by the Mission on a scale that generally exceeds European possibilities, but results have been obtained which should serve as a guide for the work that is being done in Europe and which already show clearly the need for widening and intensifying research programmes in most European countries in order to solve the particular or general problems there met with.

10. The members of the Mission greatly appreciated the opportunity of making this tour, and feel they have used it to maximum advantage. They therefore suggest that similar missions of American experts should be invited to visit Europe to secure an even better understanding by both sides of the problems involved and their solutions.

11. The members of the Mission are convinced that, if this suggestion were favourably received and there were still more

opportunities of exchanging American and European specialists, the solution of common problems would be facilitated to the benefit of all concerned.

ITINERARY

12. After spending some time at the Beltsville Experimental Centre and at the offices of the United States Department of Agriculture in Washington, the Mission concentrated on visiting the universities and experimental stations in the Corn Belt.

13. Visits to private firms and enterprises served further to illustrate the practical application of the methods recommended and developed in the universities and stations. Excluding day trips by coach and car, the distance travelled by the Mission within the United States covered some 5,000 miles.

14. The visit to the Beltsville (Maryland) station gave the Mission an insight into the general problems connected with the organisation of research in the cattle, poultry and pigs sectors and enabled it in the light of the results obtained at this station to consider the effects of breeding methods, with or without inbreeding and crossbreeding, on these various animal species.

15. In the particular case of cattle, a number of basic principles for improving breeds of dairy cattle were discussed, and conflicting ideas on dual purpose cattle immediately emerged. The members of the Mission showed particular interest in the influence of environment and the creation of breeds adapted to various climatic conditions.

16. A study of the methods used for assessing the quality of pig and cattle carcasses enabled a comparison to be drawn between the methods used in Europe and the United States. Some aspects of nutrition and diet were also discussed.

17. In Washington, the organisation of milk testing as operated by the Dairy Herd Improvement Association under the Sire Proving Programme, gave the members of the Mission an insight into this important method of improving dairy cattle, while another aspect of the co-ordination programmes was seen in the description given of the working of the "Advisory Committees". The visit to Ames (Iowa) was intended to provide fuller information on the application of methods of inbreeding, crossbreeding and crossing of inbred strains, particularly in pig and poultry breeding, not only theoretically and experimentally, but also as actually practised in private undertakings functioning as regular stud farms.

18. Visits to establishments producing hybrid chicks and to one producing incross boars for use in breeding plans based

on rotation crossings provided an excellent illustration of the development of the new breeding methods.

19. At Ames, attention was also drawn to improvement in breeding dairy cattle and the problems involved in raising beef cattle.

20. Lastly, the Regional Swine Laboratory provided an excellent example of a vast research co-ordination plan for pig breeding carried out in the States of the Corn Belt.

21. At St. Paul (Minnesota), the members of the Mission had an opportunity of actually observing the creation of new American breeds of pigs and studying the principles governing pig breeding schemes in Minnesota. Cases of the development of inbred lines and their subsequent crossing were exemplified, not only in talks, but in visits paid to public and private experimental stations. This does not mean that the breeding of dairy cattle and beef cattle was overlooked.

22. At Madison (Wisconsin), the Mission then studied the physiology of reproduction, the blood groups of domestic animals and the research work done on the breeding of poultry, beef cattle, dairy cattle and fur animals. This was supplemented by visits to Brown Swiss and Holstein Friesian breeding stations, to experimental stations, to the local Milk Testing Laboratory and to artificial insemination centres. In particular, the Mission had an opportunity of seeing the inauguration of a vast experiment on the effects of inbreeding followed by crossing in cattle.

23. At Purdue University (Indiana), special attention was devoted to some basic problems of animal genetics, physiology and hygiene before the poultry specialists, on the one hand, and the pig and cattle experts, on the other, separated to study the methods of genetic improvement and the breeding problems of these species. The poultry specialists also made a special study of the regional poultry laboratory.

24. Visits to private undertakings gave the Mission another chance to see the production of incross boars for use in a Rotation Breeding Plan and an attempt to create a type of dairy cattle adapted to hot climates.

25. The visit to Columbus (Ohio) was the last stop before the return to Washington. Here the separate groups studied the work being done on the genetics and breeding of poultry, pigs and cattle. The members of the Cattle Section also took the opportunity to visit the headquarters of the Jersey Herd Book (Jersey Cattle Club). This programme was supplemented by visits to stations.

26. On returning to Washington, the Mission obtained further information from officials of the Department of Agriculture and the Beltsville Experimental Station and also began classifying

its material. For this purpose, the members of the Mission and the organisers met in friendly fashion and had a useful exchange of views during which the Mission's preliminary report was presented.

27. A short trip was made to Virginia to visit a beef cattle research station which has developed a breeding programme for animals of this type.

28. Cornell University (New York) was the last institution visited by the Mission and here data were obtained on the physiology of reproduction, the development of a regional research programme on the causes of sterility in cattle, the working programme of the New York Artificial Breeders' Co-operative, and research on artificial insemination in relation to genetic research, while the poultry experts studied their own problems separately.

29. It will be seen from this itinerary that in the planning and execution of the programme the organisers did their utmost to comply with the dual purpose of the Mission - the study of new breeding methods and inter-State co-operation.

30. It would, of course, have been useful if more time could have been devoted to visiting farms which use for economic purposes the animals produced under the new improved breeding schemes. But it would have been impossible to fit such an extensive programme into so short a tour. The main essential was to study principles and methods and to be able to see some of the results these new methods will produce in breeding practice. During the tour, the Mission had occasion to appreciate fully the effects of inter-State co-operation programmes.

II

BREEDING METHODS IN GENERAL*

31. During recent years, evidence has been presented indicating that in crossbreeding populations including farm animals there is always a large actual and potential genetic variability. The relative efficiency of different breeding methods therefore depends in their ability both to release and exploit this variability.

32. Predicting the effectiveness of different systems of breeding is, however, hazardous even on the basis of results from the best designed experiments. The success of any system can be influenced to a large degree by such variables as foundation stock, management practices, diseases, etc. Until more experimental data are available, the predicting has therefore to be based both on our present knowledge of quantitative inheritance and on our experience of different breeding systems.

CONCEPTS OF QUANTITATIVE INHERITANCE

33. Individual differences observed in a population are due to hereditary or genotypic differences and to differences in the environment to which the individuals are exposed. The relative magnitudes of the hereditary and the environmental influences vary of course with different characteristics.

34. The hereditary variance can be subdivided into (a) the additive genetic variance, (b) the epistatic variance and (c) variance due to dominance and over-dominance.

Additive genetic variance

35. This fraction includes only that portion of the differences between individuals which is due to the additive effects of the

* The authors of this chapter acknowledge their indebtedness to the excellent article by Beel, Moore, Bofren and Warren entitled "Systems of Breeding Designed to Utilise Heterosis in the Domestic Fowl", published in 1952 in "Poultry Science", Vol. XXXI, p. 11, and the text of which has been freely used.

genes forming their respective genotypes. Each gene in a particular population has an average additive effect, either plus or minus, in genotypic combination with the other genes. Thus each individual genotype would have an expected value derived by simply adding all the average effects of its constituent genes. Variation among these expected values constitutes the additive genetic variance.

36. It may be mentioned that the ratio of estimated additive genetic variance in a population to the actually observed variance in the same population is heritability (H^2) in the narrow sense.

37. Most of the breeding plans to date have been designed on the basis of the heritability in the narrow sense of the characters involved. If heritability of the character is relatively high, individual selection would be emphasised with slight, if any, consideration to family merit. On the other hand, low heritability would bring a greater emphasis on family merit and progeny test. There appears to be little doubt that the conventional breeding methods on the basis of individual and family merit would be superior to other breeding methods in changing the frequencies of genes responsible for additive genetic variation. However, if the additive genetic variance is small, ways and means of exploiting other types of hereditary variation become increasingly important.

Epistatic genetic variance

38. This fraction is due to non-additive effects between non-allelic genes in genotypic combinations. Such effects occur when two or more non-allelic genes interact to produce a specific effect which is not the cumulative or additive action of the interacting genes.

39. Evidence has been presented indicating that a multitude of interactions must be involved in the inheritance of quantitative characters. The relative magnitude of the epistatic variation or gene effects as contrasted to the additive genetic and dominance effects is largely a matter of conjecture. It probably varies in importance from one characteristic to another.

40. The consequences of epistatic genetic variance are mainly that if such interactions are widespread and involve several loci, then neither individual or mass selection nor family selection will be very effective in improving the population. Instead, the formation of inbred lines, endeavouring to segregate out desirable homozygous epistatic combinations, would be desirable. The superior inbred lines can be recombined for further selection or they can be maintained as inbred lines for hybridization. Likewise, reciprocal and recurrent selection provide an opportunity for increasing the frequency of those genes which would combine for superior epistatic combinations in the cross

progeny. Thus either of these methods should be more effective in exploiting epistasis than the conventional or pure breeding methods.

Dominance genetic variance

41. This fraction is due to allelic genes not having additive action in genotypic combinations. Over-dominance or allelic interactions which render the heterozygote (Aa) superior or inferior to either homozygote (AA and aa) also would contribute to these deviations. Dominance effects partially account for genes having actual effects in specific genotypes which differ from their average effect in the population.

42. Dominance effects are distinguished from those due to epistasis in that the former refer to interaction within allelic series or between alleles at a specific locus, while the latter signifies interaction between allelic series or genes.

43. It may be mentioned that the ratio of the variance caused by additive, epistatic, dominance and over-dominance effects in a population to the actually observed variance in the same population is heritability (H^2) in the broad sense.

44. Evidence has been presented indicating the presence of dominance between contrasting alleles influencing different characters in domestic animals. In some cases, genes show partial or incomplete dominance and in other cases complete dominance. Indirect evidence has also been presented indicating that over-dominance may influence quantitative characters in domestic animals. However, its influence cannot be directly distinguished from epistasis with present statistical techniques.

45. While family selection and progeny testing are valuable aids in improving characters influenced by genes showing partial or complete dominance, they would be inadequate if over-dominance were present. This latter situation would mainly be due to the selection of the superior (Aa) individuals for breeding purposes. Since these heterozygous parents would segregate and produce some homozygous progeny the population average would never approach the maximum.

46. The consequences of variance due to over-dominance are rather similar to those caused by epistasis. Thus, if over-dominance is present neither individual nor family selection will be effective in improving the population. Inbreeding in combination with hybridization, however, would exploit the effects of over-dominance, provided enough inbred lines are formed and tested in sufficient hybrid combinations. Likewise, recurrent and reciprocal selection would provide an opportunity for increasing the frequency of those genes which would combine for superior over-dominance effects.

47. By deductive reasoning out from the statistical genetic concepts, it is possible, to some degree at least, to predict the effectiveness of different breeding methods for improvement of characters being influenced by genes with more or less pure additive, epistatic, dominance or over-dominance effects.

48. In practice, however, an animal breeder is faced with the task of improving a number of different characteristics, many of which are being influenced to some extent by both additive, epistatic, dominance and over-dominance effects as well as by environmental fluctuations. Genetic and environmental correlations between individual characters further complicate the task. Under these circumstances, the most efficient system of breeding for one character may be much less efficient for another character, and therefore the predicting of the efficiency of different breeding methods based on statistical genetic concepts becomes rather hazardous in practice.

BREEDING SYSTEMS

49. As indicated by the concepts of quantitative inheritance, the breeding systems may logically be divided into inbreeding, conventional breeding and outbreeding methods.

Inbreeding

50. One of the best established facts in animal breeding seems to be that inbreeding with or without selection generally results in an increasing frequency of defective individuals and a declining fertility, vitality, growth rate, etc.

51. The most widely accepted hypothesis to explain this inbreeding deterioration is the presence in crossbreeding populations of recessive deleterious genes which sometimes are linked in repulsion to dominant factors and further the presence of over-dominance.

52. Because of the serious inbreeding deterioration at higher levels of homozygosity, inbreeding per se has little use in animal breeding, except when used to detect deleterious genes in the breeding stock or to form inbred lines for hybridization.

Conventional breeding

53. Evidence has been presented that several important economic characters of livestock have been improved steadily by means of conventional breeding methods. This evidence indicates that unimproved foundation stock can be rapidly im-

proved by consistently selecting the superior individuals from each generation as the parents of the next generation.

54. A wider use of individual and family selection including progeny testing would undoubtedly significantly further raise the level of performance of our domestic animals. Until superior breeding methods have been found, it is thus important to devise ways and means of improving the conventional breeding system by such techniques as milk recording, litter, progeny and random testing, selection indices, etc.

55. However, there is more uncertainty concerning the rate of improvement to be expected from the use of conventional breeding methods within stocks that have reached a high level of performance through previous generations of similar breeding. At present, it seems as if the effectiveness of continued selection declines steadily, finally reaching a state of equilibrium, even though total genetic variability remains high. Still more serious, however, is the indication that long-continued selection seems to result in an increasing frequency of defective individuals and a declining fertility and vitality, provided those declines are not counteracted by selection.

56. As quantitative characters are being influenced by many genes more or less evenly distributed over the chromosomes and because of linkage of genes influencing different characters, selection itself may be responsible for this deterioration.

57. Even though the conventional breeding system has some rather serious limitations, it should of course not be considered obsolete until any new breeding system has been critically examined and proven superior beyond reasonable doubt.

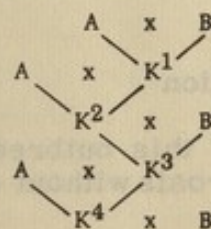
Outbreeding

58. The various systems of outbreeding may be grouped into (1) breed crosses, (2) crosses of inbred lines and (3) recurrent reciprocal selection.

Breed crosses

59. Crosses of breeds, including criss-crosses* and rotational crossings, are widely used, especially in poultry and swine-

* Alternating crossings of animals of different breed A and B according to the following diagram :



breeding, in order to raise the level of performance. In most cases, breed crosses have yielded significant improvement of the performance indicating the presence of heterosis. However, crosses of breeds without recurrent selection do not lead to any genetic improvement of the breeds and the crossbred progeny.

Crosses of inbred lines

60. The success of the corn or maize breeder in forming inbred lines and combining them into superior hybrids has obviously served as a challenge to the animal breeders, especially in the United States. However, the formation and maintenance of inbred lines and adequately testing them in hybrid combinations is much more difficult in animals than in plants.

61. Evidence has been presented that for characters with low heritability selection is rather ineffective in alleviating the inbreeding depression. In other words, the average depression per unit of inbreeding seems to occur regardless of the amount of selection applied. Furthermore, only a negligible correlation seems to exist between the performance of the inbred lines themselves and their general and specific combining ability. The conclusion may therefore be drawn that the most efficient process of establishing inbred lines is to inbreed rapidly with no within-line selection, but heavy selection among lines on the basis of combinability tests. Selection for general and specific combining ability already during the inbreeding may further increase the efficiency of the formation process.

62. It may be mentioned that even though inbreeding in itself is expensive and laborious, the bottleneck in this outbreeding system is the adequate testing of the inbred lines in hybrid combinations.

63. Much research in livestock breeding in recent years has been directed toward the development of inbred lines and in the testing of such lines for their usefulness in increasing levels of productivity by line crossing and top crossing. The results obtained are, however, far from conclusive. Critical breeding experiments with different laboratory animals are therefore needed to properly compare and evaluate the relative efficiency of this outbreeding system. Results obtained with such pilot organisms might not be transferred directly to larger animals, but they could serve as useful guide posts in designing experiments.

Recurrent reciprocal selection

64. The unique feature of this outbreeding system is that it should yield maximum heterosis without expensive and laborious inbreeding.

65. Basically, recurrent reciprocal selection is a system of progeny testing. Males from one foundation stock are crossed with females from another unrelated foundation stock. Based on the performance of the progenies, males and females are rated on their combining ability, with the opposite foundation stock. Parents of the best progenies would be selected to reproduce the corresponding foundation stock. Because selection is based on combining ability, the average merit of the cross should steadily increase.

66. Recurrent and reciprocal selection can of course be applied in many different ways. Recurrent selection could thus be applied in connection with criss-cross and rotational cross-breeding.

67. Even though reciprocal recurrent selection has created the greatest interest among animal breeders because it offers all the benefits of hybridization without the sacrifice of in-breeding, its superiority has to be proven in critical breeding experiments with different laboratory animals.

CONCLUSION

68. The tremendous genetic diversity existing within each strain of domestic animals is still the greatest challenge to animal breeding.

69. Even though considerable progress has been made during recent years, no breeding system has yet been devised by means of which the genetic variability can be fully released and exploited.

70. However, new ideas and concepts are originating much faster than ever before, and critical breeding experiments are expanding at an increasing rate. Therefore, more rapid progress in the field of animal breeding can be expected in the near future.

71. Before going into a discussion of the genetic factors which determine the fertility, etc., in the larger animals, a short survey of the hormonal interaction will be given. In a discussion like this, only a simplified scheme will be outlined, the more delicate reactions falling beyond the scope of this review.

72. In general, it can be said that fertility, measured as the number of living offspring at birth, is determined by female fecundity, fertilization rate and embryonic mortality. There is usually no need for distinguishing the potential and actual fecundity as the farmer is only interested in the total number

...the selection of the best progenies would be selected to reproduce the corresponding foundation stock. Because selection is based on combining ability, the average merit of the cross should steadily increase.

...the selection of the best progenies would be selected to reproduce the corresponding foundation stock. Because selection is based on combining ability, the average merit of the cross should steadily increase.

CONCLUSIONS

...the selection of the best progenies would be selected to reproduce the corresponding foundation stock. Because selection is based on combining ability, the average merit of the cross should steadily increase.

...the selection of the best progenies would be selected to reproduce the corresponding foundation stock. Because selection is based on combining ability, the average merit of the cross should steadily increase.

...the selection of the best progenies would be selected to reproduce the corresponding foundation stock. Because selection is based on combining ability, the average merit of the cross should steadily increase.

...the selection of the best progenies would be selected to reproduce the corresponding foundation stock. Because selection is based on combining ability, the average merit of the cross should steadily increase.

...the selection of the best progenies would be selected to reproduce the corresponding foundation stock. Because selection is based on combining ability, the average merit of the cross should steadily increase.

III

GENETICS AND REPRODUCTION

71. In animal breeding, fertility is regarded as a fundamental prerequisite for economic efficiency. Although milk production is the main economic consideration in dairy cattle, normal reproduction is essential to maintain an efficient output of the dairy unit. In swine breeding, the fertility influences the economic gain through the number of pigs per sow which can be fed to a certain slaughter weight. However, regarding the fertility of the sow, it has been demonstrated that an optimum unit exists for the number of pigs born in a litter. For large litters, the mortality among newborn pigs increases (as well as the number still-born) and, in some cases, the net result will be worse than for litters about the average for the breed in question. In fur animals, the same problems exist as in swine breeding, that is : it is the total number of living offspring at a certain age which determines the economic return. In the case of fur animals, the problems or conditions are further complicated by the fact that these species - with few exceptions - have only one short breeding season per annum. However, in the following paragraphs, discussion will be restricted to the genetics and reproduction of large animals and only few references will be made regarding special conditions in fur animals. The reproductive processes governing the laying rate in fowl will be left out as all poultry breeding is concerned with these processes. Information on this subject will be found in the special section concerning poultry breeding.

72. Before going into a discussion of the genetic factors which determine the fertility, etc., in the larger animals, a short survey of the hormonal interaction will be given. In a discussion like this, only a simplified schedule will be outlined, the more delicate reactions falling beyond the scope of this review.

73. In general, it can be said that fertility, measured as the number of living offspring at birth, is determined by female fecundity, fertilisation rate and embryonic mortality. There is usually no need for distinguishing the potential and actual fecundity as the farmer is only interested in the total number

of offspring. To be able to increase fertility it is, however, necessary to study, from a physiological as well as a genetic point of view, to what extent a low fertility is due to one of each of the three mentioned factors.

74. The number of eggs released during the oestrus (in the cow the single egg ovulated after cessation of the oestrus) is governed by the pituitary gland in interaction with the ovaries. The pituitary gland produces a hormone which stimulates the follicles in the ovary to grow to a certain stage. It should be mentioned that specific differences exist with regard to young animals' response to this follicle stimulating hormone (F.S.H.). In the calf, for example, a response can be demonstrated shortly after birth, while other species do not react before the age of puberty. Now, as the follicles grow under the influence of F.S.H., a greater amount of oestrogens (usually, but wrongly, called the female hormones) is produced by the follicles. The oestrogens in turn act as inhibitors on the production of F.S.H. The pituitary, however, produces another gonadotrophic hormone, the Luteinising hormone (L.H.), which interacts with the residual or decreased amount of F.S.H., and these two hormones cause the follicles to burst, i.e. the animal ovulates. Whether the pituitary produces only one gonadotrophic hormone, and F.S.H. and L.H. are merely fractions of one hormone, or there is a constant production, for example, of F.S.H., while the amount of L.H. is changing, are problems beyond the scope of this discussion.

75. As the amount of oestrogens increases during the follicular growth, certain changes occur in the genital tract and in the psyche of the female, the end result being the oestrus, which is the period during which the female allows mating. For most animals the ovulation takes place in the middle of this period, while in the cow the ovulation occurs several hours (average 14 hours) after cessation of oestrus. The importance of knowing this is clearly seen in connection with artificial insemination.

76. When the follicles have disposed of their eggs, a formation of luteal tissues takes place in the individual follicle resulting in the formation of corpora lutea. From this tissue, which is formed under influence of the L.H. factor, a production of another important hormone begins (probably a third pituitary hormone is necessary for this production). This hormone has been named progesterone as it causes progestational changes in the uterus, i.e. a preparation of the uterine wall for receiving the fertilised eggs. In addition, the hormone is necessary for maintaining the normal gestation. It suppresses the production of oestrogens, among other things, so that a new oestrus will not occur when an active corpus luteum is present in the ovary.

77. Besides the four mentioned hormones, others are important for the normal sex cycle in mammalian females and it cannot be emphasised too often that environmental factors are also important, e.g. that nutritional or pathological disturb-

ances easily induce reproductive disorders by influencing the whole endocrine balance. To what extent genetic factors are able to do the same is difficult to say as too little is known about this. In some cases, a clear-cut demonstration has shown a genetic disturbance, e.g. hypoplasia of ovaries, but in most cases the matter is just as complicated as is the genetics of other "quantitative" characteristics. As an example, it can be mentioned that recently it has been found from material from Swedish artificial insemination centres that a difference exists between groups of daughters from different bulls in the occurrence of cysts in the ovaries. The heritability is not yet known. This observation fully confirms the results of Casida and Chapman (1951), who found a hereditary background in the occurrence of cystic ovaries in a herd of Holstein cows. They estimated the heritability to be 43.2 per cent.

78. In the foregoing, no attention has been paid to the male. There is no doubt, however, that almost the same hormones are implied in the normal spermatogenesis and influence the libido of the male. Usually, the male hormones are named androgens, and the production of androgens is from the testicles, but governed by the gonadotrophic hormones from the pituitary. That males also excrete oestrogens is well known. Generally, the male produces enough spermatozoa for fertilisation of eggs released by a single female, when the animals are mated by hand. It is the authors' opinion that the fertility of the male is often over-emphasised on account of the female's fertility, despite the fact that results from artificial insemination breeding centres have shown differences between bulls when the conception rate is used as a measurement of fertility. It can also be mentioned that the conception rate can be raised about 10 per cent by the use of mixed semen. The reason for this seems to be physiological rather than generical. Many investigators have shown fertility differences between bulls, but it suffices to mention one example. In their study on fertilisation rates and embryonic death rates in cows, Kidder et al. (1954) classified 64 bulls as high and low fertile on the basis of non-returns, and found a fertilisation rate of 100 per cent in the high group and 71.9 per cent in the low group. The most important cause is probably a difference in the physiological condition of the bulls, but this in turn can be hereditary. That the semen production is influenced by genes has been shown in experiments with monozygous twins.

79. It is well known that fertility is influenced by a great number of factors. As mentioned before, some of these factors are environmental, some of them are pure genetical, but probably the interaction between these two categories is just as important, and it is to be expected that in some cases the genes will only manifest their effect under certain environmental conditions, e.g. high level of nutrition. Unfortunately, our knowledge of the genetic influence on fertility is in most cases incomplete. The reason for this is to some extent due to the difficulty in finding reliable measurements which are free from

more or less systematic errors, which contribute to cover the real conditions. As an example, let us look upon the calving interval, which in many studies has been used as a measurement for the fertility in the cow. It is a fact that in some herds there is an expressed tendency to get the animals to calve at a certain season, when the food is most abundant, or perhaps if the government "orders" a higher price for the milk at a season when the production is low under normal conditions. It is a common view that a cow should have a calf once a year, and the expression "calving efficiency" is based on this assumption. Further, in many countries it is common that the heifer should produce her first calf at the age of two years and thereafter regularly every year. However, the effort to get one calf a year has not always practical significance in dairy cattle breeding, because the calving interval must be adapted to the level of production of the individual cow. Also, with regard to pig breeding it is useless to talk about breeding efficiency if this expression is connected to the total number of offspring during a year or during the animal's lifetime. Climatic and nutritional conditions often lead the breeder to let the sows farrow only once a year.

80. In the artificial insemination associations, a commonly used measurement for fertility is the number of inseminations per cow per pregnancy. It is based upon the assumption that the cause for non-pregnancy is due to a disturbance in the sexual functions of the cow. The number of "returns", resp. "non-returns", at 2-3 months after insemination is often used as an expression for the bull fertility, but this depends to a certain extent on the ability or technique of the inseminator, the accuracy by which the owner observes the oestrus, etc., and can therefore be very misleading.

81. Concerning the multiparous animals, it is most common to express the fertility as the number of young in the litter, but, as mentioned, attention must also be given to the potential fertility, i.e. the number of ova released from the ovary. It has been shown that genetic factors are involved in the potential fertility, but at the same time there seems to be a correlation between the size of the female and the number of ovulations, at least for some species. The bearing of this is that genes affecting the size have an indirect influence on the potential fertility.

82. It will be noted from the foregoing discussion that great difficulties exist in expressing the fertility of our animals. A contributing reason for this is, in the authors' opinion, that fertility includes a series of physiological processes which run from gametogenesis, ovulation, fertilisation (including oestrus and mating), implantation, gestation and parturition; and from a wider point of view the post-natal development, puberty and sexual maturity too, until the continuity is accomplished. Further, it seems as if the different stages are influenced by the three components: environment, heredity and interaction

between heredity and environment. Whether the genetic influence is due to different polygenic systems or the same system which exerts its effect in different ways during ontogenesis, is not known. To what extent dominance and epistasis play a rôle is unknown too, but it is known that most of the fertility components show a pronounced heterosis in crosses between inbred strains, to mention only one example. This indicates that the additive gene effect is the less important and that overdominance plays a rôle which cannot be overlooked.

83. Before going further, it should be mentioned that when we commonly talk about fertility we usually think of actual fertility as observed in a single animal or in a herd, and usually we think about it without distinguishing between fertility, reproductive capacity, fecundity, sterility, etc. To a certain extent, it is of no importance whether we use the expression non-fertile or sterile ; but it must be remembered that fertility (resp. fecundity) is a matter of degree, while sterility is total (absolute), although sterility can be temporary or permanent.

84. The difference between the potential fertility and the actual fertility can be used as a measurement of the prenatal mortality. This mortality is the most important factor in determination of the gross fertility. However, it is not known to what extent genetic factors play a rôle or if the dominating cause is a non-genetic physiological (in some cases, pathological) one. Few cases are known where the cause is found in a single Mendelian factor, but probably the non-genetic factors are the most important, as for example the competition between eggs in multiparous animals. Very important investigations are now under way and it is to be hoped that more light will be thrown over this problem in the coming years.

85. Concerning the prenatal mortality in multiparous animals, it suffices to say that figures of 50-60 per cent are often found, and that genetic factors should be the main cause of such a high death rate can hardly be believed. However, it must be remembered that the figures presented usually include unfertilised eggs, which in some cases amount to 20-30 per cent. Under normal conditions, however, the number of unfertilised eggs is only a small fraction. In a study of the fertilisation rate and embryonic death rate in the cow, Kidder et al. (1954) found an overall fertilisation rate of 89.2 per cent. The bulls were classified as high and low fertile (cf. paragraph 78). The embryonic death rate based upon fertilised eggs dying before two-three months was 25.5 per cent in the high group and 14.9 per cent in the low fertile bull group. Hawk et al. (1955) made an estimation of the embryonic death rate on inbred and outbred cows and found that the death rate to 150 days was 22.3 per cent for inbred embryos and 19.8 for outbreds. For the dams, the figures were 19.2 for outbreds and 28.4 for inbreds (the coefficient of inbreeding varied between 0.125 and 0.375). That competition perhaps is a factor also in cows is indicated by the findings of Kidder et al. (1952). It was found

that the incidence of multiple ovulations in a herd of Holsteins was 13.1 per cent, while the incidence of twinning was only 1.92 per cent. At which stage the death occurs most frequently is not known exactly. It is often assumed that a critical stage is during the implantation phase, but it is known that embryos disappear under every stage of development.

86. An interesting fact is observed in the inbreeding experiments with cows and swine. At Beltsville (Woodward, 1946), it was clearly shown that the number of services per conception increased rapidly with an increasing inbreeding coefficient. For non-inbred cows, the average services per conception were 2.00, while cows with an inbreeding coefficient of 50 per cent and above required 3.58 services per conception. In experiments with swine (cf. Craft, 1953), it was found that not only did the number of eggs shed at a heat period decrease in inbred gilts, but the number of pigs farrowed decreased in all cases with increasing inbreeding. As a common feature of inbreeding, it can be said that this breeding method exerts a deleterious effect on fertility. Further, it has been shown that the decrease in fertility can be fully restored in crossbred animals. Durham et al. (1952) showed that the ovulation rate in topcross gilts was 10.63 against 9.00 in non-topcross gilts from three herds. Concerning the number of pigs farrowed, it was shown by the same authors that topcross gilts farrowed 9.85 pigs as an average, while non-topcross gilts had litters of only 8.69 pigs. The same findings are presented by the Minnesota workers, but it is not the place here to quote all these results. Reference is made to the special chapters on the different farm animals. That fertility is restored in crossbred animals is a fact, but whether this is due to higher livability of the eggs or better uterine environment is not so easily solved. From transplantation experiments with fertilised eggs on laboratory animals, it is known that eggs transferred to crossbred females (from two different breeds), either from pure or crossbred breeds, have a higher survival rate than eggs transferred to females of non-inbred pure breeds. This indicates that the uterine environment is the most important factor, but this better environment is produced by heterozygosity. It should be of great interest to get figures on the number of pigs born in litters where inbred females have been mated to inbred males, i.e. the eggs and the uterine environment are "inbred", compared to incrossed or crossbred eggs in "inbred" uterine environment and in "outbred" environment.

87. Turning now to the problem of the extent to which genetic factors exert their effect on different fertility components, it can be mentioned that for litter size in the pig the heritability ranges from 10 to 44 per cent, but most of the estimates give a heritability between 10 and 20 per cent (cf. Craft, 1953). The latter figures are more in agreement with the coefficient of repeatability, which has been estimated to be 0.20. For the cow, the heritability of the incidence of ovaries with cysts once in the life has, as mentioned, been determined to about 0.43, while

scrotal hernia in the pig shows a heritability of 0.15. The number of spermatozoa in the male shows a heritability of not more than 0.40, while the important trait in the cow, the constancy with which the oestrus appears, shows a repeatability between 0.40 and 0.60. In sheep, the repeatability for the interval between successive oestrus periods has been found to be about 0.20, and for the sow a little less than 0.40. It must, however, be remembered that these coefficients give too high values for hereditary differences and in a few cases no genetic source of variation can be demonstrated, although a certain repeatability exists. Concerning the length of oestrus, coefficients of repeatability between 0.45 and 0.60 have been found for the larger animals. It will be of only little use to mention more "quantitative" traits which are involved in the fertility complex of larger animals. Those which have been presented serve to demonstrate that, although no clear picture exists for most traits, there is definite evidence that genes (polygenes) exert a certain influence. The major problem is to find out to what extent dominance, epistasis, etc., is involved in the genetic part of the variation between animals. If these two - or more correctly, if other genetic factors than genes with additive effect - are more important, then it means that breeding methods and methods of selection for many years have been based on wrong principles.

88. There is another side of the genetic influence on fertility, and that is the occurrence of monsters and other abnormal individuals. In most cases, such conditions are due to single Mendelian factors which in homozygosity are lethal. Examples of lethality due to one pair of genes are found in the Dexter cattle, where 25 per cent of the offspring are monsters, and among fur animals, where litters from the mating of Platinum fox to Platinum of White Face, on an average have one kid less than litters of pure Silver fox. The frequency of genes with lethal effects is generally rather low, and only in few cases do they influence the economic output for a breed as a whole. For single herds, the occurrence of lethal factors can be of great importance. Some other conditions which affect the normal development of the reproductive organs are known to have a relatively simple genetical background, while most of the anatomical disturbances (e.g. scrotal hernia) seem to behave as quantitative characteristics. It was mentioned earlier that many of the factors influencing fertility shown rather low heritability, and that the fertility decreased with increasing inbreeding. Further, most of these characteristics show pronounced heterosis in different crosses. This cannot be stressed too often, because it indicates that different kinds of interaction play a far more important rôle than is usually believed, and if progress is to be expected other methods of selection than those usually used must be applied.

89. A matter, which in some breeds has been overlooked, is the sex dimorphism. To be able to maintain or increase fertility among farm animals, it is important to select males who look

like males and females showing female type. The difference between the two sexes is quantitative rather than qualitative, and no male is completely male as well as no female is completely female, although the individual from the moment of fertilisation is predisposed for development in one or another direction. The two - perhaps abstract - conditions, maleness and femaleness, are phenotypically manifestations of the primary production of sex hormones, which regulates the development of the secondary sex characters.

REFERENCES

- Casida, L.E. and Chapman A.B. : 1951, Factors affecting the incidence of cystic ovaries in a herd of Holstein cows. - Jour. Dai. Sci., 34, 1200-1205.
- Craft, W.A. : 1953, Results of swine breeding research. - U.S.D.A. Circ. No. 916, 51 p.
- Hawk, H.W., Tyler, W.J. and Casida, L.E. : 1955, Effect of sire and system of mating on estimated embryonic loss. - Jour. Dai. Sci., 38, 420-427.
- Kidder, H.E., Barrett, G.R. and Casida, L.E. : 1952, A Study of ovulations in six families of Holstein-Friesians. - Jour. Dai. Sci., 35, 436-444.
- Kidder, H.E., Black, W.G., Wiltbank, J.N., Ulberg, L.C., and Casida, L.E. : 1954, Fertilisation rates and embryonic death rates in cows bred to bulls of different levels of fertility. - Jour. Dai. Sci., 37, 691-697.
- Woodward, T.E. and Graces, R.R. : 1946, Results of inbreeding grade Holstein-Friesian cattle. - U.S.D.A., Tech. bull. 927, 39 p.

IV

REPORT OF THE POULTRY SECTION

INTRODUCTION

90. In addition to touring the principal State universities or colleges of the Corn Belt*, the members of the Poultry Mission visited the Agricultural Research Centre at Beltsville, Maryland; the Poultry Research Centre at East Lansing, Michigan; the three most important producers of "hybrid" chicks; a number of private breeders and one or two general farms on which poultry were kept as part of the normal activities.

91. The broad function of the Mission as defined by the E. P. A. was "to study modern breeding methods and inter-State co-operation in the field of animal production", which clearly meant a study of the work now in progress in connection with the problems of breeding for heterosis. On its way to the United States, therefore, the poultry section considered its specialised duties in some detail, and agreed on the following main objectives:

- to obtain up-to-date information about poultry production and consumption;

- to assess the merits and progress of the National Poultry Improvement Plan (N. P. I. P.);

- to study, at all possible levels, the breeding and especially the commercial performance of "hybrid" fowls;

- to compare the relative efficiencies of incrossbreeding with more recent systems of breeding for heterosis;

- to obtain up-to-date information concerning the precise significance and value of preliminary inbreeding;

- to assess current opinion on the probable future of the conventional pure breeder;

- to study inter-State co-operation in the field of poultry breeding;

* Ames, Iowa; St. Paul, Minnesota; Madison, Wisconsin; Lafayette, Indiana (Purdue); Columbus, Ohio; and Ithaca, New York (Cornell).

to study modern breeding and economic trends of broilers and turkeys ;

to discuss the subject of controlling poultry diseases (especially avian lymphomatosis) by genetic means ;

to study the technique of random sample testing.

92. It will be seen from the above that the poultry section left Europe under the impression that it was concerned only with its own specialised subject of poultry and that, while some early discussions on animal breeding in general would not be out of place and might indeed be very useful, we should be free for most of our time to concentrate on poultry and to leave cattle and pigs to their respective sections. On the whole, we were provided with a very comprehensive poultry programme in which most of our objectives were gained and, in the end, all that we could justifiably complain of was that we were tired. As regards our ten points of study, no attempt was made to place them in any order of importance ; it was felt better to leave them as stated and to raise them collectively or separately as opportunity arose. That this preparatory work was appreciated became evident on our arrival in Washington, where our technical contact immediately had it reproduced for general circulation.

93. It may be argued that the Corn Belt of America, to which we were almost entirely confined, is not truly representative of the United States as a whole. It is, however, a region of outstanding agricultural importance and much of the poultry research and commercial developments arising from the modern concept of breeding for heterosis have been initiated and are still in progress within this area. In a country like America, where so much attention is focused on problems of productivity, the research work of the Corn Belt has become of prime economic importance and its results, when firmly established, will no doubt have repercussions over the whole agricultural industry of the country. One of the outstanding lessons of our Mission, however, was the fact that results are by no means firmly established at present and that problems which at one time appeared to be relatively straightforward, if tackled with energy and imagination, are now known to be extremely complex. It will clearly be several years before any final pronouncements can be made.

94. In spite of this, however, it was heartening to note the skill and enthusiasms and the willingness to co-operate that were everywhere evident in the research and extension workers with whom we came into contact ; and we understand that this applied with equal force to farmers themselves, many of whom are, if anything, over-enthusiastic in that they tend to accept and put into practice new ideas which have not been thoroughly investigated at research levels and are certainly not established. This spirit of adventure is not entirely to be deprecated. It may lead to individual losses here and there, but it provides a valuable addition to the research work that is in progress at the

various State Colleges and other institutions, for all such experimentation is closely watched by their research and extension staffs. Moreover, America is so vast and its range of environments so extensive that breeding research initiated in one area cannot be said to have been finalised until results have been tested and compared in other and preferably all areas. One may argue that genes are not changed merely by moving them from Ohio to Florida or California ; but characters are not due to genes alone, they result from the interaction between the genes and their environment.

STATISTICS

95. The continent of the United States comprises an area of some three million square miles (over one-sixth of the world's cultivated area). In 1950, the population was about 150 million (or one-sixteenth of that of the whole world) and it is now about 165 million - an increase of about 2 per cent per annum, which is faster than that of the world as a whole. Self-sufficiency in food production is therefore a major national problem, especially as the standard of living is much higher than in most parts of Europe. Some 60 per cent of the land area is described as farming land, and over 30 per cent of the total farming population is to be found within the Corn Belt, which supplies nearly one quarter of the country's gross agricultural production. Farms vary considerably in size, from one and a half to over 40,000 hectares (three to 100,000 acres), but the average is about 80 hectares (200 acres). Within the Corn Belt, the average and most frequent size is about 69 hectares (170 acres). In this region of fertility, the majority of farmers go in for general or mixed agriculture ; they plant mainly corn (maize) and other cereals, soya beans, lucerne or other pasturage on a three- or four-year rotation ; they keep pigs and some beef cattle, and at least a couple of cows to supply the homestead with fresh milk (though this last feature is gradually disappearing as organised deliveries from central milk depots become more and more available). In addition, they keep two or three hundred laying fowls for commercial egg production and may also be engaged in broiler production and/or rearing turkeys. The average capital value of most farms is about \$20,000 and the average farm income is about \$3,000 per annum, nearly 50 per cent higher than the average for the country as a whole. Most farms are owner-occupied and run as family enterprises ; where family labour is inadequate, employees are usually engaged on some form of co-partnership basis. Mechanisation is highly developed, both on the farm and in the home, electricity is everywhere available, but water has to be drawn mainly from wells or springs. The purchasing power of the farmer's income, though much better than it was twenty years ago, has declined some 15 per cent during the past ten years owing to inflation, and there is consequently a deep and widespread interest in the possibilities of increasing productivity, especially in relation to labour and feeding costs.

96. Details of poultry production and consumption are given in the following summary and in Table 1; they refer to the year 1953, except where otherwise stated.

	U.S.A.	Corn Belt
Laying fowls - hens	151, 000, 000	56, 500, 000
pullets	254, 600, 000	127, 000, 000
	405, 600, 000 ⁽¹⁾	183, 500, 000
Other adult fowls	25, 800, 000	6, 600, 000
	431, 400, 000	190, 100, 000
Broilers	886, 000, 000 ⁽²⁾	355, 000, 000
Turkeys	60, 200, 000	14, 000, 000
Hatcheries	6, 890 ⁽³⁾	
Total capacity...	562, 000, 000	
Total output.....	1, 800, 000, 000	
	eggs	
	chicks	
	(straight-run) ⁽⁴⁾	
Average value of a laying fowl.	\$1.40	
Total egg production	61, 000, 000, 000	29, 000, 000, 000
Average rate of lay (per annum)	178 eggs	184 eggs
Average price per dozen eggs..	41.6 cts ⁽⁵⁾	35.5 cts.
	145.6 Fr.fr.	124.25 Fr.fr.
Per capita egg consumption...	407 eggs per annum	
Per capital poultry meat consumption :		
Broilers	13.4 kg. (29.6 lb.)	
Turkeys	2.4 kg. (5.4 lb.)	
Principal pure breeds kept for egg production :		
White Leghorns (over 50 per cent of total); New Hampshires;		
White Plymouth Rocks ; Rhode Island Reds ; Barred Rocks.		
Principal pure breeds employed in broiler production :		
New Hampshires ; White Rocks ; Silver Cornish and various		
dominant white breeds. Production largely in the form of		
crossbreds.		
Principal pure breeds of turkeys :		
Broad-Breasted Bronze ; Beltsville Small White ; Large		
Whites ("White Hollands").		

(1) 414 million in 1954.

(2) 1 050 million.

(3) The total number of hatcheries, including breeder hatcheries has declined by about one-third since 1943, but average output has risen by rather more than this fraction and total output has risen by about 15 per cent in about ten years.

(4) "Straight-run" = unsexed.

(5) There was some decline in egg prices and broiler prices during 1953-54 ; precise figures were not obtainable.

Table 1

REGIONAL FARM POPULATION AND POULTRY PRODUCTION, U.S.A.
(U.S.D.A. YEAR BOOK, 1953)

	FARM POPULATION		ADULT CHICKENS		EGGS		BROILERS		TURKEYS	
	Million	%	Million	%	Million	%	Million	%	Million	%
North Atlantic.....	2.1	8.2	77.2	18.0	11,500	18.9	99.8	11.3	5.3	8.8
E/N Central.....	4.1	16.3	82.1	19.0	12,400	20.3	86.6	9.8	7.1	11.8
W/N Central.....	3.9	15.5	108.0	25.0	16,500	27.0	46.0	5.2	12.6	21.0
South Atlantic.....	5.1	20.3	46.4	10.8	5,200	8.5	372.1	42.0	11.5	19.1
South Central.....	7.7	30.7	73.8	17.1	8,800	14.4	215.1	24.2	6.1	10.1
Western.....	2.2	9.0	43.9	10.1	6,600	10.9	66.4	7.5	17.6	29.2
Total.....	25.1		431.4		61,000		886.0		60.2	

97. The following figures relating to poultry in Europe may be noted for comparison; they refer to estimated numbers of chickens kept and eggs produced in 1953 (U.S.D.A. Year Book, 1953).

	Chickens	Eggs
Belgium.....	15,000,000	2,000,000,000
Denmark.....	23,400,000	1,900,000,000
France.....	70,000,000	7,000,000,000
Germany (West).....	50,600,000	5,700,000,000
Netherlands.....	15,800,000	2,500,000,000
Sweden.....	11,000,000	1,400,000,000
United Kingdom.....	89,800,000	6,300,000,000

PUREBREEDING IN THE UNITED STATES

98. We were unable to obtain any reliable estimate of the total number of purebreeders in the United States, but they would appear to be far less numerous than might have been expected in such a vast country, where poultry production plays so important a rôle. The reason is in fact quite simple. Competition is very keen in America and "big business" is the ambition of most of its people. If they do not succeed quickly in one venture, they leave it and try another. In consequence, reputable poultry breeding has fallen progressively into fewer and fewer hands and now rests with a comparatively few private breeders and commercial companies, all of whom operate on a relatively enormous scale. It is by no means uncommon, for example, for an individual breeder to maintain a flock of well over ten thousand birds, all of one breed, and the largest breeder in the country keeps over 125,000 birds and employs four PhD's to assist him in the task of recording, selecting and mating. The annual sales from any of these breeders may well be of the order of one or two million chicks. The majority of private breeders have been in operation for several years, over thirty in some cases, and most of them have established a considerable reputation in that time, some on a national basis, others more locally, but still covering a wide area. They are mostly pedigree breeders, trapnesting sufficient of their flock and keeping such individual and family records as will enable them to select future breeders for maintaining the flock and supplying hatcheries and others with pedigree stock. The balance of the flock is maintained and mated for commercial chick production. On the pedigree side, the detailed work of recording and trapping involves much labour and expense, and it need not therefore be surprising that short cuts are employed wherever possible. Pullet breeding is commonly practised as this speeds up the annual rate of genetic gains arising from selection; but some breeders still maintain a proportion of older birds for repeat matings. Pullet breeding is frowned upon in parts of Europe through fear that it leads automatically to a decline in vigour; but, while American standards in this respect are not good, we

are not aware of any experimentally established proof that the progeny of hens have greater viability than the progeny of the same birds as pullets. The American breeder argues that time is money and that outstanding families disclosed by selection among hens are to all intents and purposes the same as those disclosed by pullet records. It should not be imagined that completely untested pullets are employed. Numerous investigations, conducted by quite impartial scientists at various research centres, have established high correlations between annual egg production and production during the four winter months (October-January) ; also between production based on seven days a week trapping and that estimated from trapping only five or even three days a week. With such short cuts, calculated production is not exact ; but no breeder needs exact figures of annual egg production - he needs to select the best individuals and especially the best families, and these (he claims) can be detected just as well by means of short-cut records as by full ones. The precise order of merit of the various families may not prove to be exactly the same in both cases, but the errors involved are statistically insignificant when one is dealing with large numbers of birds. It is the comparative ranking of families that matters, not their precise score ; and, if the best 20 to 30 per cent of all tested pullets are to be retained, they will be found as a group by the quicker and cheaper method just as well (or almost as well) as by the slower and more expensive one.

99. It is well known that, in the search for greater productivity, selection must be confined to as few characters as possible and must be based on family performance where heritability is low (as in the case of egg production), though mass selection is just as good where heritability is high (as in the case of egg size). No importance is attached to uneconomic characters such as plumage colour, side sprigs and (in the case of layers) body-conformation. What is economically important is number of eggs : size, shape, strength and internal quality of eggs ; fertility and hatchability. Since selection and mating, as hatching, must be carried out at fixed times of the year if the breeding programme is not to become completely disorganised within a few years, the practice of recording egg production to 500 days from hatching (as first recommended by Hutt of Cornell) has become almost universal. This has been decried by some writers in Europe who allege that it ignores the important character of persistency. This has not been found to be the case in the United States. With hatching strictly confined to one period in the spring, and with the reduction in age at sexual maturity that has resulted from selection for this character over the past thirty years or more, pullets have a laying season of from 320 to 350 days in this 500-day period and any family that lacks persistency is bound to be exposed in that time.

100. Broadly speaking, selection for purebreeding has followed the lines advocated by Goodale nearly 40 years ago.

modified more recently by close attention to the consequences of the concept of heritability. In other words, earlier selection was based on mass records of sexual maturity, absence of winter pause, rate of winter laying, broodiness and persistency, together with hatchability ; but recent emphasis has been on selection where necessary by whole families and not by individuals. It is difficult, if not impossible, to evaluate the genetic progress that has been accomplished, for the past thirty years or so have seen many changes in feeding, housing and in environmental factors generally. The majority of American breeders are alert and devoted to their job ; they are efficient in most ways and, by working on a large scale under fairly favourable economic conditions, they have been able to invest their wealth in further and better pedigree breeding, particularly in the selection and rejection of whole families. As stated above, many of them have established a considerable reputation for themselves. After a few early years of exploration, they are not content to take over breeds produced by other breeders and sell a hotch-potch of genes ; they want to call their birds their own and to sell them as such. After this initial stage, therefore, during which they have normally bought in stock from a number of breeders and tested it in as many combinations as possible at the time, they throw out all that has proved unsatisfactory, mix the rest as thoroughly as they can by planned breeding, and then at once close the flock to all outside blood. The breeder thenceforth concentrates on developing his own strains, of which he may produce a dozen or more within the one breed. He feels entitled to call a strain his own as soon as it has been closed to outside blood for at least five years. Many flocks have been closed in fact for ten to twenty years. With so many single-sire matings possible, at least during the past ten years or so, the amount of inbreeding is negligible. To provide an income, he sells pedigree males to hatcheries that do not breed their own pure stock, and he sells commercial chicks, including sometimes crossbreds and strain-crosses derived from his pedigree stock, to all and sundry for commercial egg or broiler production.

101. As already stated, the task of pedigree breeding and selection is an expensive one. It is therefore customary for pedigree breeders in the United States to make not only what they can by the sale of pedigree and commercial chicks, but also to carry on (at the same time and on the same premises) a retail business for the sale of poultry foodstuffs, equipment and drugs. If a general framer gets into the habit of buying his foodstuffs and equipment from so-and-so's breeding and retail store, he is likely to buy his chicks there too. He knows whom he is dealing with and he likes to have a friendly chat with him at times and, when necessary, to ask his advice on his poultry problems.

102. Apart from pullet breeding, a point that might well arouse controversy in Europe is the now universal practice of intensive breeding. There can be no objection, on genetic

grounds, to mating proven birds under intensive conditions ; but the question of testing pullets prior to mating is a different matter. Even where the stock is allowed free or limited range as growers, it is housed around point-of-lay and there it stays throughout the whole testing and mating period until the breeder has no further use for it. The laying houses are artificially warmed in winter and are supplied with fourteen hours "day-light" by electricity ; and the question must arise : What happens about winter pause ? This does not bother the American breeder of today. He says that intensive housing has come to stay and that there is no longer any need to select against winter pause since, even if the genes are present in the stock, they lack the required environment for them to express themselves.

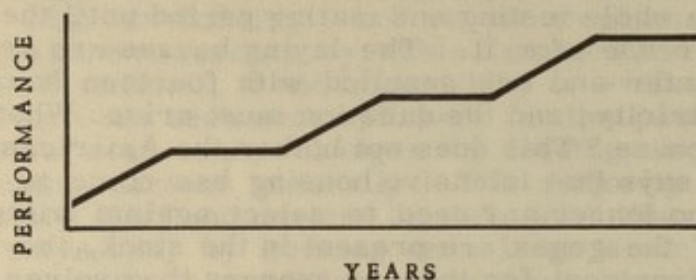
103. Another point that attracted our interest is the way in which the typical American breeder employs the total score system of selection. It has long been recognised that a successful breeder cannot select for just one character alone ; while he must keep the total number of characters as low as possible, he cannot with impunity reduce them below some five or six. Various scientists, notably Lush (Iowa), have examined the merits of different systems of selecting for more than one character and their conclusion is that the total score method is definitely the best. During recent years, with the growth and spread of knowledge about heritability, the idea has become common that it should be possible, at any rate within a large flock of one breed, to evolve some sort of formula which would apply from year to year and indicate how much importance should be attached to this character, how much to that, in order to arrive at a reliable index of overall merit. Thus, if A, B, C, D and E represent not only five such characters but also the measure of their performance, then

$$M = w_1 A + w_2 B + w_3 C + w_4 D + w_5 E,$$

where the weighting factors w_1 , w_2 , etc. would be determined previously by geneticists from a knowledge of economic conditions and of the heritability of these characters within the given flock. While some limited use is being made of such a system in relation to breeding for meat production, it certainly has no advocates (so far as we could learn) where egg production is at stake. The purebreeder in the United States is fully alive to the need for selecting for more than one character, and he would welcome more real guidance on the subject ; but he will have no truck with a static formula like the one above. If one character appears to be slipping, he increases selection pressure for that character, even at the expense of some other character or characters that are for the time being all right.

104. In spite of the advances that have undoubtedly been made in securing more and even more productivity from poultry, progress over the years is not a steady process but tends to go in leaps and bounds, producing periodic plateaux of production where average performance stands still until some means is found of breaking through whatever barrier is responsible. If

we smooth out the effects of minor environmental influences, we can illustrate this by means of the following diagram.



In the history of egg production in the United States, for example, it will be found that such plateaux existed before and after the time of Goodale, depending on the methods of selection at the time, and that these plateaux have more than once been broken by improving environmental factors such as feeding. It would appear that another of these plateaux has again been reached by many breeders during the last ten years or so and that it is of a genetic nature. It is felt that, possibly as a result of the closed flock system, the average genotype has become too uniform and "static" and that it needs shaking up a bit. Recent work on the production of "hybrid" chicks has opened up the possibilities of strain-crossing as a solution to this problem, and several research centres and private breeders are now actively engaged in investigating this system. The underlying theory appears to be simple enough, though there is probably more in the problem than meets the eye. If strains A and B have each reached a stage where selection along normal lines fails to produce any response, it is possible that each of them is lacking in certain desirable genes and that strain A lacks what B has, and vice versa. In other words, A and B may be complementary in a genetical sense. In practice, however, the problem is not as simple as would appear. Even where a breeder has only say six separate strains, he must make thirty different matings if he is to test them in all possible combinations, including reciprocal crosses, and it would be beyond the resources of the average American breeder to do this in full. All he can do is to try out as many crosses as he can, from among the apparently more promising of his strains, and to see what happens. If they "nick", all well and good; if they don't, then he must abandon that mating and try another. Even if two strains nick at the first attempt, the experiment must be repeated with different samples to prove that the first success was not due to luck. Of the various breeders engaged in this work, some claim that they have already found improved combinations which they have been able to market commercially (with great care to disguise their identity for fear that other breeders or hatcheries holding these strains would pirate his success). The whole subject is linked with that of heterosis in general, and there is undoubtedly much still to be learnt. For one thing, apart from the fact that nicking cannot be predicted but can be established only by trial and error, the fact remains

that the offspring of a strain cross are likely to be more heterozygous than their parents. They may well prove superior in phenotype performance, but they are unlikely to prove superior in genotype (breeding) performance as well. So long as this latter point is realised, straincrosses would appear to have a considerable future.

INBREEDING

105. The general effects of inbreeding fowls, i.e. of mating birds of more than average relationship to one another, have been investigated by numerous workers, but the conclusions drawn from their results are highly conflicting in matters of detail. This is partly because some of them worked with very few birds, and their results are therefore not significant in the statistical sense ; partly because different investigators employed different levels of inbreeding and exerted different selection pressures when developing their material. The main reason for different results has been that the original stocks which workers employed were independent samples of poultry and therefore quite unlikely to have the same or even very similar genetic constitutions. On the whole, however, there can be no doubt that close inbreeding does tend to cause degeneration in most stocks, if not in all, of their utility characters ; that the rate of degeneration for one character is not necessarily the same as for another ; and that very close relationships such as brother x sister should be avoided (except perhaps for experimental work), unless one is prepared for the majority of lines to die out within a few generations through sheer inability to reproduce themselves. In other words, the principal utility characters to be affected are egg numbers, hatchability and viability.

106. Knox (Beltsville) emphasised the importance of starting any inbreeding programme cautiously by avoiding very close relationships during the first two or three generations ; after which, if the stock still looked promising, one could go full steam ahead and resort to full sib matings with some confidence. He claims, in fact, to have been the first to produce inbred lines that would live and reproduce for more than a few generations.

107. Nordskog (Iowa) and Schoffner (Minnesota), working on a large scale and with various techniques, have presented evidence that the effects of inbreeding can be estimated from the following average figures :

- Each 10 per cent increase of inbreeding lowers hatchability by 2 per cent
- Each 10 per cent increase of inbreeding lowers egg production by 4 per cent
- Each 10 per cent increase of inbreeding raises total mortality by 5 per cent

108. By extrapolation, Nordskog claims that inbreeding, if carried to the 50 per cent level and then to its ultimate end, would have the following results:

Inbreeding level (per cent) ...	0	50	100
Eggs per hen per year	201	122	44
Hatchability, per cent	75	66	56
Total mortality, per cent.....	33	52	68

109. Interesting as these results are, however, they are mere averages and do not state the range of variability which he found. They are therefore of limited use in predicting what any particular stock would suffer.

110. The whole subject of inbreeding has become of such importance in the United States, not only with poultry but with livestock in general, that we may well pause and consider some of the facts and theories that are advanced to account for this degeneration.

111. In the first place, it is an accepted fact that many stocks are cursed with a variety of deleterious genes which collectively form what may be called genetic "trash". These genes are commonly recessive and, if they then occur in the homozygous condition, are harmful in one way or another. That they do not commonly affect outbred stock is due to the fact that, in such material, they are preserved in heterozygous form and are therefore unable to express themselves in competition with their respective dominant genes. Since the mating of relatives increases the chances of bringing similar genes together in the offspring, inbreeding automatically tends to throw the population into a number of pure lines, some of which contain these deleterious genes in homozygous condition and are therefore of inferior performance. According to Knox, it should be possible to control this form of degeneration by rigorous selection so long as one is not in a hurry to inbreed closely in the initial stages.

112. In the second place (and this does not appear to receive the attention that it deserves in some quarters), the fact that inbreeding tends to the creation of distinct pure lines inevitably means that any gene complexes that are favourable to utility performance are broken down, with the result that performance declines progressively as gene segregation proceeds. If we imagine a complex of just two pairs of genes for which the original stock is heterozygous, the ultimate effect of inbreeding is to break this stock into four distinct lines, only one of which will contain the double dominant and therefore represent (in this respect) the breeder's ideal. Within such a complex, it is possible for dominance, epistasis and gene interaction generally to play an important part in determining efficiency of performance and independent gene segregation is therefore capable of more or less ruining what may once have been a valuable

stock. By means of the binomial theorem, we can easily calculate the theoretical proportions in which the various new combinations should appear ; but, if a gene complex depends for its optimum expression on more than just a few gene pairs, it becomes increasingly unlikely that any extreme combination will in fact appear. Speaking on this subject in relation to corn breeding, Sprague (Iowa) estimated that for a complex of 20 gene pairs one would need to plant an area the size of Ireland if every possible pure combination were to have an even chance of making its appearance. We would add to this the fact that, even if every possible combination did thus occur, we doubt the ability of the breeder to recognise what he was actually in search of.

113. A third possibility lies in what is called "overdominance". This theory envisages that, as mentioned in chapter II, in relation to some utility characters at least, the heterozygous condition Aa is superior in phenotype performance to both homozygous types AA and aa . If this were so, the heterozygous condition could be produced in purely commercial stocks, but it would be necessary to maintain the inferior homozygous forms as breeding stock for the production of the heterozygote in maximum proportions of 100 per cent. It is of some interest to note the work of Jaap (Ohio) some few years ago in connection with White Wyandottes, in which he produced evidence that, in the United States at least, selection against single comb birds within the flock leads to a more or less static condition in which these single combs continue to appear in about 8 - 12 per cent of the flock instead of about 1 - 2 per cent. He argues that Rr birds must reproduce better than RR birds. The possibilities are interesting, though they do not tie up exactly with the theory of overdominance in that Jaap makes no claims for rr (single comb) birds.

114. From all the evidence that has been accumulated over the years, it would appear that the effects of inbreeding in poultry are due to at least the first two of these causes and possibly to the third. It need therefore not be surprising that different stocks react to inbreeding in different ways and degrees.

115. It would, however, appear that, if breeding stock can be relieved of most or all of its genetic trash, some improvement in breeding performance should follow and that this desirable end can be attained most rapidly and thoroughly only by inbreeding. Since such a system would inevitably break down any gene complexes and overdominance that previously existed, favourable combinations would then have to be restored by mating inbred lines together, in the hope that what one line lacked would be compensated by what another line possessed.

116. Considerations such as these have occupied the minds of geneticists, especially in America, for several years. In the early days of poultry genetics, attention was confined to characters whose inheritance depended on just one or two

simple gene pairs which could be readily analysed without any great effort of time or money. It is advisable to regard such work as forming but a small part of modern genetics and, in fact, to describe it as Mendelism. Utility performance of poultry and other animals, on the other hand, depends on large numbers of genes and therefore requires analysis by complicated statistical methods. This more recent science is therefore known as Population Genetics. Its techniques are beyond the average man and indeed the average breeder ; but most agricultural students in the United States have to undergo a course of training in its mysteries, from which they gain at least some useful, if rule-of-thumb, knowledge. The expert, however, must be a mathematician. Where any breeding project involving utility characters is envisaged, the mathematician is automatically and of necessity brought in at the very beginning to plan the experiment and to evaluate its results. It follows that much of the earlier work on the subject of poultry breeding has had to be rejected as insignificant, and a whole new series of experiments begun. Modern research into the new techniques of breeding based on preliminary inbreeding was thus initiated by Shull and East between 1905 and 1912. We cannot describe their work in this place, but the general subject as it concerns poultry must be given further discussion.

INCROSSING, TOPCROSSING AND INCROSSBREEDING

117. If two inbred lines of the same breed or variety are mated together, the resulting progeny are called incrosses. Where the two inbred parent lines are of different breeds or varieties, the progeny are known as incrossbreds. If one inbred line is mated with outbred stock of the same or another breed or variety, the progeny are called topcrosses. It is important to bear these definitions in mind, otherwise confusion may result. Any combination of two inbred lines of poultry is called a two-way cross, and a combination of two two-way crosses produces a four-way cross. By mating an inbred line with a two-way cross, we get a three-way cross.

118. In the case of poultry, just as with corn, it was found that two-way crosses were sometimes, but by no means always, superiors in performance not only to the inbred parents, but even to outbred stock maintained under the same environmental conditions. Some combinations of inbred lines were better than others, but performance could not be predicted from a knowledge of the pure inbreds. Some latent productive force, in other words, can be released by this process, but the right combinations can be judged only by trial and error. One may describe the phenomenon as the release of cryptic gains acquired during inbreeding, or one may refer to what has been stated above about the removal of genetic trash, followed by the restoration of favourable gene complexes. But neither of these two straight-

forward theories appears to explain the (sometimes) tremendous "boost" which these two-way crosses may possess. Industry does not always wait on science, however, and the early and rapid success with corn led to a similar interest in poultry in the hands of commercial men. While "hybrid" corn breeding on a commercial scale started with small farmers, however, and was then taken over by large concerns with sufficient capital to develop the project fully, it is from among these "hybrid" corn producers (followed by one or two other firms dependent on other sources of capital) that "hybrid" poultry have been placed on the market.

119. The process of production is relatively simple in broad outline, though details are more complex. Close inbreeding (usually brother x sister) is normally practised for three or four generations during which rigorous selection is applied to characters of economic importance, especially egg numbers, hatchability and viability. Perhaps 4 per cent of all inbred lines started survive this initial period in which most of the genetic trash is eliminated and greater breeding uniformity is established. Naturally, these inbred lines are by this time of comparatively poor phenotype performance themselves, from 80 to 120 eggs a year being regarded as good. Even among the inbred lines that survive this first period and are eventually selected for making two-way crosses, the average life of the line is said to be only 4 1/2 years ; some die out in spite of their early promise, others are replaced by new and better material. The inbred lines are then tested in various combinations with a view to finding the best two-way crosses and the selected lines are then still further purified by another one or two generations of close inbreeding, after which they are maintained as closed flocks, sires being selected by progeny testing (often on the dual-shift system advocated by Hutt of Cornell). In these closed flocks, considerable expansion in numbers may take place. Thus, one commercial producer claimed to have not less than 15,000 birds in one inbred line alone. Meanwhile, the two-way crosses have been tested for performance not only at headquarters but at various locations spread over a wide area and covering a wide range of environments. Groups of at least 40 and preferably 80 pullets are employed for these tests. Then, the more promising two-way crosses are mated together to produce the normal "hybrid" or four-way cross. This four-way cross seldom if ever surpasses its parents in economic performance ; in other words, whatever force is liberated as a result of this preliminary inbreeding and production of a two-way cross, no further gains are expected. Why then produce a four-way cross at all ? For reasons of expense. The two-way cross is produced from parents which, on the female side, produce very few eggs ; the two-way cross is therefore expensive to produce and could not be marketed as such in competition with ordinary commercial stock. But the four-way cross is produced from two-way crosses of high performance and, if the better egg layer is chosen as the female parent, the product can be marketed at a competitive rate. This is usually

around twice the cost of a conventional pure or crossbred commercial chick and, if farmers are willing to buy "hybrid" chicks at all, they do not argue about this price differential which they regard as insignificant in comparison with the extra eggs they expect to get per bird. Recent improvements in the production of these chicks have aimed at securing a white egg and better interior egg quality; but much improvement would still appear to be needed (not only with "hybrids" but with poultry stock generally throughout the United States) in respect of viability. Annual losses of 25 per cent or more could not be tolerated in most countries, and it seems curious that more efficient work has not been carried out in America against specific and non-specific disease. Signs are not lacking, however, that more attention is now being devoted to this important problem. Returning, however, to the present position of "hybrids" in the internal poultry economy of the United States, it may be noted that, while only 9 per cent of the total day-old pullet market is in this form, "hybrids" represent some 40 per cent of all pullet chicks sold in the Corn Belt (where most of the large producers are located). Of the possibilities for the future, we shall have more to say at a later stage. For the moment, we should like to quote Henry Wallace Jnr. (the pioneer of commercial "hybrid" chicks), who told us that he made no claim that his chicks were the best or that his system was bound to prevail over all others. What he does claim is that, by throwing out this challenge to the whole industry, he has done more than any other man to stimulate progress in poultry breeding.

120. Since, in the early days, it was the practice to combine inbred lines of one breed with inbred lines of another, so that two breeds appeared in a two-way, and as many as four breeds might be represented in a four-way cross, the idea has become prevalent that part at least of the success of those chicks is due to hybridization. Hence the word "hybrid", as it is commonly employed in the United States and indeed in parts of Europe today to mean, or at least to include, a bird that has been produced by incrossbreeding. The phenomenon of improved performance has thus come to be referred to as "hybrid vigour". One should be on one's guard against this unfortunate and misleading term. It suggests that the productive-gains achieved by the above process have been made by hybridization; and it also suggests that similar gains can be made by merely mating any two different breeds or varieties together. Both suggestions are incorrect. In the first place, similar gains have been achieved by the process of strain-crossing, as stated already in this report, and the phenomenon is therefore not essentially one involving hybridization. If we admit the argument of gene complexes for utility characters, however, it would be agreed (we think) that favourable combinations are more likely to arise (though they could still not be predicted) when inbred strains of one breed are mated with inbred strains of a different breed, than when one and the same breed is involved. The same argument would apply with equal force to the manufacture of ordinary crossbreds (non-inbred); although it would be impos-

sible to expect improved performance from any crossbred fowl, for the expectation would be that the progeny should be intermediate between the two parents, it is more likely that two different breeds would nick through bringing a more complete gene complex into being than that two strains of the same breed should so succeed. All we have a right to expect, in fact, when one strain is mated with another of the same or different breed, is that the progeny should be of intermediate performance, since most utility genes are dependent for their inheritance on additive gene action. Where the result is unexpected, the phenomenon should not be called hybrid vigour. The correct scientific word is heterosis (i.e. the phenomenon of being different from what was expected); and this heterosis can both in theory and in practice, prove to be either negative (in which case we do not proceed with the mating) or positive (in which case we are naturally in favour of developing it as far as we can). We found just as much carelessness and ignorance of the facts in this connection in America as we have found in our own countries; it is confusing and efforts should be made to rid the problem of this confusion.

121. One subject that interested us particularly was the claim by Nordskog and Sprague (Iowa) that it is possible to predict the performance of four-way crosses, knowing the performance of the various combinations in which the four members could possibly be mated together. Thus, with four inbred strains, A, B, C and D, it is possible to make up and evaluate six different two-way crosses - (AxB), (AxC), (AxD), (BxC), (BxD) and (CxD). The performance of these might suggest, for example, that we should mate (AxB) with (CxD) to make the four-way cross. To predict the performance of this, we take the average of (AxC), (AxD), (BxC) and (BxD). Sprague claims a very high correlation for this method (about 0.9), which suggests that, after the initial two-way cross has been made, no further heterosis occurs and results are in accordance with expectations from purely additive gene action. One consequence of this would appear to be that, once it has been decided that A, B, C and D should be the chosen inbred strains, one should select the four-way cross that contains the highest two-way cross and use this as the female parent since it produces most eggs and therefore does so presumably at the cheapest rate. In other words, if the combination (CxD) is outstanding, then the males should be bred from the mating (AxB) since the actual egg performance of the females of this cross does not appear to affect the value of the resultant four-way cross.

122. An interesting point that has arisen as a result of all the research work on this subject of inbreeding and incrossbreeding is that very considerable doubt now exists as to whether coefficients of inbreeding based on Sewall Wright's formulae can be accepted in future at their face value. Many workers are agreed that the results they have obtained, and their observations on various other characters as well, suggest that coefficients computed from these formulae give figures which are not in fact attained in actual practice. This can well be believed,

as the problem of maintaining an inbred line is often so great that one succeeds, it is suggested, largely by selecting the heterozygotes in each generation. The problem is a very intricate one and is being investigated by various means. One of the most promising, we understand, is by investigations into blood groups, of which several are known, though more work needs to be done on their classification and genetics before they can be finally employed for this specific purpose. Meanwhile, for lack of a better method, calculations of inbreeding coefficients continue to be made in the conventional manner.

123. Another problem, this time a more commercial one, that has arisen from the production of inbreeds and incross-breeds, deals with interior egg quality. As already stated, the earlier (and many present-day) incross-breeds were produced from matings in which two or more different breeds were incorporated. As a result, we have varieties of "hybrid" fowls which lay brown, tinted or white eggs, depending on which breeds have gone into their make-up. It is well known that, in general, white x white yields white; brown x brown yields brown; and that brown x white or the reciprocal, white x brown, gives tinted eggs. Sex-linked factors may operate at times, but these results are generally true. Now, the American housewife prefers a white-shelled egg to a brown or tinted one. The fact has to be accepted without asking for a reason. But the commercial firms who handle the eggs between the farm and the housewife and therefore have to do the candling have a very good reason for preferring white-shelled eggs. Not only are they easier and quicker to candle, but white-shelled eggs contain very much fewer blood spots and meat spots. Some brown-egg strains in America, we were told, produce over 40 per cent of eggs which are thus objectionable. The problem is almost certainly a genetical one, but one member of the section invited attention to the possibility that these faults may also be due to mites in the food and litter. So far as work on incrossbreeding is concerned, however, the solution at the moment appears to lie in making incrossbreeds with as little brown-egg character as possible; in other words, instead of the conventional two, three or four-breed cross, work is in progress with a view to making the four-way cross purely from different inbred lines of White Leghorns. It remains to be seen whether such "hybrids" will yield as many eggs per bird as present ones do; but some sacrifice in this direction could and would be tolerated if the problem of interior egg quality could be resolved thereby. It may not be relevant to the subject of breeding, with which we were primarily concerned, but we would add that the whole subject of interior egg quality, and indeed of shell strength and porosity, is under close examination in the United States. Various new machines have been invented for the purpose; they are at present only in the prototype stage, apart from a few simple gauges for measuring yolk strength and albumen heights in broken eggs. The problem is to evaluate such qualities without first breaking the egg, as even sampling involves some waste of material.

124. Again, the problem of multiplying an inbred line, once selected, for making two-way and eventually four-way crosses, has raised the question of "relaxed selection". One of the arguments used in favour of "hybrid" chicks as against pures is that the former can be mass-produced once the necessary prototypes have been established, whereas the pure breeder can maintain a high level of production (it is alleged) only by rigid selection year after year and by breeding only from perhaps a quarter of his flock. It is difficult to reconcile the two different practices unless indeed inbreeding has resulted in such genetic purity that selection (as the ordinary breeder understands the term) is no longer necessary. The scientist in America, if asked whether constant selection at a high level is necessary in pure stocks, admits that he does not really know the answer, whatever he may think about it ; and, at one or two research centres, notably in Iowa and Minnesota, experiments on relaxed selection within pure, non-inbred flocks have been begun. It is too early to say what the results will eventually disclose ; but work to date suggests that very curious things may happen, both under selection and in its absence, but that on the whole it appears likely that relaxed selection in such stock will lead to a gradual deterioration in performance.

OTHER SYSTEMS OF BREEDING FOR HETEROSIS

125. The theory and practice of incrossbreeding have provoked so much argument in America that the whole subject of breeding for heterosis is almost paramount in scientific thought and research. One of the main problems is : To what extent is preliminary inbreeding essential, and, if it is indeed advisable, to what lengths should it be carried for optimum results? Those who are inclined to minimise the value of this preliminary inbreeding point to the comparative success of straight crossbreds, which can be produced just as cheaply as any other conventionally bred stock and have devised at least two other methods of breeding for heterosis in which inbreeding is either reduced or is even eliminated altogether.

126. So far as straight crossbreds are concerned, we met with none in the course of our visit and we gained very little information about them in conversation. The general impression however, supported by work by Jaap (Ohio), is that these ordinary crossbreds lay about 4 per cent more eggs per annum than ordinary commercial pure-bred fowls. There was some argument among ourselves as to the merits of the crossbred fowl, at any rate where egg-laying is concerned. In the absence of properly controlled experiments, it is impossible to resolve these conflicting ideas, for they can be solved only with a full knowledge of the circumstances. For reasons that have already been explained in this report, one would expect to find more heterosis in crossbred stock than when different strains of one and the same pure breed are mated together ; but one would not

be entitled to expect much in this direction, possibly, unless the parent stocks were somewhat inbred. In America, it is the practice to describe any stock below a coefficient of some 50 per cent of inbreeding as "non-inbred"; yet the majority of pure breeds are maintained as closed flocks and have been so for many years; and, if we make allowance for the expansion that has taken place during comparatively recent years, it is quite possible that many of these stocks are in fact inbred to an appreciable degree, sufficient to lead to heterosis when one breed is mated with another. We therefore asked Professor Jaap whether he could separate his results for crossbreds into those derived from closed flocks and those from open-bred flocks. Unfortunately, his answer was that all came from closed flocks, and the matter had to be dropped there. Nordskog (Iowa) has conducted similar investigations between pure strains and crossbreds, and found the crossbreds gave on average some 6 per cent better hatchability, 7 to 13 per cent better growth rate to 8 weeks of age (which fell to about 5 per cent in the adult bird), 30 per cent better viability in the brooder and nearly 20 per cent better viability on range, with about 6 per cent advantage in the laying house. Crossbreds averaged 12 per cent better than purebreds in egg production. He found also that, in the case of Leghorn x heavy breed matings, Leghorn males gave higher mortality than the reciprocal cross, suggesting that sex-linked factors are in operation. The general consensus of opinion, therefore, would appear to be that crossbreds are superior to purebreds, at any rate under American conditions.

127. The two most prominent "new" methods of breeding for heterosis are (i) Recurrent Selection to an Inbred Tester Line, (ii) Reciprocal Recurrent Selection. The former was first proposed by Hull in 1945, the latter by Comstock in 1949. Both depend primarily on repeated progeny testing. In the first, the inbred line is used as a standard, and the outbred stock is tested reciprocally against males and females of this line, only the best families and sires thus disclosed being retained, while the remaining stock is used for commercial chick production. The selected males and females are then mated together and the resulting progeny is again tested as before to the tester line and the best families and sires again selected for reproducing the breed. The process is repeated in two-year cycles until the outbred stock combines uniformly with the tester line. A minimum of at least 30 single sire breeding pens is advisable. In the second system, no inbred material is required and two outbred stocks are simply progeny tested in reciprocal matings against each other, the best families and sires being selected as before and employed to reproduce the strain, and the process is then repeated indefinitely. At least 50 sires need to be tested each two years. In each case, therefore, a considerable number of breeding pens is required, too many for the average European breeder though well within the scope of many breeders in the United States. Considerable claims have been made by the prime proponents and by research men like Bell (Purdue). Time alone will show the merits of these new ideas. Thus far,

there is no reliable evidence on which to express an opinion, although both systems do appear to aim at securing heterosis by attacking the problem of either over-dominance or interacting genes within large gene complexes. Progress in the field of poultry is bound to be slow at first until some indications of real merit are forthcoming ; but the whole problem is so important and acute in the United States that it is now being tackled along "pilot" lines through observations on the breeding behaviour of the fruit fly *Drosophila* and of a flour beetle. An experimental laboratory has been established at Purdue (Indiana) for this precise purpose, as a regional project and with the help of funds from the Rockefeller Foundation. The ease of culturing these insects, combined with their short reproductive cycles, makes them ideal for such pilot work, for about 25 generations can be produced within a year. Most of the work to date has been confined to egg production and egg size, and to the recognition of mutant and recessive forms obtained in the course of the various breeding experiments under way. More recently, however, attention has been started on the problems of evaluating the various systems of breeding for heterosis and of assessing the merits of straightforward progeny testing within a closed flock. Work with inbred lines is therefore included in the programme. Results to date show that inbreeding degeneration can be conditioned not only by the degree of inbreeding but also by the selection pressure that one can exert, thus confirming results with poultry ; also that, in the search for the best means of predicting the performance of inbred lines when they are crossed to form two-way strains, the best inbred lines give on the whole the best results as two-way crosses. Little heterosis, however, has appeared in relation to egg size ; and it may be argued that heterosis is therefore likely to occur only where heritability is low. As regards the comparative gains to be expected under different systems of breeding, the following figures published by Bell (Purdue) are enlightening :

	DROSOPHILA MELANOGASTER	
	EGG SIZE	EGG NUMBERS
Closed flock	38.1	86
Reciprocal selection	37.6	92
Recurrent to tester	38.2	96
Inbred cross I.....	37.7	99
Inbred cross II.....	37.5	96

128. Bell's conclusions to date, which it should be remembered are based on only a limited amount of work and do not necessarily apply to poultry (though it is confidently expected that they will do so on the whole), are that :

1. The conventional method of closed flock breeding with continuous selection based on progeny testing is superior to other methods for improving characters that are governed mainly by additive genes ;

2. Reciprocal and recurrent-to-tester selection are slightly superior to conventional closed flock selection for obtaining improved performance in highly heterotic characters ;
3. Single crosses of inbred lines derived from the same foundation stock can perform at a higher level than do the crossbred populations derived from either of the recurrent selection methods.

129. The precise value of these latest systems of breeding has not yet been established, though several breeders claim that they are testing them out. In these circumstances, we had to content ourselves with enquiring into the relative production of purebreds, crossbreds and incrossbreds. The value of crossbreds has been discussed above, but more may now be said about the other two.

130. As regards pure-bred fowls, average egg production varies between wide limits, especially when recorded as the hen-housed average. This can be readily understood when one takes mortality into consideration ; for this reduces averages recorded on a hen-day or hen-month basis, while in any flock where mortality is at all high production may be expected to suffer in any system of recording because sick birds do not lay as well as healthy ones. Facts such as these should be remembered when comparing production in the United States with that in Europe, where disease is not so severe.

131. Knox (Beltsville), working with various breeds over a considerable period, obtained the following results :

Yearly egg production - 1946-1954

	HIGHEST	LOWEST	AVERAGE
Rhode Islands Reds, open	236	198	217
- inbred	195	141	163
White Leghorn, closed	234	184	212
- inbred	209	161	185
Inb. RIR x Inb. W.L.	242	228	233
Inb. W.L. x Inb. RIR	273	233	258

132. He considers that incrossbreds are worth from two to four dozen eggs a year (less say 25 per cent for hen-housed averages) more than purebreds and adds that, as he developed his own stocks from very mediocre birds in the first place, better early selection might well lead to incrossbred averages around 280 eggs a year. He doubts whether any but the best purebreds would average as many under the same environmental conditions.

133. Reference to the record of performance (R.O.P.) Annual Summary for 1952-53, published by the United States Depart-

ment of Agriculture, shows that the average annual production of all entries was 189 ; the best averages were put up by T.I.R.'s (202) and the worst by Buff Orpingtons (101). Among White Leghorns, which are far the most important laying breed in the United States, more than 10 per cent of the candidates scored over 250 eggs (say 70 per cent production). Figures such as these indicate that, given low mortality, high averages can be secured in the United States, at any rate in pedigree stock.

134. As regards incrossbreds ("hybrids"), Jaap (Ohio) found a 7 per cent advantage in their favour over commercial pure-breeds. One of the principal producers of these "hybrids" publishes annually a complete summary of his "divided flock" tests, which are conducted practically all over the United States, though, for various reasons, most of the competitors are in or near Iowa State. In a list of some 600 such tests in 1953-54, a few cases occurred where the competing breed or cross defeated the "hybrid" ; but a summary of the results gave the following overall figures :

	EGGS PER 100 BIRDS HOUSED	PERCENTAGE BIRDS LEFT IN FLOCK
Hybrids	19,220	74.4
All others	15,410	66.6

"Hybrid" advantages :

Extra eggs : 38 per bird
More birds left : 7.8 per cent

135. In view of the general agreement between these above figures and those of Knox and Jaap, we believe them to be reasonably reliable.

136. It may be said that the main purpose of our visit was to see for ourselves the practical possibilities of developing heterosis in one way or another ; and, while we were in the Corn Belt itself, we certainly heard of little else. On arrival at Cornell University (Ithaca, New York State), we found an entirely different attitude towards the whole subject of poultry breeding. The natural surroundings of this fine University, with its hills and views and winding roads, are so different from the fertile but otherwise uninteresting plain of the Corn Belt that a spirit of independence, if not of actual rebellion, may perhaps be understood, and we certainly found it in the poultry team there (of whom, unfortunately, Professor Hutt was away at the time). The Cornell attitude is briefly as follows, that poultry can be improved as much by large-scale progeny testing and family selection within existing purebreeds as it can by any laborious and expensive system involving a search for heterosis, whether or not the latter involves inbreeding. The Cornell system,

involving the double and even treble shift testing of cockerels, first advocated by Hutt, was explained to us in full detail, and the results of some years' work were given us. These suggest that, starting with comparatively poor stock, a hen-housed average of about 200 eggs a year has been attained in some twenty years' work. The Cornell system of breeding has made several valuable contributions to poultry science. It has established beyond doubt the effectiveness and economy in time of double and treble-shift matings. Progeny testing comes into practically any sound scheme of breeding, and the results are often bitterly disappointing since proven sires are far more rare than we would wish, and in the case of poultry they tend to die almost as soon as they are discovered. In these circumstances, it becomes imperative - in the absence of any better method - to test as many potential sires as possible.

137. There must, or should always, be this fundamental difference between a good breeding stock and a good commercial stock, that the breeder cannot really afford to sell the former at any price. It would be selling the goose that lays the golden eggs, for rival hands might pirate the stock in a very short time and undersell the primary breeder. For this commercial reason, breeders in the United States with big reputations to protect are very careful what they sell in the way of pedigree stock; they sell the males freely, to hatcheries and elsewhere, but they seldom sell pullet chicks; and, to the general public, they sell only commercial stock (unpedigreed) that is now coming increasingly from strain crosses in which the parentage is carefully concealed. In genetical language, the breeder realises that he wants his breeding stock to be as uniform (homozygous) as possible, but that, for scientific reasons and for his own self-protection, commercial stock should be as heterozygous as possible.

POULTRY MEAT PRODUCTION

138. Time did not permit us to make any serious study of the broiler and turkey industries in the United States. Statistics of production and consumption, already given in this report, show the importance of these industries but hardly indicate that there is at present a fairly serious recession in all forms of poultry meat, due to overproduction. In a country as large as the United States, it is estimated that it takes a level of only 2 per cent or 3 per cent overproduction to upset the market. The decline in broiler prices is attributed to the increased sales of "hybrid" chicks. This argument is, however, difficult to appreciate. No one is forced to buy day-old cockerels, hybrid or otherwise. The decline in demand for turkeys may possibly be due to sheer sympathy with broilers.

139. On the breeding side, which is closely linked with that of nutrition and general management, the object of the producer is

to turn out a 3/9/9 birds with white or predominantly white plumage and a good body conformation. It must have yellow shanks and skin. These figures mean that the bird should weigh 3 lb. at 9 weeks of age and should not have eaten more than 9 lb. of food. This is the ideal, but few producers are at present achieving it - though many are not far from the mark. To secure the white plumage, which removes the objectionable feature of black stubs, considerable interest has grown up recently in the creation of new dominant white breeds, since White Leghorn crosses are not good enough for the trade. A number of these new dominant whites are now available or in course of production.

140. One unexpected difficulty with broilers in the United States is that a disconcertingly large proportion of them have streaks of black in the flesh, and possibly on the bones, which makes the carcass very objectionable. It is not known whether this arises from purely genetic reasons or is due to nutritional causes. It was pointed out that the same characteristic, but in even worse degree, is widespread in parts of tropical Asia; and that its occurrence in the United States may possibly be due to importations, direct or indirect, from that region.

141. In regard to turkeys, the most interesting point we learned was that the Beltsville Small White, from which so much was once expected, has entered into a decline in popularity. This breed was "manufactured" by geneticists some years ago with the specific object of meeting the requirements of the housewife, whose wishes were previously obtained by a large-scale investigation. One might even describe the breed as "tailor-made", so closely did it fit in with these standards. Of recent years, however, careless breeders have been mating the Beltsville with the Large White Turkey, with the result that, especially in the second generation, crosses have lost the uniformity which the trade requires. The Beltsville has been blamed instead of the breeder, and it has suffered accordingly. There are indications that much the same sort of thing is happening, though on a far smaller scale, in parts of Europe, i.e. in England.

NATIONAL STOCK IMPROVEMENT PLAN

142. As in some countries of Europe, the problems of poultry improvement through breeding and disease control are matters of national and therefore government interest. The requirements of the public, and of such farmers as do not do their own breeding but prefer to buy in day-olds and rear them for egg or broiler production, need to be protected. It is therefore desirable in many ways to have all reputable breeders associated together and that they should enjoy some sort of national recognition so long as they comply with certain basic requirements. The same line of argument applies to hatcheries. In a

countrylike the United States, it is undesirable to think in terms of compulsory registration, but it is desirable that as many breeders and hatcheries as possible should be attracted beneath an official "umbrella" by means of some voluntary plan, preferably one that aims at a reasonably high standard of performance in egg or meat production, viability, and especially freedom from such highly infectious diseases as Bacillary White Diarrhoea (Pullorum). The standard must not be too rigid not too high, as the scheme should be a national one and anybody who thinks the standards too low is not debarred in any way from producing stock of greater merit; and, perhaps above all else, the breeder must have considerable, if not complete, freedom within the scheme to follow his own system of breeding; for breeders in the United States, as in many other countries, are individualists.

143. That there must be regulations within such a scheme is obvious; and one cannot have one separate plan for each breeder - there must be one plan for all. While, therefore, there are very considerable advantages in such a scheme, it is a most difficult matter to plan for everybody who might participate.

144. In its earlier days, the National Poultry Improvement Plan of the United States undoubtedly achieved much by giving publicity to all who needed it. This resulted in the more or less rapid elimination of the less competent breeders and hatcheries, whose trade went into the hands of those who were able to comply with the regulations and establish reputations for themselves. And, above all, some improvement (though not as much as one would wish) was obtained in the control of Pullorum Disease. The regulations regarding this disease were not strict enough, however, and they have been tightened up a good deal during the past two or three years.

145. In its present form, the N.P.I.P. provides for four grades of breeding for egg production; also for hatcheries, and for the breeding of broilers and turkeys. Space permits of a discussion only of the egg-production section. The four grades therein are:

1. U.S. Record of Performance (R.O.P.)

Stock must be trapped for at least five days a week for at least 13 weeks, 8 or more full sisters per family, 70 per cent production or over; OR, trapped for not less than five days a month over a period of at least 100 days, 6 or more full sisters per family, 65 per cent production or over.

2. U.S. Record of Performance Tested Parent Stock

The progeny of the stock under test are evaluated at a central or on-the-farm random test and must produce either at least 60 per cent production on a hen-housed

basis OR be ranked among the top third of all entries as regards rate of lay.

3. U.S. Certified for Eggs

Either the sires alone may be from R.O.P. stock and pedigreed to it OR both sires and dams are from R.O.P. performance-tested stock.

4. U.S. Approved

Both males and females offered for breeding must first be approved by authorised official agents on the basis of inspection and handling tests.

In addition, all candidates must be classified as either Pullorum-Typhoid Clean (i.e. no reactors on two consecutive official blood tests) OR Pullorum-Typhoid Passed (i.e. no reactors on the last official blood test). In other words, candidates in the latter category have had reactors, but have been repeatedly tested until they appear to be free.

146. There are many more regulations, however, and the whole document requires very careful study if it is to be intelligible to the layman; but every regulation, though issued with the authority of the Federal Government, is in fact the result of recommendations put forward by a central committee which meets at regular intervals and seriously considers any proposals that have been submitted, from whatever source and through any channel.

147. It is of interest to note that, from the 48 States in the United States, just over 4,000 hatcheries (including breeder-hatcheries) participated in 1952, representing some 34 million birds. Our main interest, however, centred in R.O.P. entries. Here, the position in the national sense is rather disquieting. The number of candidates has fallen steadily from around 470 breeders in 1945 to 146 in 1953-54, and the number of birds tested has fallen from nearly a quarter of a million to a mere eighth. Only seven of these R.O.P. breeders elected to compete in central random sample tests. In spite of all the concessions and improvements that have been made in the plan as a whole, mainly to grant the breeder greater freedom for himself, this reduction appears likely to continue, and the future of the plan from the pedigree breeding point of view does not appear to be at all bright. So far as lower grades and commercial hatcheries are concerned, there is no cause for alarm. Hatcheries have decreased in numbers, but the total volume of production in the form of day-old chicks has in fact risen over the past ten years. But the pedigree breeder is gradually withdrawing his support. Many such breeders claim that the plan has in fact contributed nothing to the improvement of poultry breeding per se, that they need nothing in the way of free advertisement as their reputations have already been made and confirmed, and that they do not wish to be regimented, even by the present rules.

148. Very detailed reports on candidates' performance are published annually by the Department of Agriculture (a Federal body operating from Washington, D.C.), for the benefit of potential customers. Entries are listed in alphabetical order by breeds and indicate the total number of birds entered, number withdrawn, egg production and size, mortality, body weight and pullorum category, and even the number of years the breeder has been in the scheme. Armed with all this information, the customer is left to his own judgment and, apart from possible local prejudices such as we have mentioned in an earlier section of this report, it is clear that poultry breeding - at any rate pedigree breeding - is a highly competitive business.

149. For on-the-farm performance tests, where the breeder elects to be judged by performance under local conditions but not entirely at random so far as environment is concerned, authorised inspectors satisfy themselves that good but not impracticable commercial conditions prevail and that records are adequate and reliable. A random sample of eggs, sufficient to ensure at least 125 chicks, is drawn by the inspector and the pullets wingbanded for identification purposes. At least six unannounced visits are made each year and, during the laying season, all eggs then laid are collected by the inspector, weighed and compared with the preceding records to see that these are reliable. Requirements in respect of egg production have been stated above.

CENTRAL RANDOM SAMPLE LAYING TESTS

150. Whether conducted on the farm or at some central location, random sample tests have definitely caught the imagination of the farmer and of the government in the United States. They are not only on the increase but are likely to become the main standard of judging the ability of a breeder. The underlying idea is that a breeder should be judged by what he sells to his customers and not by what he advertises or displays in a conventional laying test where he submits a selected sample of birds at the last moment. Naturally, one man may sell mainly breeding stock while another sells only commercial stock, and it is not fair to compare the two; but the breeder is at liberty to label what he enters in a random test and he is then judged against other competitors in the same category. These new tests began in New York State and in California some five or six years ago; similar tests have since been opened in Florida, Texas, Missouri, Wisconsin, Utah and Louisiana. While the total number of entries in 1953 was only 82, the number in 1955 was 222. Similar stations have been opened for testing meat-production in turkeys.

151. In general, conditions are as follows. Tests are conducted at central but "neutral" locations under the supervision of an official State Agency. The sample to be tested consists

of an adequate random collection of eggs selected by a R.O.P. inspector from all pullets or hens mated to produce the grade of chick designated by the breeder. The first 50 pullet chicks to hatch are started for each entry in randomised brooder accommodation and are then reared under randomised conditions. In the Central New York test (there are now two test stations in New York State), the chicks are also deliberately exposed to infection from avian lymphomatosis. At point-of-lay, the pullets are housed in separate pens (fully intensive) and egg production and mortality by pens are recorded to 500 days from hatching. At the end of each test, the records are summarised and submitted to the Department of Agriculture H.Q., which then publishes the results in detail as with ordinary R.O.P. candidates.

152. The results of such tests show what a breeder can accomplish in fair competition with others, and not just on his own farm. In a general way, much depends on mortality - especially from avian lymphomatosis - rather than on the merit of survivors, and there is great variation in this respect, even among breeders who have long been regarded as in the top rank. During our tour, we had the opportunity of visiting two such farms in one day. At one, management appeared to be almost ideal; the premises were clean and well cared for, and the stock enjoyed a very high local reputation for egg production and viability. The second farm, by comparison, was dirty; dust and fluff abounded everywhere and dirty water ran about here and there. First impressions were indeed unfavourable. Yet, in one and the same random sample laying test, the second breeder was in first place and the former was placed last at the time. He had already lost 18 out of the original 50 birds, whereas the leader had lost only three. It would appear that the first farm was, and had always been, so clean that the stock obtained no challenge and therefore had developed no resistance to disease such as existed in the neighbourhood of the test location. As a matter of fact, a good deal of the total mortality in this group was from non-specific causes, which lends an air of mystery to the matter; but, in relation to the main disease that is exposed by these tests, lymphomatosis, such tests are valuable in disclosing what the breeder may possibly not already know.

153. Random sample tests on a neutral ground can give a breeder a tremendous kick which may prove to be very unpleasant if not fatal. Serious failure may drive a man right out of business if it is repeated for two or more years in succession; and it is as well that breeders who cannot put their house in order should leave the business. Most breeders, however, study their results and reports carefully and even get the advice of their State College or of the test officials as to what improvements appear to be desirable in their stock and how they can best set about achieving progress. These are the really good breeders; they may not be the best breeders of today, but they are likely to be the best breeders of tomorrow, and they are given every encouragement apart from direct financial help.

Determined breeders of this sort enter the tests each year, however discouraging their first attempt may have been, for here is the yardstick by which they can really measure performance and progress.

154. We were interested in the methods adopted to evaluate the results of such tests. King (Cornell) has published details of the mathematical technique required for evaluating the test as a whole, particularly for determining the value of repeatability from which it can be seen whether the test as a whole compares with previous years. A high repeatability assures the management that everything has been fair and that no sudden changes in environment have been allowed to creep in which might have affected one man more than another. So far as the individual breeder is concerned, however, what matters is his annual ranking and the repeatability of this ranking over the years. Precise figures of egg production and even of mortality are bound to vary from one year to another, but rank from year to year means everything. Minor fluctuations may be disregarded, but a progressive decline in one character or another leads at once to serious thinking. Where any such change is recorded, he has the knowledge and the ability to change his selection pressure before any real harm is done, and to find out whether any new breeding technique he may have employed has been to his advantage or not. With the very full details published by the Federal Government, prospective purchasers of breeding or commercial stock can scan the reports and make their own choice, with far more confidence than they can from the records of a conventional test.

155. It should not be taken for granted that the methods of random sampling adopted in the United States should be slavishly copied elsewhere. Over there, breeders maintain large flocks which are almost invariably closed to outside blood. The cost of entering a test, though large by European standards, is not excessive in terms of American standards, and the cost of sacrificing one or two whole families is not prohibitive, especially when assessed against the value of the good that should result. In Europe, however, and especially in England, breeders of pedigree stock operate on a much smaller scale, and few flocks are maintained without periodical and sometimes frequent importations of outside blood. In such circumstances, a more flexible scheme than that in the United States appears to be desirable, e.g. one in which phenotype is first evaluated from a random sample of a breeder's pedigree mating stock, followed by a test of breeding ability involving a test of the breeder's selection of males suitable for mating with the hens from that random sample.

156. Very little information was available to us as regards the performance of "hybrid" chicks in these tests, though at Cornell we were told that entries that had been received in one New York Test from such material had proved disappointing. But, as we have already indicated, Cornell has no love for these

"hybrids", though we would not challenge the actual statement they made to us. Breeders of "hybrid" chicks are entering other tests, we believe ; and, if mortality proves to be their main disadvantage (as it may well be under random conditions), they can employ their vast resources in improving this character. Unfortunately, so far as avian lymphomatosis is concerned, the matter is not as simple as it might at first sight seem. On the other hand, "hybrids" cannot expect to gain the confidence of farmers over the whole country until they have shown themselves capable of living and winning at random sample tests in various locations.

GENETICS IN RELATION TO POULTRY DISEASE

157. In all countries of the world where commercial poultry production is an important part of agriculture, the problem of disease is one of major interest. In the long run, farmers are concerned not with the performance of birds which survive the conditions of their farms but with profitable overall returns. This profitability is obviously dependent on whether the stock has the ability to live ; if it has not, it is better that it should die early rather than during the growing or laying period.

158. Diseases generally are of two kinds, specific and non-specific. In relation to the former, it is generally considered (in America as elsewhere) that the problem is primarily one for the veterinarian who should advise on optimum conditions of management and apply himself to research into the discovery and use of appropriate drugs for prevention or cure. In the case of Pullorum disease, for example, it has long been known that some strains of fowl are more susceptible than others for genetic reasons, but the best approach to control lies at present in blood-testing the adult stock and rigorously destroying all reactors. With coccidiosis, again, there is definitely a genetic background to the disease, but control is best left to sound management (clean, dry conditions) and if necessary the use of sulpha and other drugs. Many losses in adult poultry arise, however, from a breakdown in the reproductive system for which no precise infective organism is responsible ; drugs are therefore useless and the only hope of reducing the incidence of this serious trouble appears to lie in the hands of the breeder.

159. The disease known until recently either as lymphomatosis or leukosis has similarly not responded to drugs, though it is now established that it results from virus infection. Opinion has been strongly divided as to whether it should be tackled by the breeder, through the medium of selection for resistance, or by the farmer, through strict attention to isolation of young stock. This particular disease (if we may now use the singular form of the word) is of very great importance in the United States, as in most parts of Europe. In America, losses from this "one" cause alone amount to some 53 million

chickens a year, valued at at least \$73 million ; and these tremendous figures do not take into account the impairment of growth of young stock and the reduction in egg production of laying stock caused by an onset of the disease and the inability of the farmer to keep his poultry houses full to capacity. It is, in fact, about the most serious challenge to poultry productivity that there has ever been.

160. In the United States, the whole problem of poultry disease was considered of such importance that, in 1937, a Regional Poultry Research Station was set up at East Lansing (Michigan) with the sole purpose of investigating this one subject. Eggs were bought in 1939 from a number of sources, and in almost no time at all it became obvious that all the resources of the Station would be required to study the one subject of lymphomatosis alone. From the outset, it was decided to approach the problem both from the pathological and from the genetical aspect. While a number of more general details have been under investigation, therefore, a major line of work has been to develop, by selective breeding and inbreeding, susceptible and resistant strains. In practice, it has been established that there is little if any hope of thus securing complete resistance or susceptibility - the words are therefore used in a relative sense in this report. No particular difficulty has been encountered in establishing these different lines ; and crosses between them have given such variable results that it is considered (a) that the genetics of resistance must be extremely complex and (b) that crosses between different stocks tend to increase susceptibility rather than to lower it.

161. One of the most interesting results of the work to date, however, has been the discovery at East Lansing that the visceral form of the disease (as suspected for some time) is quite a different entity from that of the neural form. Not only are the symptoms different, but the ages at which symptoms manifest themselves and take their toll are quite different. Moreover, it has been found possible at East Lansing to isolate the virus of the visceral form (their main type of the disease), whereas they have not succeeded in isolating that of the neural form. Studies since about 1940 have led to the belief that these two forms should be referred to as belonging to the avian lymphomatosis group or complex, together with the ocular form, which is not important, while osteopetrosis, the leukaemias and fibrosarcomas should be regarded as outside this group altogether. Work at East Lansing has shown that visceral lymphomatosis is communicated mainly through the eggs of infected (and possibly carrier) fowls and that it is extremely infectious in the incubator and during the first day or two in the brooder - mainly through the respiratory passages and any other mucous membranes to which the virus can gain access. Communal supplies of food and drinking water therefore presumably play a great part in spreading this particular disease. This discovery is in contrast to the claims of Hutt (Cornell),

who states that egg transmission, though possible, is not of any practical importance and that, as with neural lymphomatosis, infection is mainly airborne and therefore dependent on the proximity of young chicks to adult carrier stock. The East Lansing argument today is that Hutt and they are talking about two entirely different things in that, while they are troubled mainly with visceral, he is concerned mainly with neural lymphomatosis. At East Lansing, moreover, progress has been made recently with the inoculation of adult stock with appropriate inocula, as a result of which (it is claimed) antibodies are produced which are transmitted to the chick and this in turn develops a considerable resistance. Several separate strains of inoculum are at present under test, but no large fieldscale work has so far been initiated and nothing is therefore as yet available which the general farmer or poultry breeder can employ.

162. One leaves East Lansing with the conviction that visceral and neural lymphomatosis are indeed two separate diseases and that the former must at last be recognised as egg-transmitted. On arrival at Cornell, however, one is at once thrown back into one's earlier uncertainties. Hutt and Cole do not deny the fact that visceral and neural are different types, arising from different viruses; but they still maintain that, by and large, the former is not transmitted through the egg. The fact that susceptible Cornell strains when raised in complete isolation from the time of hatching failed to develop either form of the disease may be ignored, since the chicks were from stock in which only the neural form is of any real consequence. What does appear to be significant, and most curious, is the fact that, out of 381 chicks hatched from eggs supplied in 1954 from the East Lansing susceptible strain 15 only 1 per cent died from lymphomatosis of any sort at Cornell. There is evidently much still to be learnt on this subject.

163. Meanwhile, there can be no doubt that, under conditions in the United States and possibly in Europe, the breeder has his part to play in gaining a measure of control over at least the neural form of the disease and possibly the visceral as well, though the farmer himself must co-operate by maintaining his chicks in isolation for a few weeks as far as possible. Hutt and Cole emphasise the importance of the breeder's duties in this work; but economic and other conditions in America are more favourable than in most parts of Europe. Coles (England) has shown, for example, that in his country it would require some five years and a minimum expenditure of £5,000 (i.e. 4,900,000 Fr.fr.) before a breeder could make any real headway in establishing a resistant strain; and the general opinion of research workers in the United States, as already stated, is that - even then - one cannot predict whether the crossbred offspring of two relatively resistant strains will themselves be resistant. Moreover, there is always the risk that, in such work, the virus of the disease may itself mutate and render all such work nugatory.

164. That selection based on repeated progeny-testing can develop resistance, however, is well shown by the following data from Cornell :

	ORIGINAL STOCK 1935	1953 STOCK		
		K RESISTANT	C RESISTANT	SUS- CEPTIBLE
Total mortality	66.8 %	13 %	16.9 %	56.9 %
Neoplasm	14.6	1.1	2.5	40.9
Survivors' production .	177	188	207	135
H/H average production	90	176	192	104
Egg weight	54.1 g.	60.5 g.	59.9 g.	59.3 g.
Body weight, adult . . .	1,690 g.	2,121 g.	2,113 g.	2, 118 g.

CONCLUSION

165. Our programme of work contains the following paragraph :

"Great stress has been laid by the Food and Agriculture Committee of the O.E.E.C. and by the Sub-committee on Agricultural Technology on the importance of improving productivity in animal production through the use of modern breeding methods. In Europe, pure line breeding is the method which has been used chiefly for improving livestock quality and performance. In the United States, however, the successful experience with crossing and inbreeding in the field of plant culture has led scientists to undertake extensive research and experiments on applying similar methods for improving domestic animals. The advanced techniques in breeding which have resulted, though widely followed in the United States, are little used in Europe."

166. This quotation explains why so much of our time and study was devoted to conditions within the Corn Belt, where the search for heterosis may be said to have begun and where so much effort is now given to investigating its mysteries. One should not, however, allow the quotation to mask the efforts that have been begun in Europe along the same or similar lines. In England, for example, the production of "hybrid" chicks (with or without the use of preliminary inbreeding) has been in operation for some five or six years and, although confined to only two large companies, already amounts to some 13.5 per cent of all pullet chicks sold, while estimates for 1956 increase this figure to at least 18 per cent. These figures actually exceed

those of the United States as a whole. In Belgium, too, a Dutch firm began in 1953 to distribute commercial "hybrids" produced there from two-way crosses imported direct from America. Production is between one and two million chicks per annum, and it is said that locally produced inbreds will be brought into operation very soon. Egg production is understood to be satisfactory, but mortality is too high. A big publicity campaign is in progress and sales in the Netherlands, which have so far been insignificant, may well be developed.

167. The volume of research work now under way in the United States is most impressive ; but it must be admitted that there is still a formidable array of opinion (headed by the Cornell workers) to the effect that more thorough selection within pure breeds can give commercial performances at least equal to those of modern stocks. The Cornell attitude, however, does not appear to take into account the curious genetic plateaux to which we have referred and which we have attempted to explain on the basis of complex gene-combinations whereby even straincrosses may exceed in performance both parental strains. There is also the problem of mortality, especially that of lymphomatosis where hybridization appears to complicate matters instead of simplifying them.

168. On the whole, we feel that a great future awaits the so-called "hybrid" fowl where egg production is concerned ; but not for poultry meat production where straightforward cross-breeding between selected stocks appears more likely to produce optimum overall profits. With egg production, too, we must stress the fact that the problem has become far larger than was ever anticipated and investigations are really only in their infancy. At the moment, an unbiased summary of all the evidence supports the obvious opinion of the United States Department of Agriculture that the phenomenon of heterosis provides a most valuable tool in the search for greater productivity ; but we are still ignorant as to the best means by which this should be harnessed. It may be that preliminary inbreeding may lead to higher average egg production than other systems ; but the cost of production must be taken into account and more modern systems in which preliminary inbreeding is dispensed with may eventually be found to provide greater productivity and profit. We must be patient and await the results of the voluminous and exciting work that is in progress in the United States and elsewhere. That such work is not confined to the United States is important, and we feel that even greater collaboration between research workers on both sides of the Atlantic is advisable and that teams of Americans should visit Europe whenever possible.

169. We have refrained, in this chapter, from discussing the subject of inter-State co-operation in any detail, though it was a part of our study while in the United States, for this can best be dealt with in a comprehensive manner elsewhere in this volume. In relation to poultry, however, we would place on record our

V

REPORT OF THE PIG SECTION

REVIEW OF PIG PRODUCTION IN THE UNITED STATES

Statistical information*

170. The United States occupies a very important position in respect to pig production as about 25 per cent of the world's number of pigs are produced in this country. Although pigs are raised in all the States, more than 70 per cent are produced in the North Central States and what is popularly termed the "Corn Belt". The State of Iowa alone produced about 20 per cent of the entire nation's output during the period 1946 to 1953. The reason for the very intensive pig production in that area is that corn (maize) is the main pig feed. Roughly 40 per cent of the corn crop is fed to pigs. Pigs contribute a large share to the total farm income. In Iowa the value of the pigs sold and consumed on the farm in 1952 represented about 35 per cent of the farmer's total income, and for the entire nation 11 per cent of the total gross agricultural income. Few of us in Europe realise, for instance, that the pig population in the State of Iowa alone in proportion to the acreage and the human population is greater than the density of the pig population in any other country in the world.

Total pig population and production of pork and lard in the United States, 1945-53

YEAR	TOTAL PIG POPULATION THOUSANDS (1st JANUARY)	PRODUCTION IN THOUSAND TONS		PROPOR- TIONS LARD/ PORK
		PORK	LARD	
1945	59,373	4,851.1	937.1	0.19
1950	58,852	4,859.8	1,193.4	0.25
1951	62,852	5,208.6	1,299.1	0.25
1952	63,582	5,237.6	1,309.1	0.25
1953	54,632	-	-	-

* Agricultural Statistics 1953, United States Department of Agriculture.

171. In 1945 the total pig population in the United States was roughly 60 million which corresponds quite well to the average for a number of years. The increase from 1950 to 1952 was followed by a decline in 1953. This is probably owing to the fact that prices dropped down from 20 to 17.80 dollars per cwt. from 1952 to 1953. The surplus of lard is a rather important problem. Unfortunately, there is no trend towards a decline in the amount of lard in proportion to pork.

Meat consumption in the United States

In pounds per capita

YEAR	BEEF	MEAL	LAMB AND MUTTON	PORK	TOTAL	PORK AS A PERCENTAGE OF TOTAL CONSUMPTION
1940	54.2 (24.6)	7.3 (3.3)	6.5 (3.0)	72.4 (32.8)	140.4 (63.7)	52
1945	58.6 (26.6)	11.7 (5.3)	7.2 (3.2)	65.7 (29.8)	143.2 (64.9)	46
1950	62.6 (28.3)	7.9 (3.6)	3.9 (1.8)	68.1 (30.9)	142.4 (64.6)	48
1951	55.2 (25.0)	6.6 (3.0)	3.4 (1.5)	70.6 (32.0)	135.8 (61.6)	52
1952	61.3 (27.8)	7.1 (3.2)	4.1 (2.0)	71.6 (32.5)	144.1 (65.4)	50

The figures in brackets represent consumption in kilos per capita.

The total consumption of meat per capita has been almost constant for a number of years. Pork is a favourite meat and amounts to about 50 per cent of the total consumption.

General management

172. Pig farming in the United States presents few real problems of skill in management. The system of running pigs out of doors all summer is certainly outdoor pig-keeping seen at its best. With clean ground for the pigs each year, disease is kept down to a minimum, the pigs thrive rapidly from the day they are born and very good weaning weights are commonplace.

173. Contrary to European custom, where castration takes place about six weeks after birth, there is an increasing tendency for pigs to be castrated early in life and in some instances this is done within an hour or two of birth. No trouble appears to be experienced from undescended testicles at this early age. There is also a tendency for the breeding season to commence earlier than in the past. Instead of March, February

farrowings are becoming increasingly popular, because individual attention can be given to the sows at this earlier time, and this does not conflict with the field cultivation in the spring.

Housing

174. The housing requirements of the pig are usually quite simple. The main consideration is a warm building for farrowing purposes in early spring and usually a barn is available. Shortly after birth the pigs are removed to outdoor wooden huts in the fields. Shade from the hot sun is provided by light wood structures covered with straw.

175. As on some European farms, labour problems are becoming increasingly acute. In fact on most farms, hired labour simply does not exist. In the circumstances, therefore, anything which can save labour is a vital necessity, and for this reason dry feeders are invariably used so that the minimum amount of time is devoted to looking after the pigs.

Feeding

176. This too is of the simplest nature. The basis of all American pig foods is maize. The use of balanced mixtures is becoming more widespread and trials are being conducted using the self-service principle where the pig has a free choice of corn and his protein and mineral supplement all in the same dry feeder.

177. We were impressed by the amount of research which is being done in pig nutrition. Experiments are being conducted in the feeding of antibiotics - the use of alfalfa meal in considerable quantities with a view to retarding the accumulation of fat, and countless other trials.

178. Great attention is being paid at present to the possibilities of early weaning methods. No fewer than 5,000 farms in Iowa State have already adopted the procedure of weaning at five weeks of age. Although the varying systems of early weaning are really only in the experimental stages there is no doubt that the principle has come to stay, and may expand rapidly as time progresses. Cropping programmes for pigs entail the provision of either alfalfa, Ladino clover or broad red clover pastures for grazing purposes.

Fencing

179. Now that the value of clean grazing is appreciated, the old system of large numbers of pigs grazing in permanent paddocks has fallen into disuse, and more and more choice pigs are being maintained in smaller numbers in individual pens. This involves temporary fencing, but pig fencing wire and metal

stakes have eliminated much of the labour problems previously associated with pig fencing, and usually this only entails one or two days' fencing work per annum.

Marketing

180. The marketing of pigs also presents few problems. The packer, whether he be in a large or small way, reigns supreme. Pigs are sold either on a commission basis or directly to the packer who buys the pigs on a live-weight basis. Some pigs are purchased on a dead-weight and graded carcass basis, but these are few compared with live-weight sales.

181. Unfortunately, the packers still hold conservative views on consumer requirements and there are only small bonus payments at present for quality carcasses. It would seem that many widely divergent views are held by packers on what constitutes the ideal carcass, and until some standardised carcass requirements are made known there is little prospect of much improvement in carcass quality because financial incentives to the farmers are lacking.

INTER-STATE CO-OPERATION

182. Because the successful results achieved in producing hybrid corn had led to the use of a similar system in swine-breeding on a comprehensive scale in many States, especially in the North Central States (Corn Belt), it soon appeared desirable to organise co-operation between the States. On the initiative of the Secretary of Agriculture, the Regional Swine Breeding Laboratory was established in 1937*. It is an institution co-operating between the United States Department of Agriculture and a number of States in the Corn Belt. The headquarters are situated in Ames, Iowa, and its director is Dr. W.A. Craft. The co-operating States are: Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska, Oklahoma, South Dakota and Wisconsin. Two other States, Michigan and Ohio, are co-operating informally.

183. The Regional Swine Breeding Laboratory organises projects between the United States Department of Agriculture and State Experimental Stations in the States mentioned above, so that each station can carry out the research which it intends to undertake on the broad lines of objectives agreed on at the outset between the Department of Agriculture and the State stations. The financial support given to the Regional Swine Breeding Laboratory is received mainly from the U.S.D.A. but each State contributes financially, as well as by providing staff, buildings, equipment and animals.

* W. Craft, A report from the Regional Swine Breeding Laboratory, 1954.

Objectives

184. The principal objectives of the Laboratory are to develop and test procedures of breeding and selection which may be used by pig producers ; to speed up the improvement of pigs in respect of performance, including carcass quality ; to study the usefulness of inbred lines for improving the breeding value of the pure breeds for use in pork production ; to enlarge knowledge concerning the genetic effects of inbreeding and inheritance of characters in pig breeding, and to evaluate and demonstrate the application of such knowledge.

185. In each project the points emphasised include productivity of sows, vitality of piglets, growth rate, economy of gain and quality of carcasses. The research undertaken comprises methods of selection, systems of breeding, heritability of characters and physiology of reproduction.

Methods of operation

186. Annual conferences are held between project leaders and the United States Department of Agriculture representatives. Operations are reviewed and discussed ; topics of special interest to the group are considered. Usually a speaker outside the group discusses a special topic. The Director of the Laboratory visits each project several times a year to review the progress of work and confer with the project leaders regarding changes proposed and to encourage the preparation of reports for publication. Lists of publications are made by each station separately but joint publications are issued where multiple experiments with the same theme are concerned. Furthermore, an annual report covering research projects underway is sent to the project leaders for administrative purposes in this and related fields of research. Each station publishes popular style reports as and when necessary.

187. Most of the effort has gone towards developing and improving lines within pure breeds, and line-crossing trials are made to find the best combinations for crossing purposes to get "hybrid vigour". Litters or samples of litters are tested for growth rate and economy of gain. During the last few years boar-testing has also been developed. The boars are fed individually from weaning to 5 months of age in order to ascertain growth rate and economy of gain. The thickness of back-fat is measured on the live boars by means of special instruments.

188. Approximately 130 inbred lines have been started ; about 50 lines are on hand now and nearly 1,500 litters are being produced each year. The following breeds have been included in the projects : Poland China, Chester White, Duroc, Hampshire, Landrace, Large White Berkshire and Tamworth.

BREEDING METHODS

American breeds of pigs

189. Although the difference between the lard type and the bacon type is not so distinct as formerly, it is big enough to justify such a classification. Most of the breeds in the United States belong to the lard type and have been developed in this country. They are more popular among breeders and outnumber by far the breeds of the bacon type because they are considered to be more economical as a convertor of corn into pork.

Lard-type breeds

190. Poland China

Black in colour with white spots. It is more rugged and ranged of type than most other lard type breeds but the breed leans towards the direction of smaller size and what is regarded as intermediate type. The fertility is below average but it yields rather good carcasses.

191. Spotted Poland China

Has been developed from the original Poland China, which was spotted, but later adapted to the standard of black with white spots. The desired colour is spotted black and white, 50 per cent each. It is more prolific, smooth and hardy at present than the Poland. The rapid increase in numbers during the past 25 years answers for its popularity.

192. Duroc Jersey

Exceeds any other breed in the United States in number. Its popularity has resulted from the natural combination of large size with feeding capacity and prolificity, just the qualities the farmers regard as most important. It is red in colour but also the most lardy of all American breeds. At present, however, breeders are selecting for the intermediate type.

193. Chester White

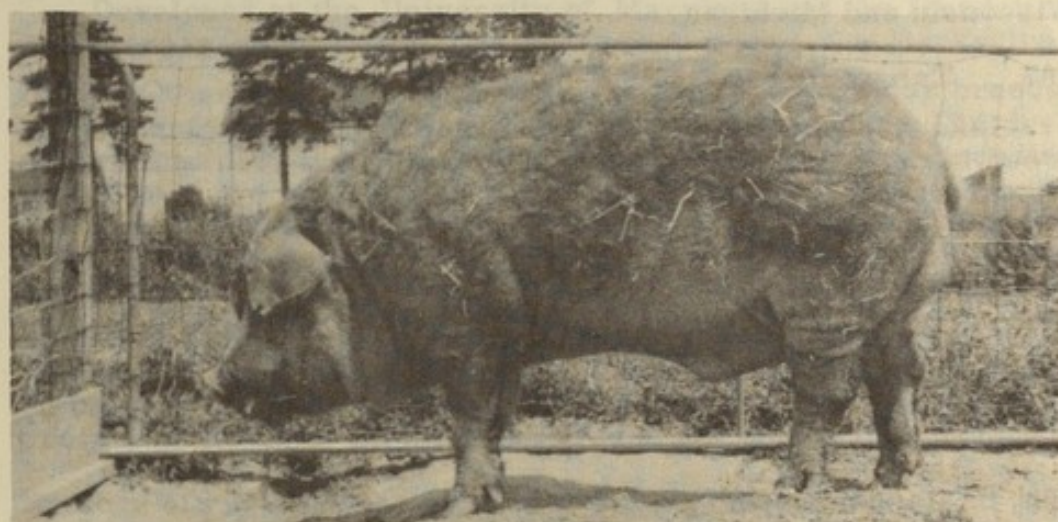
One of the most popular breeds in America, particularly in the Northern Corn Belt States. The sows produce and raise good-sized litters, the pigs are easy feeders and the barrows are popular in the market. It is next to the Duroc in fatness but the breed has an enviable record for winning grand championship honours at the barrow shows.

194. Hampshire

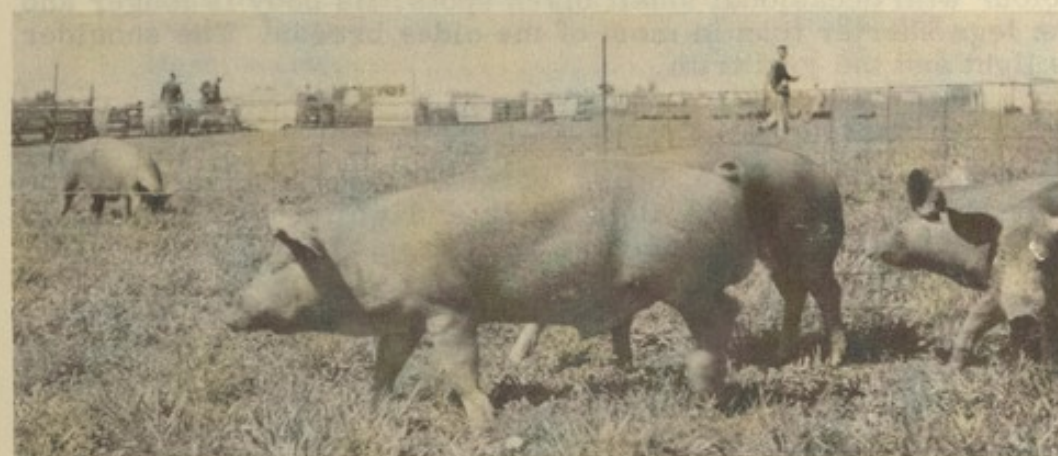
Same colour pattern as the English Wessex Saddlebacks and the Essex. It is a medium-sized breed noted for its fine hair, clean-boned jowl and refined head. It is lacking in length and fullness of ham but breeders are seeking to improve these characteristics.



Poland China inbreds in Minnesota.
Their inbreeding coefficient is 25 per cent



Duroc Jersey Boar.
Old type (Ohio)



New American breeds.
Minnesota No. 1

195. Berkshire

The only lard breed of English origin. It is black in colour with white snout and feet. It has short legs, good length of body and firmness. The carcass carries a high proportion of lean meat and is therefore favoured by many packers. It is considered as one of the breeds most suitable to meet the present market demand.

Bacon-type breeds

196. Yorkshire (Large White)

Imported from England, It is the most widely spread breed in the world and generally regarded as a standard of bacon type. Compared with the other American breeds the Yorkshire is rather long-legged, very good in length, produces extremely good carcasses and is well-known for its ability to raise large litters. Most Yorkshires are raised in Minnesota, Wisconsin and Michigan.

197. Tamworth

Like the Yorkshire, it has its origin in England. The breed is described as dark red in colour, very lean and rather slow to mature, with long legs and shallow body but poor hams. The sows are very prolific.

New American breeds

198. The new strains developed by the crossing of Danish Landrace or Yorkshire with the American breeds and later inbreeding are now recognised as new breeds and registered by the Inbred Livestock Registry Association.

199. Minnesota No. 1

The oldest of the new breeds. The foundation was the Danish Landrace and the Tamworth. It is predominantly red in colour with occasional small black spots. Its body is longer and the legs shorter than in most of the older breeds. The shoulder is light and the jowl trim.

200. Minnesota No. 2

Developed from a cross between the Canadian and the Poland China. In colour it is black and white. This breed is longer in the leg and larger in size than the No. 1.

201. These two breeds are both developed by L.M. Winters* and associates at the University of Minnesota. The best features of the breeds are that they produce strains suitable for crossing with the older American breeds.

* L.M. Winters, D.L. Dailey, P.S. Jordan, O.M. Kiser, R.E. Hodgson, J.N. Cummings and C.F. Sierk : Experiment with Inbreeding Swine, Agricultural Experimental Station, University of Minnesota, Bull. 400, 1948.

202. Hamprace

A solid black breed developed by Hutton and associates at Montana Experiment Station. The foundation was produced by a cross of black pure-bred Hampshire and Danish Landrace.

203. Beltsville No. 1

Developed by John H. Zeller* and associates at the Agricultural Research Centre, Beltsville. It is derived from a cross between the Danish Landrace and Poland China. This breed has a long body, good development of hindquarters and light forequarters.

204. Beltsville No. 2

Also developed by Zeller but four breeds are involved, namely, Yorkshire, Danish Landrace, Duroc, Hampshire.

205. Maryland No. 1

Developed at the University of Maryland and the foundation was a cross between the Danish Landrace and the Berkshire.

206. Other new strains of pigs, not yet recognised as breeds, are being developed at Beltsville and in Minnesota. The development of new breeds was provided for in the pig-breeding projects at the different stations. The purpose was a double one - to develop new breeds carrying less fat and more lean meat and breed types suitable for crossing with the older American breeds.

207. This goal has been achieved to some extent ; the best of the new breeds are longer and carry less fat than the older breeds. The breeds in which the Landrace is involved have proved particularly suitable for crossing with other breeds.

Number of registered pigs of the various breeds

Berkshire	21,437
Chester White	19,515
Improved Chester White	3,653
Duroc Jersey.....	90,209
Hampshire	68,114
Poland China	21,758
Spotted Poland China	27,670
Tamworth.....	8,809
Yorkshire	17,243
Am. Landrace	1,912
Minnesota I.....	1,044
Minnesota II	505
Beltsville I	153
Beltsville II	55
Hamprace	901
Maryland I	110

* J.H. Zeller : The Use of Danish Landrace in Swine Research Studies in United States of America. Report of the VIth International Congress of Animal Husbandry - Copenhagen 1952.

The figures show that the Duroc exceed any other breed in numbers registered, and that the new breeds comprise only a very small part of the total number.

Conventional breeding methods

208. The conventional breeding methods are purebreeding, inbreeding and crossbreeding. It is useful to reiterate in this chapter a short description of each of these methods.

Purebreeding

209. Purebreeding is the name applied when both parents are of the same breed without being closely related. Usually all animals within a breed are related more or less, but the limit between purebreeding and inbreeding is always arbitrary. When the parents are not related more closely than first cousins the breeding system is usually called purebreeding.

210. This breeding method is rather conservative. Progress could be expected if selection were applied and great skill were shown by many breeders in order to find breeding animals which would give the best results in matings.

Inbreeding

211. Inbreeding is the name given to the breeding methods when the parents are closely related to each other. How near they should be before the breeding method is called inbreeding is really quite arbitrary. In earlier times it was divided between the usual forms of inbreeding and the strongest form of inbreeding, which was called incest-breeding or breeding in-and-in. For this latter type of inbreeding it was usually required that the parents should be either full sibs or that they be sire x daughter or dam x son.

212. Latterly, this distinction has not been observed and there has been a tendency to use the word inbreeding only for the strongest form of inbreeding.

213. In earlier times it was not possible to give a quantitative description of inbreeding. Very often the relationship of the parents was taken as a measure of the inbreeding. Many systems were proposed, but now almost everyone uses the calculating methods devised by Sewal Wright and published about 1920. He was the first to draw a clear distinction between the state of being inbred and the quality of being related to another individual and to give a good quantitative measure of both by his inbreeding coefficient and coefficient of relationship.

214. Theoretical considerations and practical and scientific research had earlier led to the conclusion that inbreeding would

result in increased homozygosity when the inbreds were bred at random inter se. The formulas for the coefficients gave a measure of the quantitative increase in homozygosity.

215. Sewall Wright's calculation methods were based on the very important assumption that homozygotes and heterozygotes have the same chance opportunities to be selected as breeding animals. In some characters this assumption may be true, but in characters affected by inbreeding depression and heterosis, as in most cases of cross-fertilized animals, this assumption is to a certain degree not true.

216. The success or failure of inbreeding as a method is important because domestic animals depend completely on the actual reasons for heterosis and inbreeding depression. This question has been a topic of discussion for the last fifty years, and it is not yet settled. It is important to notice that the leading animal geneticists today do not agree with the theory of Jones, which has been the leading theory for many years. According to this hypothesis, the inbreeding depression was caused by segregating recessive deleterious genes and the heterosis was caused by dominant genes which were different in different breeds and which added their effect.

Crossbreeding

217. According to the geneticists, a cross is a mating of two individuals which differ in respect of one or more pairs of genes. As practically all cross-fertilized animals except one-egg twins have a different genotype, all matings are crosses. For practical purposes in the breeding of domestic animals a cross is a mating between two breeds. In the new breeding methods it has been necessary to alter the definition to include matings of inbreds. This will be explained later in the section concerning the new breeding methods.

218. As a breeding method crossbreeding was earlier divided into crossings between breeds in order to make new breeds, grading up and crossbreeding for the production of F₁ animals not to be used for breeding purposes. A short description will be given of these methods.

219. Crossing in order to make new breeds

This method was often used and in fact most of our breeds were produced in this way.

220. Grading

This was very often the usual way of introducing a new breed. Males of the new breed were mated to females of the old stock. For each new generation only males of the new breed were used. After a few generations the new breeds were considered to be pure enough to be registered. The number of

generations was usually rather arbitrary but, as a rule, five to six were customary.

221. Crossbreeding for producing hybrids (F1) was a widespread and common practice in order to take advantage of heterosis. Many types were in common use. The breeding animals were always of pure breeds and the offspring were as a rule of sound health and showed a very good growth rate.

Practical application of the breeding methods

Previous systems

222. In the history of animal breeding great changes have occurred in regard to breeding methods and the breeding methods for pigs have followed the general system in use for other animals. Methods have changed from crossbreeding to purebreeding and inbreeding and back to crossbreeding again.

223. It is the general opinion that the pig is more affected by inbreeding depressions than the larger domestic animals, a fact of which pig breeders are as a rule aware.

224. In the years after the rediscovery of the laws of Mendel, i.e. the years after 1900, the pig-breeding methods used in the United States were the same as those followed in some places in Europe, especially in England.

225. By and large it can be said that the breeding of pure breeds of pigs was in the hands of a few farmers who took a special interest in pig-breeding and had the knowledge and the skill needed for raising good show animals.

226. These pure-bred pigs were not numerous. Not more than about 3-5 per cent of all pigs were pure-bred. All the rest were crossbreds of different kinds according to the pig-breeders' fancy.

227. When travelling in the pig districts in the United States, we found that the commonest types of pigs seen from the roads and railways were crossbreds.

228. At the experimental stations and on the farms owned by the agricultural colleges pure-bred pigs were kept. The breeding methods as such were seldom investigated, this being thought unnecessary as they were founded on the leading theories in genetics.

229. It can be said that in this period a lot of good work was done in keeping the breeds pure and in improving some of the characters. Improvement was especially noticeable in growth rate. The quality of the carcass was not considered important, and the thickness of the backfat was greater than in most of the European swine breeds.

230. The most important swine breeds were of the lard type and they were usually sent to the slaughterhouse at a greater live weight than most European breeds of swine. The common live weight at slaughtering was around 300 lb. (136 kg.).

Application of new breeding methods

231. The application of new breeding methods, which was one of the most important reasons for the visit to the United States, had its origin in the success of hybrid corn.

232. Scientists and pig breeders of high theoretical standing started to investigate inbreeding and hy-breeding in order to find out if it could give the same good results in swine breeding as in cross-fertilised plants.

233. Work began on two lines according to the leading theories concerning the causes of inbreeding and heterosis. The two lines were inbreeding and crossing.

234. Various inbreeding experiments were begun to produce inbred lines of good quality and free from hereditary defects. Many inbred lines were started especially in Minnesota, Iowa and in Beltsville. These were used as pure-breds and incrosses.

235. In the course of time most of the inbred lines have disappeared. The inbreeding depression resulted in low fertility and low growth rate was rather strong and was often found to grow worse with an increasing inbreeding coefficient. For instance, in the Research Programme of the Regional Swine Breeding Laboratory 130 inbred lines within 7 breeds have been started. About half of them have been dropped because of poor performance. Litter size has usually shown some decline by the time inbreeding reached 25 to 30 per cent. The few inbred lines which were left were propagated by a slower rate of inbreeding. An increase of two or three per cent per generation was recommended.

236. These inbred lines had in the meantime given good results both in crosses within breeds and crosses between breeds. This point is brought out particularly in the crossing trials in the Minnesota projects. Results indicate that lines should be selected for "nicking" or combining ability in order to get the most from line crossing within a breed and between breeds.

237. Crosses of inbred lines of the same breed have usually shown advantages in growth rate in comparison with non-inbred stock of the same breed reported by the Regional Swine Breeding Laboratory. When three or more lines were represented in the crosses, the number of pigs raised per litter usually exceeded the number raised in litters from non-inbreds. Crosses of lines from different breeds generally have shown

considerably more hybrid vigour than that indicated in the line crosses within the same breed, in particular for the number of pigs per litter farrowed and weaned, the weight at weaning per litter, the weight at 180 days per pig and per litter. This strongly suggests that for the best results in crosses it is important to have as much genetic difference as possible between lines.

238. Inbreds crossed with non-inbreds (top crosses) produced gilts which gave rather good results. This was reported especially by the College of Agriculture in Wisconsin.

239. In the case of inbred animals used in purebreeding and crossing, the following rather rough classification can be used :

1. Inbred by inbred ;
2. Crossing of inbred lines within breeds ;
3. Crossing of inbred lines between breeds ;
4. Hybrid sows crossed with inbred boars ;
5. Hybrid boars crossed with inbred sows.

240. As the results of the crossings depend to some degree on the grade of inbreeding of the parent, it is very difficult to compare the breeding methods statistically, and the final result will only be representative of the material used. Differences in fertility and viability will cause such a wide variation that most of the known difference will be concealed in tests with the relatively small number of animals we can afford to use for experimental work.

241. The depression in fertility and viability has limited the use of inbred lines by themselves. The only way to use them has been by crossing inbred lines with each other.

242. The breeding method which has increased most in recent years is crossbreeding. Crossbreeding in order to develop new breeds, as already mentioned in the section on new American breeds, and grading up are still in use ; but the most rapid development has taken place in crossbreeding to produce pigs for the slaughterhouse. This is a rather complicated breeding system and means that the pig breeders have to keep different types of breeding animals and replenish them from time to time in order to produce the required type of pigs for slaughtering.

243. The crossings of this type can be grouped as follows :

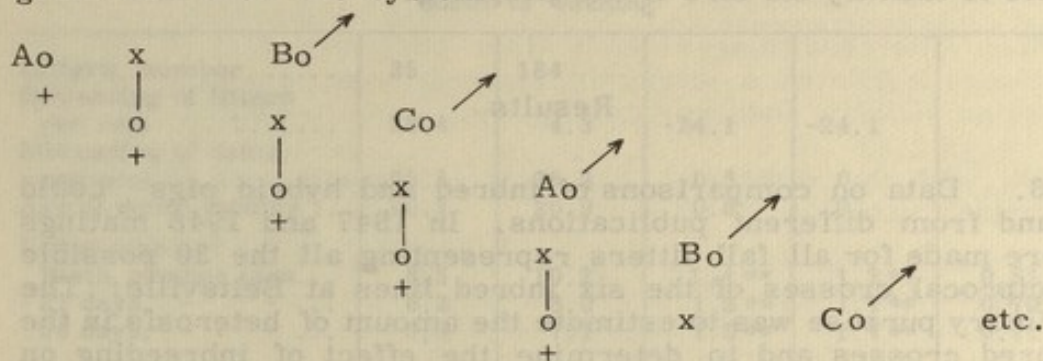
- A. No crossbreds used as breeding animals ;
- B. Crossbred sows used as breeding animals (criss-cross and rotational cross) ;
- C. Crossbred boars used as breeding animals ;
- D. Both parents are crossbreds.

244. The methods under B - D have increased most and may be called the new methods. Special mention may be made of the type under B, namely crossbred sows used as breeding animals.

245. It started first with a two-way cross. Pure-bred boars were mated to sows from the cross, alternating the breed of boar for each generation. This has given very satisfactory results so far as growth rate and fertility are concerned. The quality of carcass depends on the breeds used.

246. The system has rapidly developed from two into three or four breeds cross. The last types are often called rotational crosses.

247. If three breeds (A, B, C) are used, the following diagram will show the system :



248. When this system has been in use for some generations, it will give a constant percentage of each breed in the offspring. Starting with the last boar, it will give proportions of each breed in the following rate :

2 breeds	2 : 1
3 breeds	4 : 2 : 1
4 breeds	8 : 4 : 2 : 1 etc.

249. This method has shown good results. But the quality of carcass depends on the breeds used and it has to be tested for each special type of breed ; it looks promising, however. In-cross boars are used also in similar breeding plans.

250. The breeding methods using crossbred boars were rather new, but were already in full use on the farms. We were told that the variation - standard deviation - was rather lower than for purebreeding and inbreeding.

251. This was interesting ; but to get statistical evidence of this, many hundreds of animals should be used, as the standard error of the standard deviation is rather large.

Promiscuous breeding

252. In recent years, some experimental stations have attempted promiscuous breeding. This method was in use at the experimental stations in Minnesota. Ten boars were used for a herd of 60 sows.

253. This is in fact a type of selection where the most fertile boars will produce the offspring.

254. When all boars are of the same quality there is no danger in using this system, but when the quality differs and there is negative correlation between fertility and carcass quality, deterioration may follow.

255. It will be of great interest to all to see the results of this method, which had been used earlier in practical breeding, but had a low reputation among elite breeders, as it is impossible to identify the sire of the offspring.

Results

256. Data on comparisons of inbred and hybrid pigs could be found from different publications. In 1947 and 1948 matings were made for all fall litters representing all the 30 possible reciprocal crosses of the six inbred lines at Beltsville. The primary purpose was to estimate the amount of heterosis in the inbred crosses and to determine the effect of inbreeding on performance. The results are found in Circular No. 893, October 1951, United States Department of Agriculture, Washington, D.C.

257. In number of pigs per litter at birth the increase over inbred was 1.34 pigs per litter. The difference was highly significant and was described as the effect of heterosis.

258. In the material many adjustments and corrections had to be made as to the age of dams and grade of inbreeding of dams and differences between years. The results are given in the table below.

259. Crosses exceeded inbreds in number of pigs not only at birth but also at 21 days and 56 days and the difference was increasing. Both prenatal and postnatal viability in crosses were higher than in inbreds, since there is no reason to think that the two groups of dams differed in reproductive efficiency.

260. Crosses differed little from inbreds in pig weight at birth and at 21 days of age, but crosses were significantly heavier at 56 days of age.

261. In litter weight crosses were also superior to inbreds, partly because of the larger number of pigs in the line-cross litters and partly because crosses tended to have heavier individual pig weights.

262. Carcass data showed that crosses had a slightly higher dressing percentage, a slightly lower yield of lean cuts, and more fat than did inbreds.

Intra-year comparisons of crosses and inbreds from birth to weaning
and from weaning to a final weight of about 225 pounds (102 kilos)
(Circular No. 893, October 1951, United States Department of Agriculture)

OBSERVATION	INBREDS (I)	CROSSES (C)	DIFFERENCE (C-I)		DECLINE PER 10 PER CENT INBREEDING OF LITTER
			OBSERVED (2)	ADJUSTED (1) (2)	
Birth to weaning					
Litters, number	35	184			
Inbreeding of litters per cent	28.4	4.3	-24.1	-24.1	
Inbreeding of dams, per cent	25.5	25.2	-0.3	0	
Age of dams, months ..	20.1	20.9	0.8	0	
Litter size at :					
Birth, number pigs...	8.8	10.2	1.4 **	1.2 **	0.51
21 days, - - - ...	6.2	8.0	1.8 **	1.7 **	0.70
56 days, - - - ...	5.9	7.7	1.8 **	1.7 **	0.71
Pig weight at :					
Birth lb.	2.64	2.59	-0.05	-0.05	
kg.	(1.19)	(1.17)	(-0.02)	(-0.02)	
21 days lb.	10.1	10.4	0.3	0.3	0.12
kg.	(4.6)	(4.7)	(0.1)	(0.1)	
56 days lb.	26.7	29.3	2.6 **	2.7 **	1.1
kg.	(12.1)	(13.3)	(1.2)	(1.2)	
Litter weight at :					
Birth lb.	23.3	26.1	2.8 **	2.4 **	1.0
kg.	(10.5)	(11.8)	(1.3)	(1.1)	
21 days lb.	63.6	82.8	19.2 **	17.9 **	7.4
kg.	(28.8)	(37.5)	(8.7)	(8.1)	
56 days lb.	159.4	226.8	67.4 **	63.7 **	26.5
kg.	(72.3)	(102.9)	(30.6)	(28.9)	
Weaning to 225 pounds					
Pigs fed, number	48	237			
Inbreeding of pigs, per cent	30.2	3.9	-26.3	-26.3	
Pig weight at :					
56 days lb.	30.2	31.9	1.7	0	
kg.	(13.7)	(14.4)	(0.7)		
98 days lb.	76.6	83.6	7.0 **	6.6 **	2.5
kg.	(34.7)	(37.9)	(3.2)	(3.0)	
140 days lb.	148.5	158.5	10.0 **	9.3 **	3.5
kg.	(67.4)	(71.9)	(4.5)	(4.2)	
Total gain lb.	194.1	191.8	-2.3	0	
kg.	(88.0)	(87.0)	(-1.0)		
Daily gain lb.	1.58	1.65	0.07 *	0.06 *	0.024
kg.	(0.72)	(0.75)	(0.03)	(0.03)	

(1) Differences adjusted to a mean difference of zero in age and inbreeding of dams, except differences in daily gain adjusted to zero difference in initial weight and total gain.

(2) * $P < 0.05$ significant ; ** $P < 0.01$ highly significant.

263. Not all crosses had the same heterosis effect. The lower the relationship between inbred lines the higher, in general, was the heterosis effect. The differences found here are naturally affected by the degree of inbreeding, and if we would like to compare the breeding methods, they should be compared to special test lines of common pure breeding.

264. The performance of the crosses was adjusted to correspond to that of crosses between non-related inbred lines and the advantages in their favour were generally higher than was indicated by the actual results.

265. The results agree with other published data in that the crosses exhibited a proportionately greater advantage in litter size or viability than in rate of growth.

266. In the summary, the most important data were summarised and this is cited :

		Crosses exceeded inbreds by	
Pigs per litter	at birth	1.2 pigs	14 per cent
	at 21 days	1.7 "	27 " "
	at 56 days	1.7 "	29 " "
Litter weight	at birth	2.4 lb. (1.1 kg.)	10 " "
	at 21 days	17.9 lb. (8.1 kg.)	28 " "
	at weaning	64.0 lb. (29.0 kg.)	40 " "
Weight per pig	at 21 days	0.3 lb. (0.1 kg.)	3 " "
	at 56 days	2.7 lb. (1.2 kg.)	10 " "
	at 98 days	6.6 lb. (3.0 kg.)	8 " "
	at 140 days	9.3 lb. (4.2 kg.)	6 " "

267. At the University of Wisconsin, Mr. Eric Bradford presented some data concerning topcross (inbred boars mated to 8 non-inbred sows versus 8 non-inbred sows mated to non-inbred boars).

Non-inbred gilts	Topcross exceeded non-topcross by
Number farrowed per litter	0
Number raised per litter	0
5 months pig weight	3 lb. (1.4 kg.)
5 months litter weight	17 lb. (7.7 kg.)

These matings of only 8 sows in each group are not decisive but it looks to be the same number of pigs and a better growth rate when inbred boars are used. The average number of pigs in a litter at 5 months was not given.

268. Extensive tests of boars from inbred lines (Hazel et al 1948, Durham et al 1952 and Dickerson et al 1954) in comparison with non-inbred boars of the same breed have indicated no average superiority for the inbred boars but have provided evidence of line differences. Inbred boars cannot be considered as superior to the non-inbred boars in swine.

269. Gilts from the topcross were compared with non-topcross gilts, when both groups were mated to non-inbred boars. The results are shown in the following table :

Non-inbred boars	Topcross gilts exceeded non-topcross gilts by
Number farrowed per litter.....	0.8
Number raised per litter.....	1
5 months pig weight.....	5 lb. (2.3 kg.)
5 months litter weight.....	160 lb. (72.6 kg.)

270. The topcross gilts had litters with greater number both at birth and raised. The growth rate of the pigs was also better than for pigs from non-topcross gilts.

271. A great number of sows and litters are necessary to get really significant differences, but the figures look promising.

272. Consequences of the inbreeding rise were estimated from intra-season paired comparisons of line-crosses with the parent inbred lines. Data for litter were calculated as differences per 10 per cent of inbreeding of litter and of inbreeding of dam.

	DIFFERENCES BETWEEN INBREDS AND CROSSES PER 10 PER CENT INBREEDING OF			
	LITTERS		DAMS	
	NUMBER	POUNDS PER PIG	NUMBER	POUNDS PER PIG
At birth.....	-0.20	0.02 (9)	-0.17	-0.06 (27)
At 21 days ...	-0.35	0.08 (36)	-0.31	-0.11 (50)
At 56 days ...	-0.38	0.03 (14)	-0.25	0.06 (27)
At 154 days ..	-0.44	-3.44 (1 560)	-0.28	-0.13 (59)

Weight in grams is given in brackets.

273. The superiority of crosses over purebreds was demonstrated clearly by Winters et al, 1935, in Minn. Agr. Exp. Sta. Bul. 320 and by several other workers.*

* England and Winters, Journal of Animal Science, Vol. 12, 836-847, 1953.

From Winters et al, a comparison will be given on cross-ings and purebreds.* The table shows clearly the great gain of the crossbreds versus purebreds.

	MORE THAN PUREBREDS		
	FIRST CROSS	THREE BREED CROSS	BACK CROSS
Farrowing results			
Live born per litter	0.93	1.66	-0.19
Weight per live pig lb.	0.05	0.01	0.37
gr.	23.00	4.00	168.00
Litter weight lb.	2.83	4.38	2.53
kg.	1.30	2.00	1.10
Nursing period			
Lost per litter	-0.60	0.39	0.87
Litter number at weaning.	0.33	2.05	0.68
Weight per pig at weaning lb.	5.00	5.00	7.00
kg.	2.20	2.20	3.20
Litter weight lb.	39.00	96.00	63.00
kg.	17.70	43.50	28.60
Fedlot period			
Daily gain lb.	0.12	0.11	0.14
gr.	54.00	50.00	64.00
Less feed per 100 lb. (45.4 kg.)	12.68	16.21	12.15
Birth to 220 lb. live weight (100 kg.)			
Fewer days to reach 220 lb. (100 kg.)	17	17	22
Fewer lb. per 220 lb. pig (100 kg.)	27.90	35.66	26.73

274. All the results found concerning the differences between crosses and purebreds depend to a great degree on the genetic diversity of the animals used in the crosses, and the breeding methods used in producing the purebred stock.

275. England and Winters** have a rather interesting comparison over crosses of inbred lines of swine in the overall swinebreeding programme of the University of Minnesota. All differences in number and weight were calculated as a percentage of the parental average.

	MEAN PERCENTAGE SUPERIORITY OF		
	SINGLE CROSS	CRISS-CROSS	ROTATIONAL
Narrow relationship ...	5.40	11.27	8.64
Medium	9.17	9.53	-
Wide	13.50	14.78	13.19

* Spe. Bul. 180, 1936.

** Journal of Animal Science, Vol. XII, 1953.

276. The material consisted of 2,332 crossbred pigs, but the varying number and differing viability make almost all statistical treatment impossible when the variance is taken into account.

277. In the summary, it is pointed out that a close agreement was found between genetic diversity and the amount of heterosis expressed.

278. Pre-weaning characteristics exhibited greater heterosis than post-weaning characters with a distinct effect on prenatal survival being evident.

279. To get an impartial standard, each cross was also compared to an average of all parental performance. This showed a close agreement between the performance of a line as such and the performance of that line in crosses. These findings strengthen the case for performance testing as the basis for selection.

280. The results of this study suggest three genetic essentials for obtaining maximum heterosis in swine crosses : (1) full utilisation of genetic diversity ; (2) the use of stock from high performing lines ; (3) the use of stock from lines that have been sufficiently purged and purified to ensure the regular transmission of effective gene combinations from one generation to another.

Conclusions on breeding methods

281. The breeding methods now commonly used in swine-breeding in the United States differ considerably from the methods used in Europe. Crossings and hybridization are extensively used. Seen from the standpoint of purebreeding this may seem shocking, as interest is concentrated on the hybrids and not on the purebreds.

282. If the system is seen as a whole, there is no danger for the future of the purebreds. A stock of purebreds of high quality is the foundation of the crossbreds.

283. Crossbreeding and improvement of the pure breeds have to go hand in hand if the crossbreeding is to be successful.

284. In the long run the pure breeds will maintain their position, but as the situation is with the marketing of swine products today, the relative numbers of animals in the different breeds will change and new breeds will be started in order to meet the demands of the market.

SELECTION

285. The degree of improvement in animal breeding depends on the ability to select the right animals for breeding purposes, i.e. animals which are superior in genotype to the average of the population for the desirable characters.

286. In the United States special emphasis is laid on performance characters such as fertility, viability, conformation, growth rate and feed efficiency, but carcass quality and other features are also taken into consideration. This statement is based mainly on the results of the pig-breeding projects in States co-operating with the Regional Swine Breeding Laboratory.

Measuring and evaluation of performance characters

287. The methods used in evaluating performance characters differ somewhat from station to station but similar records are taken at each station of particular characters.

Litter testing and sample testing

288. The productivity of a sire and a dam is measured by taking records of their progeny. There are only minor differences in the methods used from birth to weaning. The number of pigs born and weaned and the weight of the individuals, together with the weight of the entire litter, are recorded at weaning, normally at 56 days of age. In some cases the litters are weighed at 21 days but this is not regarded as necessary, as it has been shown that the 56-day weight is superior to the 21-day weight.* In the period from weaning to slaughter-weight similar systems of testing are used at the various stations although they differ in some respects.

289. In the Iowa project* and in other projects, four pigs (usually two barrows and two gilts) from selected litters are fed in dry lots, and records are taken on growth rate and feed efficiency. After slaughter, at 200 to 225 lb. (90.7 to 102.1 kg.) of weight, some data are obtained on the carcasses. Before selecting the group the smallest and the biggest are culled and the four chosen correspond to the average of the litter. With such careful selection a sample of four pigs must be considered as sufficiently indicating how the entire litter would do. Lush** has studied the Danish system of progeny testing and come to the conclusion that the optimum size of the best litter should never be less than 2 or more than 5.

290. However, when it is possible to test the whole litter it should be preferred. In Minnesota, for instance, selected litters are fed separately in pasture lots and this plan is followed to some extent at other stations. Also in the Minnesota project some pigs of the tested litters are used for carcass studies.

* W. Craft, Circular 916, United States Department of Agriculture ; Results of Swine Breeding Research 1953.

** J.L. Lush, Genetic Aspects of the Danish System of Progeny Testing, Swine Research Bulletin, Iowa State College, No. 204, 1936.

291. Litter testing has at many stations been supplemented by visual judging of individuals for conformation.* Several methods have been used but usually a number of conformation features were scored by means of a points scale ranging from 1 to 9. Also the relationship between scores for a number of items at different ages has been investigated. The results show that early scores had little value for predicting the final scores at market weight and in general the relationship between scores and over all performance proved to be low. The scoring scheme was largely discontinued but some plan of rating individuals at weaning or later is still practised in some projects.

Boar testing

292. Boar testing is a new method of testing recently introduced in the breeding programme. One or two boars are selected from a litter consisting of at least 8 pigs weaned. Growth rate and feed efficiency are recorded. Having reached 200 pounds (90.7 kg.) in weight the thickness of back-fat is measured on the live animal by means of a special ruler or an electric needle (see description in the chapter on carcass quality). If satisfactory results are obtained in all respects the tested boars and also the sibs are recommended for breeding ; if not, the boars are castrated and sent for slaughter and the rest of the litter discarded.

293. It is suggested that boar testing could be more effective than the present method of testing. Since pigs no longer need be slaughtered to obtain estimates of carcass quality, the good ones can be sent back for breeding, and improvement would be more rapid and could be guided more effectively than at present. It must, however, be borne in mind that back-fat thickness is not the only criterion of carcass quality, in spite of the important relationship between back-fat thickness and the total amount of fat and lean in the carcass.

Other methods of progeny testing

294. A method of progeny testing similar to that use in many European countries has recently been organised by Ohio State University. A special testing station where groups of pigs can be tested under standardised conditions is built for the purpose. The work concerns pure breeds only. Every litter must be inspected before it can be tested. Out of approved litters, 2 pigs (one barrow and one gilt) are sent to the station, where growth rate and economy of gain are recorded from the 63rd day of age to 210 lb. (95.25 kg.) of weight. Having reached this weight, the pigs are slaughtered for carcass evaluation. Records are taken on dressing percentage, weight of 5 primal cuts, length of body, thickness of back-fat and the surface area

* L.M. Winters and W.W. Green, A Study of Predictive Value of Scores on Body Conformation of Pigs Taken Previous to Final Score ; Jour. Anim. Sci. 3 : 399 - 405, 1944.

of the eye muscle (at the 10th rib). The results of the test are sent to the breeder for selection purposes. New breeds are included in this programme.

295. In Indiana the breeders' societies use a different system of testing. The participating breeders send to the testing station an in-pig gilt. The feed consumed by the gilt is checked during the gestation and suckling periods. Litter size is tested in the usual way. The entire litter is fattened and, after it reaches a weight of 210 lb. (99.79 kg.), one barrow is slaughtered and carcass information is obtained. For the remainder of the litter the back-fat is measured on the live animals. The breeder receives the results of the test in order to enable him to select his pigs for breeding.

Carcass quality

296. The main purpose of pig production in the United States is to convert the corn crop into pork, lard and other pig products. Until the First World War lard was the main cooking fat used and, furthermore, the United States had a considerable export of lard to other countries. The rather lard-type American breeds of pigs were ideally suited for that purpose. The First World War, however, saw the end of the export trade for lard. Some years later new methods were developed for producing vegetable fat from oilseeds and products comprising these fats became keen competitors of lard on the American market, because they were quite satisfactory for cooking purposes and could be produced at a very reasonable cost. This revolutionary change on the market for pig products led to a gradual decline in the demand for lard, so that processors are now selling lard for not more than two-thirds of the price per lb. paid for the live pig. There is evidence also of increasing consumer preference for lean meat, so that pork cuts must be trimmed relatively free from outside fat or the consumer will discriminate against them. It became rather important, therefore, in the pig improvement plans, to give more attention than usual to the quality of the carcass in order to reduce the yield of lard and increase the yield of lean meat. Before mention is made of the steps which are being taken in the field of carcass improvement it might be of interest to give a brief description of the usual methods of cutting and trimming.

Cutting and trimming

297. The methods of cutting and trimming used by American packers are almost always the same. In general, five principal cuts are made. These are: ham, loin, boston butt, picnic shoulder and belly (bacon). These five cuts account roughly for over 70 per cent of the carcass weight.

298. The ham is removed from the side by sawing 2-1/4 inches from the aitchbone straight down at a right angle to an imaginary

line drawn from the centre of the shank to the top of the aitch-bone. The flank side of the ham is cut off sharply and rounded so as to leave maximum flank on the belly. The tail bone is removed and the rugged edges of skin and fat are trimmed off.

299. The shoulder is removed by a straight cut through the second rib, the boston butt is separated from the picnic shoulder just below the neck bone and trimmed to leave half an inch of fat. The picnic is trimmed by removing the jowl, the breast flap and any loose fat.

300. The loin is separated from the belly in a straight line from the point where the first rib joins the vertebrae to the underside of the tender loin. It is trimmed to a maximum of half an inch of fat covering;

301. The belly is trimmed so that 1-1/4 to 1-1/2 inches of back fat are on the outside of the loin scribe. The shoulder end is straightened and the flank end is trimmed with a one-inch slant so that the belly side is one inch longer than the back-fat side. The trimmings such as spare ribs, feet, jowls, plates, fat, etc., amount to roughly 30 per cent of the carcass weight. The belly only is used for bacon.

Carcass improvement plans

302. Although changes in market requirements have made it necessary to alter the type of pig so as to produce more lean meat and less fat, it seems doubtful whether the majority of pig-producers have adjusted themselves to this change as well as they might have done. They still seem to believe that the lard-type pig is more economical as a converter of corn into pork than the meat-type pig, even though there is not sufficient evidence for that opinion. Furthermore, the packers have not shown very much interest in carcass improvement as they have not until recently been paying a premium for lean carcasses, which might be the most efficient way of getting the breeders interested.

303. From the official side, some attention has been given to this problem for a number of years past. In connection with pig-breeding projects in progress at Universities and experimental stations, carcass studies have been made in order to find suitable methods of improvement. In comparison with the considerable number of pigs involved in the breeding projects in the different States the figures available from carcass studies are rather limited, probably because characteristics such as fertility, viability, growth rate, etc., have been emphasised more than carcass quality.

Carcass quality of inbred lines and line crosses compared with outbreds (pure breeds)

304. It is particularly interesting to compare the carcass quality of inbred lines and line crosses with outbreds (pure breeds) in the case of all the breeds involved in the inbreeding

and crossings. It has not been possible to get figures for such comparisons. A bulletin published by Winters and Cummings* gives information obtained from the Minnesota project which provided comparisons between inbred and outbred Poland China, the Minnesota No. 1 and No. 2 and different crossings.

Mean carcass measurements and yields by breed groups

BREEDS	PRIMAL CUTS per cent *	FAT CUTS per cent *	AVERAGE BACKFAT Inches	CARCASS LENGTH Inches
Outbred P.C. 15	70.36	18.84	1.50 (3.81)	29.6 (75.2)
All inbred lines of P.C. 155	69.63	18.39	1.48 (3.76)	29.9 (75.9)
3 best inbred lines of P.C. 123	71.18	16.97	1.44 (3.66)	29.7 (75.4)
Other inbred lines of P.C. 32	68.85	19.10	1.50 (3.81)	30.0 (76.2)
Minnesota No.1 30	70.47	18.88	1.71 (4.34)	31.2 (79.2)
Minnesota No. 2 4	71.21	15.93	1.27 (3.23)	31.7 (80.5)
1 x 2 21	69.78	18.35	1.58 (4.01)	31.0 (78.7)
1 x M and V line ... 72	69.91	18.80	1.58 (4.01)	30.4 (77.2)
2 x M and V line 43	71.26	16.26	1.42 (3.61)	30.4 (77.2)
2 x 1 x 2 4	71.78	17.79	1.63 (4.14)	29.8 (75.7)

* Percentage of cold carcass weight.

Measurements in centimetres are given in brackets.

Note : P.C. = Poland China ; 1 = Minnesota No.1 ; 2 = Minnesota No.2 ; M and V = Inbred P.C. lines.

The body length is measured from the aitchbone to the front edge of the first rib. The back-fat thickness is an average of three measurements, one is taken at the thinnest part and the other at the 7th rib. The third measurement is taken either at the thickest part on the shoulder or at the thickest part of the loin. The figures are adjusted to a carcass weight of 150 lb. (approximately 68 kg.).

* L.M. Winters and J.N. Cummings, A Study of Factors Related to Carcass Yields in Swine ; Agricultural Experimental Station, University of Minnesota, 1951, Technical Bull. 195.

305. As one might expect these figures do not show any difference between the total number of inbred P.C. lines and the outbreds of this breed, but naturally the best lines are superior to the general average. The Minnesota No. 1 and No. 2 show a longer carcass than the Poland China. Figures in the bulletin by Winters indicate that Minnesota No. 1 gives more loin, lighter shoulder and more belly than the other breeds. In general the Minnesota No. 2 gives a better carcass than the No. 1 and the No. 2 also cross better with the inbred P.C. lines than the No. 1. The highest yield of the 5 primal cuts is obtained by crossing No. 1 and No. 2 followed by backcrossing to No. 2. In evaluating the figures it must be considered that the number of pigs in some of the groups is very small; furthermore, the ratio of the two sexes (barrows and gilts) within the groups is not mentioned and, finally, the three measurements of backfat are not always taken at the same place and, therefore, are not quite comparable. For this reason it is difficult to draw conclusions as to the progress being made. There is no doubt that the carcasses involved in the project are better than those from commercial production, and the figures also indicate that the quality has been improved by using the best crossings. The very important question whether inbreeding combined with crossing is superior to pure breeding based on progeny testing, and what improvement in carcass quality has been achieved has not been answered fully.

Correlation between characters

306. The carcass data obtained in the Minnesota project have been used for calculations to determine the relationship between different characters. Only a very brief summary of the results obtained need be given here.

1. Average back-fat thickness and the ratio of back-fat thickness to length of carcass (back-fat/length; T factor) showed high correlations with the yield of five primal cuts. - 0.65 and - 0.67 respectively. An increase of 1 inch (2.6 cm.) of back-fat thickness indicated a decrease of 5 per cent in the yield of the five primal cuts and an increase of 7 per cent in the index of fat cuts. It has been suggested that the T factor rather than the back-fat thickness alone should be used for predictive purposes because carcass value is also influenced by its length.
2. The length of the carcass did not show a high degree of relationship with the percentage yield of the five primal cuts, though the correlation was significant (correlation coefficient $r = + 0.13$ and regression coefficient $b = + 0.245$).
3. Loss on skinning hams was high, correlated with thickness of back-fat $r = + 0.47$; $b = + 0.62$.

4. There was a slightly positive association between growth and leanness of carcasses within the line of Poland China and the Minnesota No. 1 but not within the other breed groups.

307. Winters and associates have developed a new method of determining the content of fat and lean in the carcass. A probe is taken just behind the last rib from inside by means of a special instrument. The amount of lean and fat are weighed and the total amount in the carcass is calculated by the formula:

$$\text{Percent fat} = 25.16 + (0.23 \times \text{LRF } \%) + 0.96 (\text{ABF}) - 0.04 \times \text{CW};$$

$$\text{Percent lean} = 75.127 - 0.775 (\text{ECF } \%);$$

LRF = percent fat in the probe;

ABF = average backfat thickness;

CW = carcass weight (cold);

ECF = estimated carcass fat.

Correlation between percentage of fat in the probe and in the whole carcass was as high as + 0.93.

Measuring backfat thickness on the live pig.

308. Several studies have been made on measuring the thickness of backfat on the live pig. Hazel and Kline* have developed a rather simple and rapid method. Incisions about 1/4 inch (0.6 cm.) deep and 1/2 inch (1.3 cm.) long were made with a scalpel. A narrow metal ruler with a blunt end was pressed through the soft fat to the firm tissue underneath. Pressure on the ruler is relaxed and the reading marked at skin level with the thumb nail or a sliding metal clip on the ruler.

Measurements were taken at four places and the pigs were slaughtered so as to check the measurement on the carcass. The correlation between the average backfat thickness on the carcass and on the live pigs was as follows: behind shoulder, 0.79; middle of back, 0.59; middle of loin, over longissimus dorsi 0.67; middle of loin over-vertebra, 0.73; and average of four measurements 0.81. The correlation between the yield of the five primal cuts and backfat thickness was higher when measured on the live pig than when measured on the carcass. The method is very quick and easy to apply and causes little discomfort to the pig.

309. Another instrument has been used by Dr. Andrew, at Purdue University. It is based on the difference between the lard and the tissue underneath with regard to conductivity of an electric current. A needle with two battery-operated electrodes is progressively pressed through the lard, in the same way as the above-mentioned ruler. When the needle reaches the tissue underneath, a flow of current is obtained and is measured by a meter. The thickness of the fat is thus measured.

*L.N. Hazel and E.A. Kline, Mechanical Measurement of Fatness and Carcass Value in Live Hogs, Journal of Animal Science, Vol. II, No. 2, 1952.



Measuring the thickness
of backfat on a live pig
at Ames (Iowa)

Methods of selection

310. Selection of breeding stock is practised differently at different stations. The most remarkable thing is that some stations use a selection index and others do not.

Selection indices

311. Most stockbreeding operations, and those of pig-breeding in particular, are complicated, involving as they do a number of characters. Their improvement therefore depends on each individual character being improved. Lush and his collaborators have shown, as we have already mentioned, that attempting to improve successively the different characters, affecting the breed to be improved, does not give as good results as simultaneous but independent selection of the various characters. The latter method again is itself less effective than a method based on a selection index which enables all the characters to be selected simultaneously but which evaluates the global value of the breeding animals considered as a whole and not as a group of characters taken separately.

312. The selection index is a number proportional to the global genetic value of an individual and is therefore a criterion which can be used for retaining or discarding the individual for breeding purposes.

313. A selection index also enables account to be taken not only of the qualities of the individual itself but also of those of its relatives (ancestors, offspring or collaterals) ; this gives the maximum information on the animal which it is proposed to select for breeding purposes.

314. Computing a selection index requires prior knowledge of the relative economic value of the different characters to be selected, of their heritability and the phenotypic and genetic correlations which can exist between them.

315. It may well be asked whether it is right to use the same index for different herds or for different races or regions, etc. Theoretically speaking, an index computed from data obtained from a single herd cannot be used on a large scale, for the following reasons :

the economic value of the different characters may vary from one region to another ;

the genetic constitution of herds may vary, depending more particularly on the method of mating used (inbreeding to a greater or lesser degree) ;

different breeding and operating conditions, as well as the views expressed by different people, can give different data for computing the index.

316. Until fuller information, therefore, can be obtained about the genetic variations which can exist between herds and races, the more cautious method is to apply an index only to the population from which it has been computed. When sufficient indices have been computed, it will be possible to compare them and study the extent and nature of any differences which exist.

317. We propose to examine here the two indices of which we were able to make a close study during this Mission : L.N. Hazel's index* as used at the Iowa State College and that of A.B. Chapman (Wisconsin).

Selection index of the Iowa State College (1941)

318. This index is based on the researches of L.N. Hazel and of J.L. Lush and A.E. Molln**. In J.L. Lush's view, there are three characters which are economically fundamental : individual growth rate, the market grade of the pigs and the litter rating. The economic values of these three characters are respectively : $1/3$, 1 and 2.

319. The individual growth rate is determined from the weight at 180 days of age. The market grade is determined

* L.N. Hazel, The Genetic Basis for Construction Selection Indexes : 1943 - Genetics 28 : 476 - 490.

** J.L. Lush and A.F. Molln, Litter Size and Weight as Permanent Characters of Sows ; United States Department of Agr. Bull. 836.

from the live pig by several experts solely on eye appraisal. The global result is expressed in points. The litter rating (P) - or productivity of the sow - is expressed by means of the formula calculated by Lush and Molln, utilising for this purpose both the number of piglets and the weight of the litter at different ages :

$$P = n_0 + n_{21} + n_{56} + \frac{W_{21}}{10} + \frac{W_{56}}{30},$$

where n_0 , n_{21} , n_{56} represent respectively the number of piglets alive at birth, at 21 and 56 days of age, and W_{21} and W_{56} the weight of the litter at 21 and 56 days of age.

320. Hazel computed three types of indices by making use of a varying number of these characters in order to judge the comparative effectiveness of each.

321. The three indices compared were the following :

1. Index I_1 , using the individual weight W and the market grade S of the piglet at 180 days ;
2. Index I_2 , using in addition the productivity of the dam P ;
3. Index I_3 , including, in addition to the above three characters, the average weight W and the average market, S of the litter.

These indices are :

$$I_1 = 0.137 W - 0.268 S$$

$$I_2 = 0.136 W - 0.232 S + 0.164 P$$

$$I_3 = 0.098 W - 0.165 S + 0.167 P + 0.101 W - 0.243 S.$$

As certain regression coefficients used for I_3 vary with the number of piglets per litter, we give I_3 here as an actual average of 8 piglets weaned per litter.

322. It should be pointed out that in these three indices Hazel disregarded the genetic correlations between various characters, holding such correlations to be very insignificant.

323. It is a matter of interest here to compare the effectiveness of selection based on these different indices with that based on simpler methods. If 1 represents the maximum effectiveness which would theoretically be obtained if the genotype of each breed of animal were exactly known, it would give the following figures

Selection based solely on S (mass selection)	0.137
Selection based solely on W (mass selection)	0.350
Index computed empirically by Hazel when beginning his experiments	0.364
Index using W , P and W	0.390
Index I_2 (W , S and P)	0.395
Index I_3 (W , S , P , W and S)	0.404

324. At the present time, a slightly different index is being used for the pig herd of the Iowa State College. In addition to the factors used previously, it includes the weight at 154 days of age instead of 180 days and the defects. This index is :

$$I = (0.65 W + P + C) \times (1.0 - a)$$

Where W = weight at 154 days ;

P = productivity of the dam ;

C = sib credit ;

a = penalty for defects.

325. The productivity of the dams is expressed in deviations from a standard age, number of litters, number of piglets and weight of the litter at 21 and 56 days of age. The weights, which are taken a little before or after the 56th day, are adjusted for 56 days by means of the following formula :

$$Y = Z \frac{41}{X - 15}$$

where Y = weight, adjusted for 56 days ;

Z = weight on the day of weighing ;

X = age in days at time of weighing.

326. The weight at 154 days is found by two weighings, the first about a week before the 154th day and the second about a week after the 154th day. Here again, the weights are adjusted for 154 days by means of the formula :

$$W = Z \frac{142.5}{0.0032143 X^2 + 0.58 X - 23}$$

where W = weight, adjusted for 154 days ;

Z = weight on day of weighing ;

X = age in days at time of weighing.

The average is then taken of the two adjusted weights, which gives the weight at 154 days in pounds.

327. In the new index, C (sib credits) is expressed in points which are added or deducted according as the average weight of the piglets in the litter is more or less than 140 pounds (63.50 kg.) at 154 days, at a rate of ± 0.4 points for each pound by which the average weight exceeds or falls short of 140 pounds (63.50 kg.).

328. Penalties are added to give the factor a, so that each defect disallowed reduces the index by 10 per cent. The defects disallowed are cryptorchidism, hernia, blindness and anal atresia.

329. Unfortunately, we do not know the relative value of this new index as compared with the earlier indices.

Selection index used in Wisconsin

330. This index, which was devised by A.B. Chapman of the Department of Genetics, Madison University (Wisconsin), from the same bases as L.N. Hazel's index, has been used since 1944 for the selection of breeding boars and sows from herds belonging to about a hundred Wisconsin breeders who agreed to take part in a co-operative selection programme.

331. The factors forming the index are worked out by mechanical calculators from data supplied by the breeders.

332. The simplified formula for Chapman's index is :

$$I'_d = 0.5 X_1 + 7 X_2 - 0.02 X_3 + 0.5 X_4$$

where X_1 = number of piglets born ;

X_2 = number of piglets at 154 days ;

X_3 = total weight of litter at 154 days ;

X_4 = individual weight at 154 days.

333. In practice, an even simpler index is used in Wisconsin without the effectiveness of the selection being noticeably impaired :

$$I'_a = 4.5 X_2 + 0.5 X_4.$$

334. In all these indices, the size of the litter has been regarded as 20 times more important than individual weights.

335. From the different regression coefficients computed as above, it has been possible to establish a scale of points for each character adopted for selection purposes. These points are at present allotted as follows :

1 point for each piglet up to 12 (no points are allotted for piglets in excess of 12 as in such cases the average mortality rate is very high) ;

2 points for each piglet alive at 5 months ;

0.7 for each pound in excess of 75 pounds (34.2 kg.) at 154 days ; weights at 5 months are precisely adjusted for 154 days as in Iowa ;

the sum of the individual weights at 154 days gives the weight of the litter. This weight, expressed in pounds and divided by 100, gives the number of corresponding points.

Finally, if a gilt farrows her first litter before 18 months of age, 10 points are added to the last number.

336. Chapman studied, in the same way as Hazel, the gains in accuracy that could be expected if a larger or smaller number of characters were taken into consideration. The results are given below :

	Effectiveness
$I_a = 0.950 X_2 + 0.103 X_3$	0.394
$I_b = 0.070 X_1 + 0.990 X_2 + 0.103 X_4$	0.395
$I_c = 1.330 X_2 + 0.003 X_3 + 0.103 X_4$	0.397
$I_d = 1.102 X_1 + 1.459 X_2 - 0.004 X_3 + 0.103 X_4$	0.399

337. Chapman's index was computed from 161 different crossbreed herds of pure race in Wisconsin, and the author believes it will hold good for most herds in the region which are reared under the same conditions.

Conclusions

338. The indices used for pig selection in the United States are of great theoretical interest because they have been determined mathematically in terms of the various parameters adopted for selection purposes. However, these calculations, which are lengthy and difficult, require knowledge of heritability rates and genetic correlations, and for the latter in particular there are still not sufficient data available.

339. Furthermore, the relative economic value concept for the various characters, although simple in itself, is difficult to express under very changeable economic conditions which develop much faster than the genotypes of the breeding animals.

340. Finally, in establishing these indices, the existence of linear regressions has been assumed though there is very likely an optimum which must not be overstepped, at least so far as certain characters are concerned.

341. We also consider that under European working conditions it would be useful to include the feed index figure when computing pig selection indices, since this is checked directly in most of the progeny test methods, as well as a mark for carcass quality determined not as now by inspection of the live animal, but after slaughtering.

342. While the index method theoretically gives the best annual genetic improvement, it would seem that in practical conditions it would be advisable to combine it with the method of selection based on independent culling standards, so that those characters which appear first can be selected without waiting for the others to make their appearance.

Other methods of selection

343. In the Minnesota Project, a more flexible method of selection is used. It is based on the following five production traits : number of pigs farrowed alive ; number of pigs weaned and weight per litter ; growth rate from weaning to 200 lb. ;

economy of gain and conformation. The method used is described in the Minnesota Bulletin No. 364*. More litters are farrowed than can be tested. Therefore first selections are made at weaning. These are based largely on litter size, which emphasises the number farrowed, number and weight of pigs weaned. Litters thus selected are fed out separately in pasture lots to obtain records on growth rate and economy of gain to 200 lb. (91.2 kg.). Pigs are rated individually when the test is finished. Scores are based on eye appraisal of vigour and thrift, length of body, conformation, animal as a whole and market grade. Each item is rated on a scale ranging from 1 to 9.** Data obtained on each litter are recorded on summary sheets, a separate sheet being used for each litter. After selections have been made on a basis of the records obtained, each selected pig is inspected for serious defects. Pigs showing such defects are culled although their records otherwise may be good. Approximately 30 per cent more gilts are saved than are required for farrowing. Therefore some culling is practised on the basis of gilts' settling and later development. Generally gilts are kept only if they settle at first service.

344. Boars are selected in a similar manner as gilts but as a much smaller number are needed more emphasis can be laid on performance of litter mates and on the pedigree.

Intensity and effectiveness of selection

345. Conventional systems of livestock breeding are based on the selection of superior individuals in each generation as parents for the next generation. It is indicated by Lush*** that improvement can be obtained rather rapidly in unimproved livestock whereas it is more uncertain that continued selection within stocks that have already been highly improved will be effective. More likely, effectiveness of selection for performance may decline steadily, finally reaching a state of near-equilibrium, even though, according to Dickerson,**** genetic variability remains high.

346. The effectiveness of selection within inbred lines has been studied intensively by many genetic experts in the United States and a tremendous amount of literature is available on the subject. It has received special emphasis in the co-operative research work of the original Swine Breeding Laboratory. In

* L.M. Winters, R.E. Comstock, R.E. Hodgson and others, Experiment with In-breeding Swine and Sheep, Minnesota, Agricultural Experimental Station, Bulletin 364, 1943.

** L.M. Winters and W.W. Green, A Study of Predictive Value of Scores on Body Conformation of Pigs Taken Previous to Final Score; Journal of Animal Science, 3: 399-405, 1944.

*** J.L. Lush, Genetics and Animal Breeding, 1951.

**** G.E. Dickerson, Effectiveness of Selection for Economic Characters in Swine, Journal of Agricultural Science, 10: 12-18, 1951.

circular 916 of the United States Department of Agriculture, Craft, in collaboration with the officials at the State Experimental Stations co-operating with the Laboratory, has given a summary of the investigations made at different stations on the effect of selection within inbred lines.* As mentioned above, a more detailed report by Dickerson and others** was published later. The data used to measure the intensity of selection included 4,521 litters from 38 lines during the period from 1932 to 1948. The analysis includes as many lines as possible in order to avoid selection between lines and the results therefore correspond to what would be obtained if the lines had been chosen at random. Only a very brief summary of the conclusions from this study can be presented here.

347. Young boars sired 74 per cent and gilts farrowed 60 per cent of the pigs weaned. The generation interval was 1.22 years for sires and 1.44 for gilts. Only 8 per cent of the boars but 33 per cent of the gilts weaned were used for breeding. Apparently about 50 per cent of the gilts and 80 per cent of the boars were culled because of diseases, defects, post-weaning mortality and reproductive failures, and discriminating against pigs from younger litters. Analysis of the data indicates that positive selection has been practised but that not every opportunity for selection has been used.

348. If boars and gilts had been selected at random (i.e. if the numbers taken from each litter had been proportional to the numbers available at weaning age), the selection for larger litters automatically would have been nearly as large as actually obtained. Opportunity for deliberate selection among boar and gilt pigs was utilised most fully for growth rate, less for conformation and least for litter size. Also, selection favoured the less inbred pigs and dams; it is indicated that 8 to 12 per cent of the variance in total performance was due to variation in the level of inbreeding between litters within the same line and season, which reduces effectiveness of selection as much as a comparable amount of environmental variation, slows the calculated rate of inbreeding and makes actual reduction in heterozygosity lag behind that indicated by the calculated inbreeding coefficient.

349. This is what is expected of inbreeding, when heterosis is influencing the selected characters, but it has not been demonstrated so clearly in practical breeding experiments before. Analysis of data from twelve lines at the Iowa stations showed no indication of curvilinear regression on inbreeding.

* W. Craft, Circular 916, United States Department of Agriculture; Results of Swine Breeding Research.

** G.E. Dickerson, C.T. Blunn, A.B. Chapman, R.M. Kootman, J.L. Krider, E.J. Warwick, I.A. Whately Jr., in collaboration with M.L. Baker, J.L. Lush and L.M. Winters, Evaluation of Selection in Developing Inbred Lines of Swine, North Central Regional Publications, No. 38, 1954.

350. Linear regression of performance on time within 47 lines at 5 stations averaged -0.15 and -0.22 pigs per year in litter size at birth and 56 days respectively. Linear yearly change averaged zero for birth weight, -0.19 lb. (86 g.) for 21-day weight, -0.41 lb. (186 g.) for 56-day weight and -4.0 lb. (1.814 kg.) for 154-day weight of individual pigs. Linear rise of calculated inbreeding varied from 2.3 to 3.9 per cent a year.

351. After removing the expected effect of the inbreeding rise, this linear change per year in performance of the 47 lines averaged -0.03 and -0.01 for litter size at birth and 56 days of age, 0.01 and -0.47 and -2.8 lb. (4.5 g., 213 g. and 1.27 kg.) in weight per pig at birth, 56 and 154 days of age. These average results indicate that selection as practised during development of mildly inbred lines failed to improve the measurable genetic merit of the lines.

352. Heritability for some of the performance characters was calculated. For number of pigs farrowed per litter, 0.15 to 0.17 is suggested as a reasonable estimate. Heritability of number weaned ranged from 0.15 to 0.32 and for litter weight 0.07 to 0.16. Estimates for heritability of growth rate based on weight at 154 days of age ranged from 0.17 to 0.40.

353. The real value of an inbred line cannot be expressed by the performance of the line itself, but by the advantage obtained in crossing with other lines of the same or of other breeds. It seems reasonable therefore that selection should be more effective if it is based not only on the performance of the line but also on the development of the crosses. Different systems of test crossing are in progress at the various stations. It is most interesting that reciprocal-recurrent selection has recently been taken into use, for instance at Beltsville. This method requires a considerable number of individuals and has been used successfully in laboratory animals with high productivity and in poultry. Some experts are against using the method in swine because of its rather low productivity.

COMMERCIAL USE OF BREEDING METHODS

354. The breeding projects now in progress at universities and experimental stations and the co-operational work of the Regional Swine Breeding Laboratory were developed for two major purposes :

- to study genetics in swine with special reference to inbreeding, crossbreeding and methods of selection ;

- to test procedures of practical breeding so that the result of the studies could be utilised as soon as possible in the commercial production of pigs.

355. These two points have already been described and discussed in special chapters in the Report, but it might be of interest to give a brief outline of the procedures followed for utilising the results on the farms. It was realised that an effective use of such breeding methods which involve in-breeding required teamwork between science and practice. Establishing and keeping inbred lines could not be done by the farmer because it is expensive and too complicated. The most common procedure has been that the inbred lines are established and kept at the Experimental Stations and either selected inbreds or incrossed (hybrid) boars are distributed to farmers from the Experimental Stations. In details, however, the methods differ from State to State. In some cases, the distribution of boars to farmers is combined with testing work. Such systems are practised at Beltsville. The Research Centre has a contract with 28 breeders in Pennsylvania. Four breeds are usually represented in the programme. Half the breeding sows of each breed are used for pure breeding and the other half are served by a boar from one of the Beltsville herds. The breeding work is inspected from Beltsville and records are taken of performance of the litters. Rotation crossing is used in order to find out which boar crosses best with the different breeds. A similar system is used with success in Wisconsin. In some States, the University or Experimental Station is co-operating with private enterprise. This is the case, for instance, in Iowa where, on special privately-owned stations, the pure breeds or lines are kept. The necessary local assistance is obtained, partly from the State Experimental Station and partly from scientists employed at the private station. This station will have contracts with a number of breeders who will receive in-breeding animals from the station for crossing. What crossings shall be made is decided by the manager of the station. The crossbred boars are raised on the farm, and, having reached a certain weight, they are sent to the station for later distribution to commercial breeders. These breeders do not know about the pedigree of the incrossed boars, the main requirements being to make sure that a farmer gets a boar suitable for his sows. A similar system is practised in Minnesota.

CONCLUSIONS

356. A great effort has been made in the United States to improve efficiency in pig production and to attempt to change the somewhat lard type American pig into a leaner type of animal more suited to modern market requirements. The main principle involved in the evolution of the breeding programme is in-breeding followed by various cross matings in order to combine and stabilise the required characters, and an attempt to improve the general performance by means of heterosis (hybrid vigour). Inbred lines have been developed both within breeds and from crosses of breeds. These lines are subsequently crossed and

the male offspring of these crosses (hybrid boars) are being widely distributed to farmers for breeding purposes. New breeds are being established by crossing between breeds followed by inbreeding and selection for performance.

357. This method of breeding, however, is a rather expensive method ; many of the inbred lines must be discarded because of deterioration and it seems doubtful that a necessary number of satisfactory lines can be kept in the long run without a continuous production of new lines for replacement. Consequently, a number of pure breeds must be kept in order to keep the process going and steady improvement of the purebred foundation stock is necessary for further progress with the "inbred" lines.

358. It has been noticed that, although outstanding American experts agree amongst themselves on the main principles involved, they differ at times over some ideas, and that can only indicate that many problems concerning this breeding method are not yet resolved. An expansion of the experimental work on laboratory animals with a good performance of reproduction could probably have contributed to solve some of the problems.

359. It would probably also be worthwhile to enlarge the research work on crossing between pure breeds for comparison with crosses on inbred lines.

360. Taking into consideration how difficult experimental work on animal genetics and animal breeding really is, because of the low ability of reproduction in farm animals and the dominant influence of environment, it could not be expected that the new American breeding methods in the rather short time they have been used should give a final answer to the different breeding problems. Nevertheless, it is unquestionable that this work has been of great importance and has already proved of inestimable value in increasing our knowledge of the genetics of farm animals and has also proved useful in the commercial production of pigs under American conditions.

361. To what extent American breeding methods can be used in European countries in the future cannot fully be answered for the time being. Pure breeding and selection based on progeny testing have shown excellent results in some countries over a number of years and many of the countries are now adopting the system. These countries already have expensive equipment erected for these purposes and have wide experience in the problems of progeny testing. Moreover, the production of inbred lines involves very high capital investment and satisfactory development could only follow by the use of State financial aid or the formation of large-scale, privately-owned pig-breeding enterprises, assisted by research on a comprehensive scale. Therefore, the possibilities of commercial use of inbreeding in most of the European countries are very low. However, in some countries it should be possible to use a systematic two- or three-bred crossing.

362. In some countries in Europe attention has lately been given to the possibility of determining the carcass quality on the live pig. The results of experiments on this subject in the United States might be helpful to settle this problem in Europe.

363. It has indeed been very interesting to study the methods of pig breeding used in the United States. It is recognised nowadays that it is essential that research workers from all over the world should meet at fairly frequent intervals to discuss their problems. With the rapid development now taking place in pig husbandry it is undoubtedly essential that regular contact should be maintained between the various countries.

VI

REPORT OF THE CATTLE SECTION

INTRODUCTION

364. Within the wider framework of the Mission, the purpose of which was to study new breeding methods and inter-State co-operation in the United States, the members of the Cattle Section proposed to compile some market statistics, to obtain information on the operation and function of Herd Books, to assess the development of artificial insemination, to study milk recording at national and local level, to discuss the methods used for the selection of dairy cows and dairy bulls, to examine the bases and organisation of progeny-testing, to devote special attention to the efforts made to improve meat production, to follow up recent progress in applying a knowledge of blood groups in breeding and, lastly, to collect all the information and documents obtainable on inbreeding and crossbreeding experiments.

365. In order to study these various points in greater detail each member of the Section undertook responsibility for a particular question in the preparation of this report which contains as many sections as there were problems to be studied. Inbreeding and crossbreeding experiments have been treated at some length as they constituted one of the principal aims of the Mission. Inter-State co-operation is illustrated by specific examples in most sections. It was felt preferable to study this subject in each concrete case rather than to devote a special section to it. Nevertheless, a short account is given of the North-Eastern States' Regional Project on fertility in dairy cattle, which had not been covered elsewhere.

STATISTICAL INFORMATION

Livestock

366. In the United States livestock and its products bring in more than half of the total farm cash receipts, which in 1953 amounted to about 31,000 million dollars.

367. Meat production accounts for more than half of the income from livestock. In this way meat animals bring in more income to farmers in the United States than any other product. They give more than twice as much income as the second most important item, viz. dairy products.*

368. Making a breakdown in meat production the farm-value of beef production is one third higher than the cash income from hogs, whereas farmers' income from dairy products is just between, as is shown in Table 1.

Table 1
Farm cash receipts by products
United States 1953

PRODUCT	MILLION DOLLARS	PER CENT
Livestock and products		
Total	17,104	55.0
Meat animals total	8,852	28.5
cattle and calves	4,887	15.7
hogs	3,649	11.8
sheep and lambs	316	1.0
Dairy products	4,269	13.7
Poultry and eggs	3,760	12.1
Other livestock products.	223	0.7
Crops		
Total	13,797	44.3
Food grains	2,431	7.8
Feed crops	2,075	6.7
Other crops	9,291	29.8
(cotton		
oil crops		
tobacco		
vegetables		
fruits and nuts)		
Government payments (1) ..	213	0.7
Total cash receipts	31,114	100

(1) Under the Agricultural Conservation and Sugar Act programmes.

Source : Agricultural Marketing Service U.S.D.A.

* Shepherd : Marketing Farm Produces, p.301-302, (Iowa State College Press).

369. In the still rather young American history livestock has always played an important part. This was already the case with the first immigrants who settled on the Chesapeake Bay (Virginia) with their cattle and pigs shortly after 1600.

370. In the 17th and 18th century immigration mainly took place along the coast of the Atlantic Ocean and in the South (Texas and the delta of the Mississippi) and finally also in California.

371. The great expansion to the West started at the end of the 18th century, after the War of Independence against England. In the beginning people migrated along the banks of the Ohio River and the northern part of the Mississippi. In these districts livestock production also rose to greater importance, although about 1850 more than half of the livestock were found in the Eastern States along the coast of the Atlantic Ocean and only 3 million head west of the Mississippi.

372. This was followed by a quick and strong expansion caused by the exploration of the vast grassland-belts east of the Rocky Mountains, by the construction of railways (also used for shipping of livestock to the East) and by the establishment of big slaughter houses and meat packing plants (in Chicago, Kansas City, St. Louis, Omaha, etc.).

373. As a result of this development livestock numbers considerably increased from 18 million in 1850 to 60 million in 1890.

374. The periods of decrease alternated with periods of a strong rise. Here, for the first time, the cattle cycle (of 12 to 15 years) was noticed. The peaks appeared in 1890, 1903, 1917, 1933 and 1945. The estimate for January 1955 even showed a higher number than ever before.

375. These fluctuations in the number of cattle have been caused partly by economic circumstances (e.g. marketing possibilities and the cattle- and feed-price ratio) and partly by physical factors (weather conditions - such as severe drought resulting in shortness of feed - and bad coarse grain yields).

376. The figures in Table 2 clearly show the long-term rising trend in cattle numbers but also the rather strong decrease in the number of sheep and the sharp fall in the number of horses and mules after World War II.

377. Further, as can be seen from Table 2, poultry numbers also showed a considerable fall just after the last war, whereas in the following years there were only small fluctuations around 440 million birds.

378. Hog production, which especially in the last two years of World War II assumed unprecedented proportions, later showed - although with some fluctuations - a decreasing trend (except in the years 1951 and 1952).

Table 2
Number of livestock on farms, January 1st, 1900-1955

In 1,000 head

YEAR	TOTAL CATTLE AND CALVES	TOTAL SHEEP AND LAMBS	HOGS	HORSES AND MULES	CHICKENS
1900	59,739	48,105	51,055	20,995	-
1910	58,993	50,239	48,072	24,221	355,988
1920	70,400	40,743	60,159	25,742	381,109
1930	61,003	51,565	55,705	19,124	468,491
1940	68,309	52,107	61,165	14,478	438,288
1945	85,573	46,520	59,373	11,950	516,497
1950	77,963	29,826	58,852	7,781	456,549
1955 *	95,433	30,931	55,002	4,551	447,310

* Preliminary estimate.

Source : Agricultural Statistics 1952, Table 480, U.S.D.A., and Livestock and Meat Situation, March 1955, page 5.

379. From Table 3 it can be seen that the number of milk cows and milk heifers, which also increased during World War II and then fell again to the pre-war level, have remained almost stationary during the last few years.

380. On the contrary, beef cattle - after a short depression between 1946 and 1950 - have recorded a regular, strong increase in numbers, so that the peak reached during World War II has been exceeded. This increase of beef-production has taken place in the North Central States and especially in the Western States as a result of favourable weather conditions and abundant coarse grain yields, while in several Southern States these conditions were unfavourable (long dry periods) and led to some decrease in production.

381. In order to get a further insight into the geographical distribution of livestock (milk, cattle, beef cattle and sheep) livestock numbers per region are given in Table 4.

Table 3

Number of cattle and calves on farms and ranches

January, 1930-1955

In thousand head

YEAR	MILK CATTLE				BEEF CATTLE					
	COWS AND HEIFERS 2 YEARS OLD AND OVER	HEIFERS 1 TO 2 YEARS OLD	HEIFER CALVES	TOTAL	COWS AND HEIFERS 2 YEARS OLD AND OVER	HEIFERS 1 TO 2 YEARS OLD	CALVES	STEERS	BULLS	TOTAL
1930	23,032	4,851	5,199	33,082	9,162	2,799	8,885	5,608	1,467	27,921
1935	26,082	4,995	5,280	36,357	11,151	3,362	10,980	5,323	1,673	32,489
1940	24,940	5,525	5,967	36,432	10,676	3,357	10,936	5,283	1,625	31,877
1945	27,770	6,307	6,772	40,849	16,456	5,069	12,871	8,329	1,999	44,724
1950	23,853	5,394	6,208	35,455	16,743	4,754	12,516	6,805	1,690	42,508
1955*	24,408	5,968	6,644	37,020	24,166	6,223	17,878	8,308	1,838	58,413

* Preliminary.

Sources : Agricultural Statistics 1953, page 332.

Livestock and Meat Situation, March 1955, page 5.

Table 4
Number of cattle and sheep on farms
by region, January 1st, average 1941-50 and 1954

In thousand head

REGION	CATTLE		SHEEP	
	AVERAGE 1941-50	1954*	AVERAGE 1941-50	1954*
North Atlantic	5,155	5,821	599	476
North Central**	36,224	42,579	9,309	7,062
South Atlantic	5,311	7,223	817	760
South Central	19,403	22,953	10,546	6,548
Western	13,371	16,101	16,609	12,059
Total United States..	79,464	94,677	37,880	26,905

* Preliminary.

** North Central Region includes following States : Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska and Kansas.

Sources : Agricultural Statistics 1953, p. 331 and 363.

Livestock News Market Service Statist, Bulletin No. 143, p. 1 and 2.

In Table 5 further details are given concerning the total number of cattle per State, in the prominent livestock-producing States (i.e. each with more than 2 million head of cattle) together with a breakdown between beef cattle and milk cattle.

382. By and large livestock is produced where feed is grown, because in most cases it is cheaper to ship livestock or meat to the consuming areas than to ship feed long distances to the livestock.

383. For this reason hog production is heavily concentrated in the Corn Belt, where supplies of feed grains are the greatest.

384. Production of beef-cattle and sheep, however, is more evenly spread over the United States because these are primarily range and hay-consuming animals.

385. About two-thirds of the beef cattle shipped from the western grazing areas each year are sold for immediate slaughter ; the remaining one-third is shipped into the Corn Belt and other States to be fattened before slaughter.*

* Shepherd : Marketing Farm Products, p. 324-326.

Table 5

States listed according to number of cattle and calves on farms
January 1955

In thousand head

STATE	TOTAL NUMBER OF CATTLE	TOTAL BEEF CATTLE AND CALVES	BEEF COWS 2 YEARS AND OVER	MILK COWS 2 YEARS AND OVER
1. Texas.....	8,501	6,956	3,784	1,031
2. Iowa.....	6,279	4,603	980	1,111
3. Nebraska	5,016	4,318	1,558	442
4. Kansas	4,341	3,534	1,392	545
5. Wisconsin....	4,318	438	47	2,656
6. Illinois	3,946	2,486	612	884
7. Minnesota....	3,939	1,510	315	1,496
8. Missouri.....	3,910	2,459	977	1,034
9. California....	3,583	2,094	822	909
10. South Dakota..	3,301	2,721	1,260	340
11. Oklahoma	3,182	2,302	1,196	552
12. Montana	2,441	2,275	1,130	108
13. Ohio.....	2,438	887	195	1,018
14. New York....	2,356	139	31	1,527
15. Mississippi ..	2,080	1,128	614	643
16. Colorado.....	2,054	1,770	709	183
17. Indiana.....	2,054	1,146	318	624
18. Michigan.....	2,003	467	78	963

Source : The Livestock and Meat Situation, March 1955, p. 18-19.

Table 6

Cattle and calves on feed*
January 1st, 1930-1955

In thousand head

YEAR	EAST NORTH CENTRAL STATES**	WEST NORTH CENTRAL STATES***	TOTAL NORTH CENTRAL STATES	WESTERN STATES	PENN- SYLVANIA	TOTAL UNITED STATES
1930	619	1,964	2,583	-	-	3,113
1935	579	1,229	1,808	-	-	2,215
1945	907	2,662	3,569	772	70	4,411
1950	976	2,473	3,449	926	88	4,463
1955 ****	1,236	2,969	4,205	1,527	84	5,816

* These estimates include only cattle being fattened for market as a more or less distinct agricultural enterprise.

** These are : Illinois, Indiana, Ohio, Michigan and Wisconsin.

*** These are : Iowa, Minnesota, Missouri, North and South Dakota, Kansas and Nebraska.

**** Preliminary.

Sources : Agricultural Statistics 1954, p. 333 ; Livestock and Meat Situation March 1955, p. 7.

386. During the last few years the total number of cattle in the United States has not risen, although there have been variations in the different regions ; in California and the other Western States numbers have increased regularly, while in the North-West Central States a small decrease has occurred.

387. As to the fattening of cattle, Iowa is certainly the most important State. In 1953 the number amounted to 1,274,000 head, which was a good fifth of the total number for the United States and a little more than the total number for the 13 Western States together.

388. Nebraska is second with almost 3/4 million head and Illinois third with half of the number of Iowa and then - with quite a long interval - Minnesota and Missouri, each with about 350,000 cattle.

Production

389. Three major forces are at the back of the changes in livestock production in the last decades. They are :

- the shift from animal to mechanical power ;
- the variations in the total feed supply, and
- the higher production per animal.

These forces in turn have been influenced by the prices of livestock products and other economic changes.*

390. The decrease of more than 21 million in the number of horses and mules between 1920 and 1955 released land that could grow feed for an equivalent number of productive livestock (animals and their products, that are produced for human use). The saving in grain alone during the last year has amounted to about 22,000,000 tons (enough to feed about 45,000,000 hogs to market weight).

391. Yearly changes in the total feed supply have been as influential in their effects on livestock production. Years of severe drought or of short feedgrain crops resulting from bad weather conditions have placed definite limits on the expansion of livestock numbers or have even caused a temporary decrease.

392. In this connection it has also been observed that a favourable livestock-feed price ratio resulting from a large feed grain crop may stimulate heavy feeding as well as the breeding of more animals. There has been a rising trend in the quantity of feed produced during the last 15 years which also meant more feed per animal and especially per cow.

* See Sherman Johnson : Changes in American Farming, p. 5-8 and p. 45-51.

393. In addition to the changes in the supply of feed there have been notable changes in quality, resulting in the feeding of rations that are better balanced with respect to protein and other nutritive elements. The gradual increase in the protein content of the hay supply (because of the pronounced shift from grasses to higher yielding legume hays) and the greater supply per animal of oilseed meals and other high-protein feeds since World War II also helped to balance the feeding rations and to push livestock production upward.

394. Higher production per animal after the First World War and especially during and after the Second World War resulting from better feeding, management and control of disease as well as from improvement in breeds and breeding methods, has largely contributed to increased efficiency in livestock production.

395. Thus the total increase in livestock production is derived from larger numbers of breeding stock and from the higher output of meat and milk per unit of breeding stock.

Meat production

396. Total output of red meat has been more than doubled since the beginning of the 20th century.

397. As already mentioned, during and shortly after World War II a sizable expansion in the numbers of beef cattle and hogs augmented meat supplies.

398. During the period 1947-1954 pork production fluctuated around 4,763,000 tons (with the exception of 1951 and 1952, when approximately 5,216,000 tons were produced). However, in 1954 and the first half of 1955 the number of sows farrowing increased considerably. In order to maintain their income, farmers are now raising more hogs, notwithstanding lower prices for several dairy products, poultry and eggs as well as acreage allotments on wheat and cotton. However, large stocks of feed grains on farms (especially corn), which are not under loan, make this expansion possible.*

399. Beef production has been increasing continuously since 1948. After rising sharply in 1953 and somewhat more in 1954 the main feature of cattle production at present seems to be stability at high volume. This is due to the fact that the estimated number of cattle on January 1st, 1955, and the commercial slaughter of cattle in the first half of that year were only slightly above the 1954 figures.

400. However, in 1955, more cattle were fed than ever before and, in the spring, 28 per cent more feed cattle (mainly heifers) and calves were received in 9 Corn-Belt States than in the spring of 1954.

* Livestock and Meat Situation, July 1955, p. 7 and 11-13.

Table 7

Meat production from total United States slaughter 1900-1955 *

In million lb. (Figures in brackets represent weight in million kg.)

YEAR	BEEF	VEAL	LAMB AND MUTTON	PORK **	TOTAL RED MEAT	POULTRY MEAT ***	RED AND POULTRY MEAT	LARD
1900	5,628 (2,553)	397 (180)	493 (224)	6,329 (2,871)	12,847 (5,827)	-	-	1,651 (750)
1910	6,647 (3,015)	667 (303)	597 (271)	6,087 (2,761)	13,998 (6,349)	1,904 (864)	-	1,553 (704)
1920	6,306 (2,860)	842 (382)	538 (244)	7,648 (3,469)	15,334 (6,955)	1,932 (876)	-	1,958 (888)
1930	5,917 (2,684)	792 (359)	825 (374)	8,482 (3,847)	16,016 (7,265)	2,626 (1,191)	-	2,227 (1,010)
1940	7,175 (3,255)	981 (445)	876 (397)	10,044 (4,556)	19,076 (8,653)	2,514 (1,140)	-	2,288 (1,038)
1945	10,276 (4,661)	1,664 (755)	1,054 (478)	10,697 (4,852)	23,691 (10,746)	4,154 (1,884)	-	2,066 (937)
1950	9,538 (4,326)	1,230 (558)	597 (271)	10,714 (4,860)	22,079 (10,015)	3,782 (1,715)	25,861 (11,730)	2,631 (1,193)
1955 ****	13,500 (6,123)	1,700 (771)	700 (318)	10,950 (4,967)	26,850 (12,179)	4,800 (2,177)	31,650 (14,356)	2,500 (1,134)

* Units are carcass weight equivalent (excluding edible offals).

** Excluding lard.

*** For 1900-1945 figures represent farm and non-farm production of chickens (dressed weight) including commercial broilers since 1934, but excluding turkeys, 1950-1955, chickens, including commercial broilers and turkeys (eviscerated basis).

**** Forecast.

Source: Livestock and Meat Situation, March 1955, p. 20.

401. The total output of beef in the United States is made up of carcasses of a wide range of kind and quality. Their variation is due largely to differences in breeding, sex, age and degree of finish of the animals slaughtered.

402. The highest grades of beef are produced from well-fed-beef-type cattle. Careful intensive feeding produces a carcass which has liberal quantities of fat that adds to the tenderness and flavour of the meat. A large part of the fresh beef sold in retail stores comes from young animals which have had a turn in feedlots.*

403. All the year-round feeding is becoming more common, especially with large operators and in the Western States where short-term feeding is more usual than it is in the Corn Belt.

404. Calculations based on detailed reports from Iowa, Illinois and three other States indicate that, in 1954, close on 45 per cent of the total beef supply came from the slaughter of fed cattle.

405. Of the total number of nearly 26 million head of cattle** slaughtered in 1954, and producing 13,000 million pounds of beef, almost 10 million head were fed cattle producing 5,800 million pounds of beef.

406. From these calculations it is also estimated that in 1953 and 1954 approximately 55 per cent of all beef produced was steer beef. About 30 per cent of all beef output was cowbeef, nearly 12 per cent heifer beef and 3 per cent bull beef.

407. But of fed beef output more than 80 per cent was steer beef and most of the rest heifer beef.

408. Though about 45 per cent of all beef was fed, about two thirds of both total steer beef production and total heifer production came from animals that received feedlot feeding. Little cow beef is fed beef.

Meat consumption

409. Nearly all the meat produced in the United States is consumed on the home market.

410. The quantity of exported meat in relation to total production is almost negligible (in the years under review about 180 million pounds (81,600 tons) per year, mainly pork), whereas imports of meat amounted to between 400 and 500 million pounds (181,437 to 226,796 tons) a year, of which more than half was beef and about 40 per cent pork.

* Livestock and Meat Situation, March 1955, p. 13-16.

** Excluding calves, the slaughter of which amounted in 1954 to more than 13 million head.

Table 8

Consumption of meat and lard (in pounds*) per capita in the United States and population figures, 1900-1955

YEAR	BEEF	VEAL	LAMB AND MUTTON	PORK**	ALL RED MEATS	POULTRY MEAT	LARD	POPULATION JULY 1st in millions
1900	67.1 (30.4)	5.2 (2.4)	6.5 (2.9)	71.9 (32.5)	150.7 (68.4)		13.2 (6.0)	76.1
1910	69.5	7.1	6.4	61.4	144.4		12.3	93.7
1920	(31.5)	(3.2)	(2.9)	(27.9)	(65.5)		(5.6)	
	58.3	7.9	5.4	62.6	134.2		12.2	108.0
	(26.4)	(3.6)	(2.4)	(28.4)	(60.9)		(5.5)	
1930	48.2	6.4	6.6	66.1	127.3		12.7	124.8
	(21.9)	(2.9)	(3.0)	(30.0)	(57.7)		(5.8)	
1940	54.2	7.3	6.5	72.4	140.4		14.4	134.0
	(24.6)	(3.3)	(2.9)	(34.5)	(63.7)		(6.5)	
1945***	58.6	11.7	7.2	65.7	143.2		12.4	140.9
	(26.6)	(5.3)	(3.3)	(29.8)	(65.0)		(5.6)	
1950	62.2	7.9	3.9	68.1	142.5	24.3	13.8	152.3
	(28.4)	(3.6)	(1.8)	(30.9)	(64.6)	(11.0)	(6.3)	
1955****	78.0	10.0	4.1	67.0	159.1	28.1	11.0	164.0
	(35.4)	(4.5)	(1.9)	(30.4)	(72.2)	(12.7)	(5.0)	

* Carcass weight equivalent.

** Excluding lard.

*** Only civilian use ; excludes military use and relief actions overseas.

**** Forecast.

Note : Figures in brackets represent equivalent in kilogrammes.

Source : Livestock and Meat Situation, March and July 1955.

411. Judging by the 1955 slaughter estimates, consumption of all meat for that year was probably about 159 or 160 pounds per person, i.e. nearly 4 per cent above the average 153 pounds in the two previous years and close on the record 163 pounds consumed in 1908.

412. Most of the increase in 1955 over 1954 was in the consumption of pork, as rates for the other meats did not change much.

413. 1955 was possibly the third year in succession when the proportion of beef consumption was unusually high and the proportion of pork was still relatively low.

BREEDERS' ASSOCIATIONS

414. The Mission was unable to study the operation of Herd-Books in detail and the only opportunity offered was a visit to the offices of the American Jersey Cattle Club in Columbus (Ohio). It was also able to visit two Wisconsin farms with registered herds, one of Brown Swiss and the other of Holstein Friesian. The information given here is, therefore, necessarily limited. One member of the Mission took part in the annual congress of the Holstein Friesian Association of America, at Philadelphia.

415. In the United States the Herd-Books are closed books in which only animals bred from registered parents can be registered. There is a national association for each breed, with branches in each State. The national Herd-Book associations may be members of the Purebred Dairy Cattle Association which lays down general rules. This is the case for the following associations: the American Guernsey Cattle Club, the American Jersey Cattle Club, Ayrshire Breeders' Association, the Brown Swiss Cattle Breeders' Association, the Holstein-Friesian Association of America. As an example of what the Purebred Dairy Cattle Association does, it may be mentioned that it has, jointly with the American Dairy Science Association, approved the rules on milk recording as practised under the Herd-Books* in two possible forms (Advanced Registry Tests and Herd Improvement Registry Tests) and the rules and regulations governing the use of artificial insemination in purebred dairy herds.

416. The total number of breeding animals followed by the Herd-Books probably represents barely 5 per cent of all cattle stock. For information purposes and to give an idea of the size of the various associations, it is interesting to note the number of annual entries in the various Herd-Books.

* See Milk Recording, page 125.

Entries in Herd-Books for 1952
(Agricultural Statistics)

DAIRY BREEDS	BULLS	COWS
Ayrshire	2,604	20,604
Brown Swiss	4,633	18,466
Guernsey.....	13,669	100,240
Holstein-Friesian.....	32,424	157,266
Jersey.....	7,988	63,525
Total	61,318	360,101

BEEF BREEDS	BULLS AND COWS
Aberdeen-Angus	164,329
Devon	500
Hereford.....	548,418
Polled Hereford	72,433
Red Poll	5,011
Shorthorn	80,487
Brahman.....	24,013
Total	895,191

417. Each Herd-Book pursues its own improvement programme which generally includes different stages, following the tendency, which will also be noted in milk recording, to try to induce breeders gradually to use the best methods of recording and selection. Breeding animals can be registered under various descriptions according to their own performance and that of their ascendants or descendants.

American Jersey Cattle Club

418. Take, for example, the case of the American Jersey Cattle Club.

419. It has already been stated that animals derived from registered stock are the only ones which can be registered. Care is taken to check pedigrees by asking the breeder, when sending in the application, to provide the Club with a satisfactory identification of the young animal (sex, proposed name, numbers and letters of brand, colour of tongue, etc.), the names and registration number of the sire and dam, the date of birth, the signature of the owner of the sire at the time of mating and of the owner of the dam at the same period, etc. It should be pointed out that, in the case of all breeds, breaches of the rules are judged by the courts and punished by exclusion from the Association. A special procedure is provided for animals bred by artificial insemination.

420. The older the animal to be registered the higher is the registration fee. Thus, the fee for a male under 6 months is \$3.50, and \$5 if it is between 12 to 14 months. These fees apply to owners who are Club members; for non-members they would be \$4.50 and \$6 respectively.

421. Breeders are admitted to membership of the Association by the Committee of the Club and must be sponsored by at least five members. The entry fee is \$50.

422. The animals registered may be classified in various ways according to the performance of their ascendants (selective registration of bulls) or descendants (tested sire, tested dam). If they do not satisfy these conditions, they are simply entered as "Qualified Registration".

423. Regular milk recording programmes are also in use and are described, page 125, but the Jersey Cattle Club also works in conjunction with the Dairy Herd Improvement Associations (D.H.I.A.).

424. To guide breeders in their selection of animals for breeding purposes, a programme is prepared for judging conformation and the type of the animals registered. Breeders are thus offered an opportunity of having their stock judged by an official expert appointed by the Association. A grading scale has been drawn up, on the basis of which the stock is scored. The classification is as follows for the American Jersey Cattle Club :

Excellent	(90 points or over)
Very good	(85 to 90 points)
Good plus	(80 to 85 points)
Good	(75 to 80 points)
Fair	(70 to 75 points)
Poor	(under 70 points)

425. Females may only be judged for conformation after the first calving and must wait until the second to be classed "Excellent". Males can be judged from the age of 24 months onwards but can only be classed "Excellent" from the age of 3 years. As a rule, when a breeder asks for his stock to be scored, it is incumbent on him to submit all the breeding animals in his herd which are eligible for grading. Extra fees, in proportion to the number of animals presented, must be paid by the breeder for this operation. Breeders may form groups to submit their stock for conformation scoring. In this case they are asked to pay \$3 a head if the group presents at least 180 animals.

426. Bulls, which have sired heifers complying with minimum standards for yields and satisfactorily classified for type, may be given a special title (Senior Sire and Senior Superior Sire).

427. We found that this concern about type was also shared by breeders of other breeds, in particular Holstein-Friesian and Brown Swiss.

428. The Herd-Books are powerful associations which carry out their own improvement programmes. They take a reserved attitude towards the cross-breeding which will be described later, but follow the experiments with interest.

429. The Purebred Dairy Cattle Association helps to co-ordinate the efforts of the associations in looking after the interests of the various dairy breeds.

ARTIFICIAL INSEMINATION

430. In several respects artificial insemination and the use of deep-frozen semen open up entirely new possibilities of improving productive efficiency. In the United States, where such great efforts are being made to solve fundamental problems in relation to animal breeding, the application of these techniques can be expected to yield rapid results.

Organisation in general

431. The first insemination association in the States was organised in New Jersey in 1938, when Dr. K. Larsen, from Denmark, acted as technical adviser. Since then its growth has been very rapid and in 1954 more than five million cows or over twenty per cent of the total cow population were inseminated. Although these cows were very largely in dairy herds, there has also been a noticeable increase in the use of beef bulls.

432. From the very beginning, artificial insemination has been organised either through co-operative associations or through commercial enterprises. At present the co-operative movement is dominant, but the presence of commercial enterprises has provided competition and acted as a stimulus to still more efficient management. Development has thus followed the conventional American system of free competition.

433. In the States, the Artificial Insemination (A.I.) movement is restricted to insemination. Thus, no sterility treatment or pregnancy diagnosis is carried out by the staff of the A.I. movement. This explains why artificial insemination is almost entirely carried out by trained technicians.

434. In 1947 a central organisation, The National Association of Artificial Breeders, was founded, the object of which

is to act as a forum for the interchange of experiences and to co-ordinate research of interest to the A.I. movement. The central organisation is supported both by co-operative associations and commercial enterprises.

Training of technicians

435. Although artificial insemination is a promising procedure for the breeder, it can be used successfully and with safety only by skilled persons specially trained.

436. In the States, many of the larger artificial insemination co-operatives and associations have their own courses of training for technicians. In general, these technicians acquire knowledge of the anatomical structure of the reproductive organs and methods of cleaning and sterilizing their equipment and of the sanitary procedures to be observed within a herd as well as between herds. Collection, evaluation, dilution and preservation of semen and insemination techniques are, of course, the main objectives of the training courses. At the end of a course, the men selected for the courses are trained for about a month in the field by senior technicians before assuming responsibility themselves. The excellent results achieved and the rapid expansion of the A.I. movement in the States prove the efficiency of the system.

Insemination techniques

437. During the past fifteen years of artificial insemination work, the co-operatives, in collaboration with the scientific research workers at State colleges, have exerted every effort to improve the level of technical efficiency. As a result, the normal conception rate has risen from about 50 per cent non-returns to 70 per cent, after 40 to 60 days while the dilution rate has grown from 1 : 4 to 1 : 50 and more. According to present knowledge, 10,000 million motile sperm per insemination is a sufficient number.

438. For the preservation of unfrozen semen, diluters which contain either citrate-buffered yolk or heated milk are used. An anti-bacterial agent such as penicillin or streptomycin is always added. Milk diluters are preferred where one-day-old semen is used. When older semen is used, preservation with yolk is preferred.

439. Experiments concerning the maximum use of bulls have shown that about 35,000 semen portions per bull per year can be obtained and by induced sexual excitements the sperm-output can be doubled. With 2 ejaculates at eight-day intervals it was possible to obtain 75,000 semen portions per bull per year.

Preservation of semen by freezing

440. As the breeding season in some States is very limited, and as there can never be a constant demand for semen from day to day, it is impossible in practice to make use of a bull's full yielding capacity with current preservation methods. Increasing the use of the semen by improving these methods is therefore a matter of great importance and the freezing method, investigated by Polge and co-workers in England, has in this respect opened up new and highly interesting possibilities. At present, large-scale deep-freezing experiments are being conducted all over the States and promising results have already been obtained.

441. Thus, in Minnesota, where 1,012 cows were inseminated with frozen semen, 74 per cent non-returns were reported as compared with 72 per cent non-returns with frozen semen. In the Central Ohio Breeding Association, 26 out of 91 technicians used only deep-frozen semen and the remaining wanted to change over from fresh to deep-frozen semen as soon as possible. The use of deep-freezing mechanical equipment instead of dry ice seems to have increased the effectiveness of this new preservation technique.

Breeding programme

442. During the rapid expansion of the A.I. movement, most of the interest has been concentrated on improving insemination techniques and controlling various fertility disturbances.

443. The main aims of the breeding policy have been to improve commercial dairy herds and to make good bulls available to the owners of small herds. Bulls registered with the different breed registry organisations have been used and preference has been given to bulls proved in the Dairy Herd Improvement Associations (D.H.I.A.) or Herd Improvement Registry (H.I.R.).

444. To increase the accuracy of progeny-testing, some associations are adopting the Danish system of building special heifer-testing stations. In other associations the progeny-tests on field-collected data are being improved. The successful use of deep-frozen semen may in the near future greatly affect progeny-testing also.

445. The Purebred Dairy Cattle Association on its side recognises the importance of artificial insemination, which allows wider use to be made of the best bulls, but in its publication "Requirements Governing Artificial Insemination of Purebred Dairy Cattle" the Association emphasises the special and rigorous precautions which have to be taken in order to safeguard fully the proven worth of animals whose pedigrees

are registered in the Herd-Books of that Association. To that end, contracts in particular are drawn up with the semen-producing businesses and precise instructions are given to the inseminators.

446. As mentioned in other chapters of this report, great efforts are now being made in the States to solve breeding problems in general. The results obtained in this work will, of course, have a great influence on breeding policy in the A.I. movement.

Finance

447. In the co-operative associations a farmer has to pay from 5 to 15 dollars as a membership fee. This fee will in most cases be repaid when he leaves the association. In some cases the co-operatives also sell fixed-interest bonds and in other cases the expansion of the association may be financed by loans in the open market.

448. Depending mainly on the density of the cow-population in the movement, the insemination fee varies from 5 to 8 dollars. In some areas with low cow-density, the cost of artificial insemination is too high to make insemination possible, even with financial support from the Government. In commercial enterprises the work is completely financed by insemination fees.

Conclusion

449. Since the introduction of artificial insemination in the United States, great progress has been made not only in the spread of the movement but also in its management and in the insemination techniques. As a result of more efficient progeny-testing and the application of the deep-freezing technique, very great improvements can be expected in future in breeding policies.

MILK RECORDING

Historical background

450. In the United States, as has often been the case in Europe, milk recording was begun by the dairy cattle breeders' associations which were set up from 1870 onwards to safeguard the purity of breeds and the accuracy of the data collected.

451. 1886 saw the first attempt to make the recording of milk yields of registered cows reliable. Data published before that time consisted merely of non-comparable private surveys, tinged to some extent with fantasy.

452. In 1890 Babcock's test was introduced into milk analysis, and breeders' associations were thus able to establish Milk Recording Divisions in 1900, using more reliable methods.

453. About the same time, in 1905, the first Dairy Cow Testing Associations were organised by Helmer Raebild, a native of Denmark attached to the Food and Dairy Industry Department of the State of Michigan.

454. These associations test all dairy cows, whether registered or not, so as to supply all affiliated members with practical data on the management of their cows.

455. The association's milk inspector was approved by the College of Agriculture. The Federal Department of Agriculture soon became aware of the movement started by Raebild and got him to help in developing a Federal milk recording programme which culminated in 1930 in the conversion of the Dairy Cow Testing Associations into Dairy Herd Improvement Associations (D.H.I.A.) and the establishment of a national programme for the development of these associations and a national sire-improving programme.

Type of milk recording

456. This brief historical survey explains why there are at present two types of milk recording in the United States :

- a) milk recording operated by the Herd-Book Societies,
- b) milk recording operated by the D.H.I.A.

457. Milk recording in these freely constituted organisations is operated on a voluntary basis. In the case of the Breed or Herd-Book Societies, it should be noted that all the Herd-Books in the United States are closed and that most societies register in their Herd-Books only milk records guaranteed by the Associations.

Milk recording in the Herd-Book Societies

458. This type of milk recording is carried out and guaranteed by the Pure Breed Associations. It takes two separate forms :

- 1) Advanced Registry Tests applicable to one or more cows registered in the Herd-Book. Cows are officially tested for 24 or 48 hours every month. The daily yield measured by the owner must also be reported monthly to the Association. Yields are calculated on the basis of 305 or 365 days' lactation.

- 2) Herd Improvement Registry Tests, being monthly milk tests of the whole herd. In this case the breeder is not asked to state the weight of daily yields.

459. Out of 24, 000, 000 dairy cows in the United States some 350,000 are at present subject to milk recording organised by the Herd-Book Societies.

460. The chief purpose of this recording is to develop the best pure-bred animals and assemble the data needed for selection within the Herd-Books.

461. With the exception of the Jersey Herd-Book (Jersey Cattle Club), breeders' societies do not yet accept the results of milk recording organised by the Dairy Herd Improvement Associations.

462. Nevertheless, in 25 per cent of the cases the inspectors who work for the D.H.I.A. also do the milk recording for the breeders' societies.

Milk recording carried out
by the Dairy Herd Improvement Associations (D.H.I.A.)

463. These are associations of farmers who own dairy cows - not necessarily pure-bred or registered in the Herd-Books - and which, as stated above, are freely constituted on a voluntary basis. This milk recording is guaranteed by the Agricultural Colleges. The programme is worked out jointly by the Federal Department of Agriculture, the universities or agricultural colleges and the Associations.

464. The primary aim of a Dairy Herd Improvement Association is to provide members at low cost with data enabling them to improve the productive efficiency of their herds.

465. These data comprise a description of the animal (ringing the right ear for animals not registered in the Herd-Books), their pedigree, their progeny, their yield, cost of feed and gross income. The farmer can thus eliminate unprofitable cows, feed the others according to their yield, and select the most suitable animals for breeding purposes in order to increase the productivity of the herd.

Organisations

1. Local associations

466. A typical local association consists of about 25 farmers, each owning on an average 35 dairy cows, and jointly employing a milk inspector officially approved and trained by the College of Agriculture.

467. To be certain of selecting a competent inspector, the directors of the association usually apply for advice to the dairy husbandry expert attached to the State Extension Service.

468. The qualities generally required of a milk inspector are : a thorough knowledge (acquired by experience, study or training) of modern methods of breeding, feeding and management of a dairy herd and last but not least, enthusiasm for the job. In addition, before starting work, he is carefully trained by the College of Agriculture in the technique and practice of milk recording.

2. County associations

469. In recent years more and more associations have been organised on a county basis - a subdivision of an American State comparable to a French "département".

470. The county association employs as many milk inspectors as it needs to organise milk recording in the herds of all members. The present tendency is for these county associations to set up a central analytical laboratory in each county where all samples are analysed and the results calculated.

3. National associations

471. In certain States the local or county associations have formed a National Federation, the board of directors being composed of the representatives of the local or county associations.

472. Such a national organisation, where it exists, renders substantial services in developing the Federal dairy herd improvement programme in the State ; in particular, it facilitates :

- the establishment of the policy and rules of the Dairy Herd Improvement Association Programmes (D.H.I.A.P.) for the whole State ;

- the co-ordination of the programmes of local associations ;

- the uniform interpretation of the rules of the D.H.I.A.P. ;

- the establishment of working standards for milk inspectors ;

- the standardisation of the statutes of local or county associations and of milk inspectors' contracts ;

- the co-ordination on a State basis of insurance and social security questions concerning milk inspectors.

473. There is no federation or Federal organisation of the D.H.I.A.

Types of D.H.I.A. milk recording

474. Four types of milk tests are carried out under the D.H.I.A.

1. Standard milk test

This is carried out monthly during the period of lactation. It is based on 305 days at two milkings a day and is adjusted for the age of the animal. The age correction factors vary according to breed and are changed with every 3 months of age.

2. Bi-monthly milk tests

This is the same as the standard milk test, but is carried out twice a month.

3. Combined milk test

The cow is tested once a month by the official inspector as in the standard test and once by the owner in the interval between the official tests. Only the official data are used in the Federal programme.

4. Owner-sample test

This is carried out entirely by the owner of the animals, who weighs each cow's milk and takes samples. The official inspector assembles the data of this test, collects the samples when visiting the neighbourhood and has them analysed in the central laboratory. The results of the analysis and the calculations made are sent to the breeder by post.

The results of such milk recording are used only in the breeder's herd. They are not published and no official use is made of them, understandably so since they are not obtained by an impartial person. These data are, however, important to the breeder since they enable him to feed his cows according to their production, to eliminate unprofitable cows and to select those whose daughters will replace animals which are being withdrawn from the herd. Very often the owner-sample test serves as a prelude to the breeder's participation in the standard milk test and to his joining the Federal improvement programme.

475. Some 1,400,000 cows are at present subject to standard, fortnightly or combined milk tests. 500,000 animals are covered by the owner-sample test (O.S.).

Work of the milk inspector

Bases

476. In order to obtain comparable and reliable results the standard milk test is carried out in accordance with the rules laid down by the American Dairy Science Association; the principal points are summarised below:

- a) in all herds weighing, sampling and analysis of milk must be done by the milk inspector (the analysis may be entrusted to an official central laboratory);

- b) all cows of milking age in the herd must be tested ;
- c) all cows in the herd, including dry cows, which have been tested during the year, must be included in the annual average of the herd ;
- d) the inspector must use the figures which he has obtained himself on the testing day as a basis for calculating the monthly and annual yields. All reports must be written and submitted by the inspector.

477. The inspector may never alter these basic rules and is responsible for applying them. The interpretation of these rules is the concern of the dairy husbandry expert of the State Extension Service.

Daily routine

478. It is unnecessary to dwell at length on the daily routine of the milk inspector. Sufficient to say that, in addition to the milk weight and the fat content analysis (analysed by the inspector on the spot or in the central laboratory), the inspector records in the Barn Book :

- detailed description of the animals ;
- dates of drying off ;
- consumption of feed ;
- quantity and cost of feed consumed during the testing period ;
- selling price of the milk or fatty matter ;
- weight of cows after calving (estimated with tape).

479. He also transfers the following data at regular intervals to the Herd Record Book which will be described later :

- total and average individual yields ;
- data concerning total and average yields of the herd ;
- other data necessary for herd improvement purposes.

480. In the case of cows which have completed the first 305 days of their lactation period and of dry cows, the inspector fills up one statistical card per cow (B.D.I.-718) and sends it to the State Dairy Service which forwards it to the Federal Bureau. The date of transmission of this card is entered in the Herd Record Book.

481. The Barn Book and the Herd Record Book are supplied by the College of Agriculture and remain the property of the farmer.

482. Furthermore, on the basis of the data collected in the Herd Record Book, it is the milk inspector's job to discuss with the owner any problems arising in the herd and explain to the breeder how to use these data to improve the feeding, management and selection of his dairy herd. The assistance of the dairy husbandry expert may, if necessary, be requested for this purpose.

Documents used

a) Barn Book

483. This consists of a loose-leaf notebook, size 25/28 cm. (front sheet, fig. 1 and back sheet, fig. 2). The blank sheets are kept by the milk inspector who adds a page to the notebook every month.

484. In addition, the milk inspector enters on the back monthly recommendations for the proper feeding of the herd.

485. The Barn Book sheet is always completed in duplicate, the farmer keeping the carbon copy and the original being forwarded by the inspector to the State Central Office.

b) Herd Record Book

486. This is also a loose-leaf notebook bound in a special cover. It is designed to reduce the inspector's written work as much as possible, and yet to provide the breeder with full information on his cows and herd.

487. The main forms which it contains are as follows :

Monthly herd summary (B.D.I. - D.H.I.A. - 12)

Each month the totals in the Barn Book are transferred to this form (fig. 3). At the end of the year the total and the average performance of the herd are thus obtained, and also :

- the value of the products,
- the feed consumed,
- the cost of the feed,
- and the gross profit of the herd for the year.

Ten-yearly herd summary (B.D.I. - D.H.I.A. - 14)

The average annual results as shown on the form (fig. 3) are transferred each year to the ten-year table (fig. 4) and compared with the Association's averages. The farmer can thus see whether the performance of his herd over several years is higher or lower than the general average for the Association and what progress his herd has made. On the back of this sheet (fig. 5) there is a table for recording the number of animals which have left the herd for various reasons (disease, sale, death, etc.).

Register of animals in herd

This is also included in the Herd Record Book and gives the name, ring or brand number, date of birth, breed, sex, name and number of sire and dam, and date of identification of animal. This herd index is kept constantly up to date by the milk inspector.

Yearly record of individual cows (B.D.I. - D.H.I.A. - 21)

Every year the inspector enters on this form (fig. 6) the annual record of each individual cow, together with the total and average for the herd.

Life record of each cow (B.D.I. - D.H.I.A. - 22)

As seen from figure 7, this form is designed to record the daily and monthly production and the feeding data for one cow over a period of four years (front-back), together with notes on the end of lactation, calving, mating of cow, etc. A summary is provided at the bottom of this form. All these data are taken each month from the Barn Book.

Proved-sire record (B.D.I. - D.H.I.A. - 32)

The proved-sire record of the bull used on the farm is established by comparing the yields of at least 5 of his daughters with those of their dams in order to determine the milk and butter production capacity transmitted by the sire. The yields are those recorded for the first 305 days of lactation, adjusted for age, on the basis of two milkings a day. This is not really an ideal test of the sire, as the dams and daughters are not necessarily quite identically situated as regards environment and feeding; but it is a test of the sire in normal working conditions. Even if the dams and daughters are bred on the same farm, it is impossible to eliminate completely the influence of the year, for example, on the milk record. This comparison is, however, considered sufficient to give the breeder useful information about the value of his bull and its capacity to transmit dairy characters. Research work done in the United States has shown that in normal working conditions the comparison of 5 couples of dams and daughters gave adequate proof of a sire; in general, however, it is considered that the larger the number of dams and daughters tested, the more reliable will be the conclusion reached. This question will be discussed later in the paragraphs on selection of dairy cattle.

This form (fig. 8) is not completed by the milk inspector but by the Federal Dairy Bureau. On the basis of the statistical card B.D.I. - 718 (fig. 9) giving the yearly record of individual cows, the Central Registry prepares several copies of this form, four of which go to the State - for the inspector, the owner, the county officer and the State Dairy Bureau.

Transmission of results to the Central Bureau

488. For the purposes of statistical analysis of the milk recording at State and Federal level, the milk inspector has to send the State Central Bureau :

i) for each cow which has completed its first 305 days of lactation (or dried off), the statistical card B.D.I. - 718 (fig. 9).

Association Greene County Owner (12437) Jim Smith Address Smithville, Md
Date tested Oct 20, 1948 Centering date 20th Test period from Oct 5, 1948 to Nov 4, 1948 Days in test period 31 Days on pasture 0 James Row Supervisor.

Sample No.	Cow's name and ear tag or registration No.	Days in Testing Period			Milk (Pounds)		BUTTERFAT		VALUE OF PRODUCT		DAILY AND MONTHLY FEED AMOUNTS				COST OF FEED				VALUE ABOVE OR BELOW FEED COST (circle negative)	REMARKS Dates: Bred, calved, dry, aborted, sold, purchased, sick, dead, etc. Notes: Number of quarters, offspring, other factors affecting record	
		On test	In milk	Dry	DAILY		Monthly total	Per-centage	Pounds	Price		Pounds	Pounds	Pounds	Pounds	Pasture	Barn or rack-fed roughage	Con-centrates			Total
					p. m. a. m.	Total				Butter-fat Milk	Total										
1	51-4825 Dot	31	31		7.4 8.4	15.8	500	4.8	24	1.13	27.10										
2	51-4821 Rosini	31	31		14.5 14.5	29.0	900	3.5	32	1.13	36.20										
3	51-4817 Lucie	31	24	7	10.1 10.7	20.8	500	4.4	22	1.13	24.90										F. 10-9-48 19. 51-4967
4	1209330	31	31		10.1 10.4	20.5	640	4.1	26	1.13	29.40										
5	51-4836 Stubby	31	31		7.9 8.9	16.8	530	4.0	21	1.13	23.70										
6	51-4850 Betty	31	31		9.5 6.4	15.9	500	4.2	21	1.13	23.70										
7	51-4847 Daisy	31	31		7.8 7.1	14.9	470	4.0	19	1.13	21.50										
8	1402567	31	31		14.1 12.0	26.1	810	4.2	34	1.13	38.40										
9	51-4838	31	11	20		7.6	80	3.6	3	1.13	3.40										Dry 10-16-48 11 days Oct credit
10	51-4826	31	31																		
11	1043987	31	31		10.0 10.2	20.2	620	3.6	22	1.13	24.90										
12	51-4824	31	31		13.2 12.9	26.1	810	4.1	33	1.13	37.30										
13	51-4828 Jane	31	31		13.0 15.0	28.0	870	4.0	35	1.13	39.60										
	51-4821 Rosini		7			29.0	220	3.5	7	1.13	7.90										F. 9-25-48 7 days H. 51-4968 credit Purchased 9-23-48 11 days Sept credit
	51-4828 Jane		11			28.0	310	4.0	12	1.13	13.60										
This form is being revised and this page of the Manual will be replaced when the new forms are available.																					
Total		403	345	58			7130		292	330	105270	4650	3230	6026	7270	132.90	197.26				
Average ¹		13.0					556	4.0	22.5	25.39	405	358	248	4.63	5.59	10.22	15.17				

¹ The average entered in the first column (cow-months) is obtained by dividing the total days on test by the number of days in the testing period. To obtain the other averages, divide each total by the number of cow-months.

16-80829-2

[OVER]

FEED PRICES

(Fig. 2)

ROUGHAGE

CONCENTRATES

Kind	Quality	Price per ton	Amount	Kind	PROTEIN		Cost	
					Percentage	Pounds	Per cwt.	Total
Silage (10 baskets 17")				corn and cob meal	100*	5.3	5.3	7.50
(170" x 31 days) 5270	G	7.00	18.40	Oats	200*	9.4	18.8	7.00
Mixed Hay (3 bales 50")				Barley	100*	10.0	10.0	1.50
(150" x 31 days) 4650	F	18.00	41.80	Bran	100*	13.0	13.0	7.50
Total			60.20	Oil meal	100*	30.8	30.8	3.00
					600*	77.9		13.50

Pounds of protein = Percentage protein in grain mixture
Pounds of concentrates =

Cost \$7.25 per cwt.

PRICE RECEIVED FOR PRODUCT: Butterfat _____ per pound. Whole milk \$4.50 (4% 5¢ differential) _____ per cwt.

Bottled milk _____ per gallon. Other _____ per _____ Skim milk (price credited) _____ per cwt.

Suggested ration:

no change

Cost _____ per cwt.

Herd and dairy improvements noted:

Individual animals being fed more nearly according to production

Improvements suggested:

none

Separator test _____ percent.

Pounds of butterfat lost _____

Value of butterfat lost, \$ _____

This form is being revised and this page of the Manual will be replaced when the new forms are available.

[OVER]

MONTHLY HERD SUMMARY

Budget Bureau No. 40-R1694.1.
Form approved.

Centering date _____ Record from _____, 19____ to _____, 19____

Herd of _____

Date that test was made	Testing period	TOTAL COW-DAYS			PRODUCTION			Unit price Milk Fat	Total value of product	HERD AVERAGE		FEEDS CONSUMED DURING TESTING PERIOD				Cow-days on pasture	COST OF FEED				Value above or below cost of feed (Circle negative)
		On test	In milk	Dry	Milk (pounds)	Test %	Butterfat (pounds)			Milk (pounds)	Butterfat (pounds)	Roughage (pounds)		Concentrates (pounds)			Pasture	Barn or rack-fed roughage	Concentrates	Total cost of feed and pasture	
												\$	¢	\$	¢						
Monthly adjustment	to																				
Monthly adjustment	to																				
Monthly adjustment	to																				
3 mo. total																					
Monthly adjustment	to																				
Monthly adjustment	to																				
Monthly adjustment	to																				
6 mo. total																					
Monthly adjustment	to																				
Monthly adjustment	to																				
Monthly adjustment	to																				
9 mo. total																					
Monthly adjustment	to																				
Monthly adjustment	to																				
Monthly adjustment	to																				
Total for year ¹																					
Average cow-year basis ²																					

¹ Data on "Total for year" line are reported on Form BDI-780.² Data on this line are transferred to Ten Year Herd Summary sheet, BDI-DHIA-14.³ Total cow-days on test is divided by 365 to obtain number of cow-years. Data on line "Total for year" are divided by number of cow-years to obtain herd average on cow-year basis.

Yearly summary reported

(Date)

(Supervisor's signature)

(Fig. 3)

TEN-YEAR HERD SUMMARY

(YEARLY HERD AVERAGES—COW-YEAR BASIS)

Budget Bureau No. 40-R1605.1
Form approved.

Herd of

[illegible]

TEN YEAR PROGRESS IN IMPROVING YOUR HERD

The table below, when properly filled out each year, will enable you to see the year-by-year progress you are making in improving your herd. As you continue testing, the proportion of cows in the high-production brackets should increase and the proportion of cows in the low brackets should decrease or disappear.

The rectangle of the production group in which the association average falls is boxed in each year so you can see at a glance how many cows you have *above, at, or below* the average cow of the association.

TO THE SUPERVISOR:

At the end of the association year, record the number of cows in the herd in each production group. Include all cows on test 12 months.

Obtain these data by checking the yearly production of each cow on Form BDI-DHIA-22, Lifetime Record of Individual Cow. Count the number of cows in each production group. Use actual production of butterfat as recorded. Do not compute to a 2-time-milking mature-equivalent basis.

When the average production of butterfat per cow for the Association is obtained, record the average on the bottom line of the table at the right. Also run a heavy line around the rectangle of the production group in which the association average falls.

Butterfat production per cow:	Number of cows producing different amounts of butterfat each year—									
	19__	19__	19__	19__	19__	19__	19__	19__	19__	19__
425 pounds or more.....										
400 to 424 pounds.....										
375 to 399 pounds.....										
350 to 374 pounds.....										
325 to 349 pounds.....										
300 to 324 pounds.....										
275 to 299 pounds.....										
Under 275 pounds.....										
ASSOCIATION AVERAGE.....										

(Fig. 4)

NUMBER OF COWS LEAVING THE HERD Each Year—by Age

16-6120-1-12

REASONS for leaving herd	19____ Age (in years)										19____ Age (in years)										19____ Age (in years)										19____ Age (in years)									
	Age (in years)										Age (in years)										Age (in years)										Age (in years)									
	2	3	4	5	6	7	8	9 and Over	Total	2	3	4	5	6	7	8	9 and Over	Total	2	3	4	5	6	7	8	9 and Over	Total	2	3	4	5	6	7	8	9 and Over	Total				
HEALTH:																																								
Mastitis																																								
Bangs																																								
Udder trouble																																								
Sterility																																								
Tuberculosis																																								
Other																																								
Subtotal																																								
Low production																																								
Old age																																								
Died																																								
Accident																																								
Sold for dairy purposes																																								
Other reasons																																								
Total																																								
Leaving for health reasons %	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x						

REASONS for leaving herd	19____ Age (in years)										19____ Age (in years)										19____ Age (in years)										19____ Age (in years)									
	Age (in years)										Age (in years)										Age (in years)										Age (in years)									
	2	3	4	5	6	7	8	9 and Over	Total	2	3	4	5	6	7	8	9 and Over	Total	2	3	4	5	6	7	8	9 and Over	Total	2	3	4	5	6	7	8	9 and Over	Total				
HEALTH:																																								
Mastitis																																								
Bangs																																								
Udder trouble																																								
Sterility																																								
Tuberculosis																																								
Other																																								
Subtotal																																								
Low production																																								
Old age																																								
Died																																								
Accident																																								
Sold for dairy purposes																																								
Other reasons																																								
Total																																								
Leaving for health reasons %	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					

(Fig. 5)

INDEX AND YEARLY RECORD OF INDIVIDUAL COWS

This index shall be made at the beginning of each testing year and shall include all cows on test during the testing year. At the end of the testing year, or when a cow leaves the herd during the testing year, the production totals for each cow are transferred from her individual Lifetime Record (BDI-DHIA-22) to this form. Total production for the herd for the testing year is obtained by totaling the individual production records listed on this form. As cows leave the herd, their records (BDI-DHIA-22) are moved either to the back of the cow-record section or to an inactive book.

[illegible]

LIFETIME RECORD OF INDIVIDUAL COW

Page No. 6

Registration name _____ Registration No. _____ Barn name Rosnu Eartag No. 51-4821
Breed La. H. Date of birth Jan. 26, 19 45 Check if cow is progeny of artificial insemination ☐ Sire Rosnu Homestead, Netherlands, Legio Eartag or Registration No. 489435
Date fresh _____ Date bred _____ Sire used 518841 Dam Rosnu Eartag or Registration No. 51-4768
before testing year Aug. 22, 19 47 before testing year Dec. 16, 19 47

Testing period from <u>Apr. 5, 1947</u> to <u>Apr. 4, 1948</u>	Days on test	Days in milk	Num- ber days milking (same as test)	Milk produced (pounds)		At- tache- ment (%)	Butter- fat (pounds)	Value of product	Concen- trate fed monthly (pounds)	Cost of concentrate	Total cost of feed	Value of product over feed cost (net)	Remarks: Dates bred, calving, dry, shorted, sick, died, When 305-day record ends, etc.	Weight 1125	Classification	Production since last fresh	Days on test	Days in milk	Num- ber days milking (same as test)	Milk produced (pounds)		At- tache- ment (%)	Butter- fat (pounds)	Value of product	Concen- trate fed monthly (pounds)	Cost of concentrate	Total cost of feed	Value of product over feed cost (net)	Remarks: Dates bred, calving, dry, shorted, sick, died, When 305-day record ends, etc.	Weight 1125	Classification	Production since last fresh
				Daily	Monthly															Daily	Monthly											
Production since last fresh																																
4/5 to 3/4	30	30	21.3	7790	236	22	2720	270																								
3/5 to 2/4	31	31	22.6	7003	22	22	2870	250																								
Total to date	61	61	x	1340	x	44	5590	520																								
2/5 to 1/4	30	30	23.0	6903	21	21	2790	240																								
Total to date	91	91	x	2030	x	65	8380	760																								
1/5 to 12/4	31	31	24.7	3503	13	13	1500	190																								
Total to date	122	122	x	2380	x	78	9880	950																								
12/5 to 11/4	31	31	25.1	2380	x	78	9880	1070																								
Total to date	153	153	x	2003	7	7	790	150																								
11/5 to 10/4	31	31	24.0	9003	32	32	3620	310																								
Total to date	184	184	x	3480	x	117	14490	1530																								
10/5 to 9/4	30	30	25.4	8503	28	28	3530	300																								
Total to date	214	214	x	4330	x	145	17820	1830																								
9/5 to 8/4	31	31	26.5	8203	26	26	3360	310																								
Total to date	245	245	x	5150	x	171	21180	2140																								
8/5 to 7/4	31	31	24.5	7603	26	26	3190	280																								
Total to date	276	276	x	5910	x	197	24370	2420																								
7/5 to 6/4	28	28	23.6	6603	23	23	2800	260																								
Total to date	304	304	x	6570	x	220	27170	2680																								
6/5 to 5/4	31	31	21.7	6703	23	23	2810	280																								
Total for year	365	365	x	7240	34	34	29980	2960																								

LACTATION PRODUCTION SUMMARY

The Supervisor shall report all 305-day lactation records to State Agricultural College on Form BDI-718

Date fresh	Weight when fresh	Age Year/Month	Days in milk	Number days milked 2 times a day	TOTAL PRODUCTION			FIRST 305 DAYS		305-DAY MATTER EQUIVALENT RECORD		Date reported on 718	Supervisor's initial when record is reported
					Milk (lb.)	Test (%)	B'fat (lb.)	Milk (lb.)	B'fat (lb.)	Milk (lb.)	B'fat (lb.)		
8-22-47	1150	7-7	338		10170	3.4	343	9610	324			6-20-48	JRB

Fig. 7. Front page of the lifetime record

BARITA ORRENTY TORRES REBORN
Born 4-29-43; passed 8-31-50; alive; alive;
Soc. 707000; 190000;
Used in Northwest Minnesota A. B. A.

Holstein 2150 (M. F. 1900)

State: Minn.

SEVEN OF THE 1000

Year	Age	Sex	Weight	Height	Length	Width	Depth	Area	Volume	Weight	Height	Length	Width	Depth	Area	Volume
1943	1	M	100	10	10	10	10	10	10	100	10	10	10	10	10	10
1944	2	M	110	11	11	11	11	11	11	110	11	11	11	11	11	11
1945	3	M	120	12	12	12	12	12	12	120	12	12	12	12	12	12
1946	4	M	130	13	13	13	13	13	13	130	13	13	13	13	13	13
1947	5	M	140	14	14	14	14	14	14	140	14	14	14	14	14	14
1948	6	M	150	15	15	15	15	15	15	150	15	15	15	15	15	15
1949	7	M	160	16	16	16	16	16	16	160	16	16	16	16	16	16
1950	8	M	170	17	17	17	17	17	17	170	17	17	17	17	17	17
1951	9	M	180	18	18	18	18	18	18	180	18	18	18	18	18	18
1952	10	M	190	19	19	19	19	19	19	190	19	19	19	19	19	19
1953	11	M	200	20	20	20	20	20	20	200	20	20	20	20	20	20
1954	12	M	210	21	21	21	21	21	21	210	21	21	21	21	21	21
1955	13	M	220	22	22	22	22	22	22	220	22	22	22	22	22	22
1956	14	M	230	23	23	23	23	23	23	230	23	23	23	23	23	23
1957	15	M	240	24	24	24	24	24	24	240	24	24	24	24	24	24
1958	16	M	250	25	25	25	25	25	25	250	25	25	25	25	25	25
1959	17	M	260	26	26	26	26	26	26	260	26	26	26	26	26	26
1960	18	M	270	27	27	27	27	27	27	270	27	27	27	27	27	27
1961	19	M	280	28	28	28	28	28	28	280	28	28	28	28	28	28
1962	20	M	290	29	29	29	29	29	29	290	29	29	29	29	29	29
1963	21	M	300	30	30	30	30	30	30	300	30	30	30	30	30	30
1964	22	M	310	31	31	31	31	31	31	310	31	31	31	31	31	31
1965	23	M	320	32	32	32	32	32	32	320	32	32	32	32	32	32
1966	24	M	330	33	33	33	33	33	33	330	33	33	33	33	33	33
1967	25	M	340	34	34	34	34	34	34	340	34	34	34	34	34	34
1968	26	M	350	35	35	35	35	35	35	350	35	35	35	35	35	35
1969	27	M	360	36	36	36	36	36	36	360	36	36	36	36	36	36
1970	28	M	370	37	37	37	37	37	37	370	37	37	37	37	37	37
1971	29	M	380	38	38	38	38	38	38	380	38	38	38	38	38	38
1972	30	M	390	39	39	39	39	39	39	390	39	39	39	39	39	39
1973	31	M	400	40	40	40	40	40	40	400	40	40	40	40	40	40
1974	32	M	410	41	41	41	41	41	41	410	41	41	41	41	41	41
1975	33	M	420	42	42	42	42	42	42	420	42	42	42	42	42	42
1976	34	M	430	43	43	43	43	43	43	430	43	43	43	43	43	43
1977	35	M	440	44	44	44	44	44	44	440	44	44	44	44	44	44
1978	36	M	450	45	45	45	45	45	45	450	45	45	45	45	45	45
1979	37	M	460	46	46	46	46	46	46	460	46	46	46	46	46	46
1980	38	M	470	47	47	47	47	47	47	470	47	47	47	47	47	47
1981	39	M	480	48	48	48	48	48	48	480	48	48	48	48	48	48
1982	40	M	490	49	49	49	49	49	49	490	49	49	49	49	49	49
1983	41	M	500	50	50	50	50	50	50	500	50	50	50	50	50	50
1984	42	M	510	51	51	51	51	51	51	510	51	51	51	51	51	51
1985	43	M	520	52	52	52	52	52	52	520	52	52	52	52	52	52
1986	44	M	530	53	53	53	53	53	53	530	53	53	53	53	53	53
1987	45	M	540	54	54	54	54	54	54	540	54	54	54	54	54	54
1988	46	M	550	55	55	55	55	55	55	550	55	55	55	55	55	55
1989	47	M	560	56	56	56	56	56	56	560	56	56	56	56	56	56
1990	48	M	570	57	57	57	57	57	57	570	57	57	57	57	57	57
1991	49	M	580	58	58	58	58	58	58	580	58	58	58	58	58	58
1992	50	M	590	59	59	59	59	59	59	590	59	59	59	59	59	59
1993	51	M	600	60	60	60	60	60	60	600	60	60	60	60	60	60
1994	52	M	610	61	61	61	61	61	61	610	61	61	61	61	61	61
1995	53	M	620	62	62	62	62	62	62	620	62	62	62	62	62	62
1996	54	M	630	63	63	63	63	63	63	630	63	63	63	63	63	63
1997	55	M	640	64	64	64	64	64	64	640	64	64	64	64	64	64
1998	56	M	650	65	65	65	65	65	65	650	65	65	65	65	65	65
1999	57	M	660	66	66	66	66	66	66	660	66	66	66	66	66	66
2000	58	M	670	67	67	67	67	67	67	670	67	67	67	67	67	67
2001	59	M	680	68	68	68	68	68	68	680	68	68	68	68	68	68
2002	60	M	690	69	69	69	69	69	69	690	69	69	69	69	69	69
2003	61	M	700	70	70	70	70	70	70	700	70	70	70	70	70	70
2004	62	M	710	71	71	71	71	71	71	710	71	71	71	71	71	71
2005	63	M	720	72	72	72	72	72	72	720	72	72	72	72	72	72
2006	64	M	730	73	73	73	73	73	73	730	73	73	73	73	73	73
2007	65	M	740	74	74	74	74	74	74	740	74	74	74	74	74	74
2008	66	M	750	75	75	75	75	75	75	750	75	75	75	75	75	75
2009	67	M	760	76	76	76	76	76	76	760	76	76	76	76	76	76
2010	68	M	770	77	77	77	77	77	77	770	77	77	77	77	77	77
2011	69	M	780	78	78	78	78	78	78	780	78	78	78	78	78	78
2012	70	M	790	79	79	79	79	79	79	790	79	79	79	79	79	79
2013	71	M	800	80	80	80	80	80	80	800	80	80	80	80	80	80
2014	72	M	810	81	81	81	81	81	81	810	81	81	81	81	81	81
2015	73	M	820	82	82	82	82	82	82	820	82	82	82	82	82	82
2016	74	M	830	83	83	83	83	83	83	830	83	83	83	83	83	83
2017	75	M	840	84	84	84	84	84	84	840	84	84	84	84	84	84
2018	76	M	850	85	85	85	85	85	85	850	85	85	85	85	85	85
2019	77	M	860	86	86	86	86	86	86	860	86	86	86	86	86	86
2020	78	M	870	87	87	87	87	87	87	870	87	87	87	87	87	87
2021	79	M	880	88	88	88	88	88	88	880	88	88	88	88	88	88
2022	80	M	890	89	89	89	89	89	89	890	89	89	89	89	89	89
2023	81	M	900	90	90	90	90	90	90	900	90	90	90	90	90	90
2024	82	M	910	91	91	91	91	91	91	910	91	91	91	91	91	91
2025	83	M	920	92	92	92	92	92	92	920	92	92	92	92	92	92
2026	84	M	930	93	93	93	93	93	93	930	93	93	93	93	93	93
2027	85	M	940	94	94	94	94	94	94	940	94	94	94	94	94	94
2028	86	M	950	95	95	95	95	95	95	950	95	95	95	95	95	95
2029	87	M	960	96	96	96	96	96	96	960	96	96	96	96	96	96
2030	88	M	970	97	97	97	97	97	97	970	97	97	97	97	97	97
2031	89	M	980	98	98	98	98	98	98	980	98	98	98	98	98	98
2032	90															

This card is sent to the College of Agriculture to be checked by the dairy husbandry expert and is then forwarded to the Federal Bureau. The type of animal (judged at shows for example) is determined by the following classification :

Excellent	(E)
Good plus	(G+)
Good	(G)
Fair	(F)
and Poor	(P)

ii) Monthly reports

Every month the milk inspector forwards to the dairy husbandry expert a monthly report on the milk records obtained in his association. The form of these reports varies from one State to another. Data of general interest to the State on the progress and improvements recorded and the activity of the associations are extracted from the report and published.

iii) Annual report

At the end of each inspection year an annual report is forwarded on card D.H.I.A. - 780 (fig. 10) for each herd tested.

This states

- total annual production of herd,
- total value of products obtained,
- total quantity of feed consumed by the herd in the inspection period,
- total cost of feed.

These latter data are extracted from forms B.D.I. - D.H.I.A.-21 (fig. 6) and B.D.I. - D.H.I.A. -12 (fig. 3) described above. The quality of the fodder, silage and grass is classified as :

Excellent	(E)
Good	(G)
Fair	(F)
Poor	(P)

489. These data are analysed at association and State level by the dairy husbandry expert and at Federal level by the Bureau of Dairy Industry in order to determine :

- herd production levels in the various associations,
- relation between production and value of products,
- quantity of feed consumed,
- cost of feed consumed,
- gross income over and above cost of feed.

Use of D.H.I.A. milk records

490. In view of the considerable volume of data handled, a special Federal department is responsible for centralising and analysing them with the help of the latest electrical office

DHIA PRODUCTION REPORT
FIRST 305 DAYS OF LACTATION PERIOD

COW IDENTIFICATION		BREED		SIRE OF COW		BREED		USE BLACK INK ONLY		DO NOT FOLD	
NUMBER	DATE OF BIRTH	MONTH	DAY	YEAR	NUMBER	DATE OF BIRTH	MONTH	DAY	YEAR	NUMBER	DATE OF BIRTH
3477008	12-19-50	12	19	50	33 RH	1072626	RH				
11-30-52	11	30	52		3049896	RH					
DATE OF CALVING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING	DATE OF MILKING
MONTH	DAY	YEAR	MONTH	DAY	YEAR	MONTH	DAY	YEAR	MONTH	DAY	YEAR
11	30	52	11	30	52	11	30	52	11	30	52
REMARKS:				FOR RECORDS LESS THAN 305-DAYS:				DO NOT WRITE IN THIS SPACE			
HERD OWNER NAME AND ADDRESS				DATE DRY				DATE COW LEFT HERD			
John Doe, R. 1, Markesan				17144				17144			
ASSOCIATION:				Dodge Co. Co-op. D.H.S.A.				Dodge Co. Co-op. D.H.S.A.			
CERTIFIED BY DHA SUPERVISOR:				STATE				DATE			
Jack Smith				W.I.				3-3-54			
REPORTED THROUGH AND APPROVED BY STATE AGRICULTURAL COLLEGE											

100-851696

HERD CODE 12437	OWNER'S NAME Tom Smith	TESTING YEAR 1948	TESTING YEAR 1948
BREED OF HERD H	ADDRESS OF OWNER Smithville, Md.	COW-DAYS MILKED 3 X 782	
AV. WT. OF HERD 1260	ASSOCIATION OR COUNTY Green County	COW-DAYS MILKED 3 X 782	
TOTAL COW-DAYS ON TEST	CONCENTRATES FED	14	468
MILK (POUNDS)	TOTAL COW-DAYS ON PASTURE	6	2596
BUTTERFAT (POUNDS)	COST OF PASTURE		214
VALUE OF PRODUCT	COST OF ROUGHAGE		782
SUCCULENT ROUGHAGE FED	COST OF CONCENTRATES		1053
DRY ROUGHAGE FED	TOTAL FEED COST		2048
CERTIFIED BY DHIA SUPERVISOR: H. W. R. R.	DATE:	3-21-49	

Fig. 10

machines. This is the Central Registry of the United States Bureau of Dairy Industry.

491. On the basis of the statistical card B.D.I.-718 described above, this department prepares two cards for each cow :

- i) cow summary card, for the Bureau of Dairy Industry (fig. 11).
- ii) detailed cow card, for the Dairy Husbandry Research Branch (fig. 12).

492. These two cards enable these departments to undertake any relevant statistical studies, in particular the proved-sire record, the preparation of B.D.I. - D.H.I.A. - 32 (fig. 8) for each bull and the publication of the list of proved sires.

493. On the basis of D.H.I.A. - 780 the Federal Documents Reproduction Department prepares the perforated card shown in figure 13, entitled "Herd and Association Total Card", which is used for statistical analyses concerning herds and associations.

494. Thus jointly centralised and analysed, the milk records enable the American authorities to develop the national breeding and selection programme, to study the progress accomplished over the years, to trace high-grade breeds and lines and to disseminate information to encourage propagation of these lines among dairy herds.

495. During its first fifteen years of operation this Central Registry has compiled 4,000,000 records.

496. Data for the analysis of individual herd improvement have been compiled and centralised for over 40,000 association herds and 150,000 sires have been proved by comparing the production of dams and daughters. This shows the vast extent of this milk recording and breeding programme, which becomes larger and larger every year.

Conclusions

497. The system of milk recording used in the United States seems to meet the requirements which might be formulated in this field. Of the 24,000,000 dairy cows in the country, only 1,333,886 are inspected, i.e. 5 per cent of all livestock. Such a low percentage may seem surprising, but the fact that participation in the D.H.I.A. is entirely voluntary, without any direct or indirect obligation, explains its slow progress. It should also be noted that the low percentage of cows tested acts as a limiting factor in the testing of bulls. For this reason steps to increase it are at present under consideration in the United States.

[illegible]

IBM 787694

149

OHIA 1096 (5-54) DETAIL COW RECORD CARD

IMB4B549

IBM 840548

498. The average number of cows owned by association members is much bigger in the United States than in Europe, which makes it easier to organise milk recording more efficiently and to employ one full-time milk inspector per association.

499. It would probably be useful to consider introducing an unofficial test like the owner-sample test in certain European countries, alongside the official milk tests, in order to develop the practice and knowledge of milk recording. Such a programme would make it possible gradually to enrol the present inert mass of breeders in the livestock improvement programme. Here we have in mind more particularly certain countries where it is difficult to develop milk recording because of the distances involved and the difficulties of communication.

500. Although it is very efficiently organised, milk recording in the United States has its weak points and certain problems similar to those arising in Europe have emerged over the years, in particular the difficulty of engaging well-trained milk inspectors with the necessary intellectual ability for the work involved. The responsible authorities have, however, taken steps to restore the situation to normal, *inter alia* :

- by providing each inspector with a handbook explaining in detail the work to be done ;
- by raising the salaries of inspectors ;
- by training inspectors before they start work.

501. The centralisation of results in the United States Bureau of Dairy Industry, Washington, makes it possible to develop a vast sire-proving programme which, for all its defects, is an excellent means of testing annually on their progeny a very large number of bulls from all dairy breeds.

SELECTION OF DAIRY CATTLE

502. Selection would have no point if variation did not occur. As variation does occur, however, selection offers a way of making progress.

Selection of cows

503. The selection of cows must be directed toward improving both milk production and type. As a measure of milk production one can use the total yield of butterfat per year or per lactation. The heritability of fat production is low and, as pointed out by Legates and Lust,* improvement of characteristics with low

* F.E. Legates and F.L. Lush, A Selection Index for Fat Production in Dairy Cattle Utilising the Fat Yields of the Cow and her Close Relatives. *Journal of Dairy Science*, January 1954, Vol. XXXVII, p. 744-753.

heritability can often be enhanced if, in the selection, attention is paid to the phenotypes of close relatives in addition to the animal's own phenotype. The individuals receive nearly all the emphasis when heritability is high, but there is room for more attention to the relatives' phenotype when heritability is low.

504. Legates and Lush* have derived an index for more accurate intra-herd selection for fat production by utilising properly all the information on the individual cow and her close relatives. Fat yields of the cow, her dam, her daughters, her maternal sisters and her paternal sisters are used to predict the cow's breeding value. The proposed index combines these items of information about the cow and these relatives in such a way that the index value for the cow will be correlated more closely with the breeding value than if the information was combined in any other manner.

505. The data for this study were the corrected fat production records of all herds on the Herd Improvement Registry Test for at least four years during the period 1943-47. A total of 23,300 lactation records for 12,405 cows in 293 herds were studied. These herds were located in 42 States. The average fat production was 429 lb. (194.6 kg.). The records computed in the calendar years 1943 to 1947 averaged 421, 420, 433 and 439 lb. (191, 190.5, 196.4 and 199 kg.).

506. The statistics required from the data were :

1. Repeatability of fat records of the same cow ;
2. Correlation between fat records of maternal half-sisters ;
3. Correlation between fat records of paternal half-sisters ;
4. Heritability of fat production.

507. The data found were :

1. Repeatability 0.412 ;
2. Correlation between maternal half-sisters 0.073 ;
3. Correlation between paternal half-sisters 0.12 ;
4. Heritability 0.201.

508. The index derived was :

$$I = x_1 + 0.4 x_2 + b_3 x_3 + b_4 x_4 + b_5 x_5$$

where x_1 and x_2 are the estimated real producing abilities of the cow and her dam respectively, and x_3 , x_4 and x_5 are the sums of the estimated real producing abilities of the cow's daughters, maternal sisters and paternal sisters. These x 's are all expressed as a deviation from the herd average ; b_3 , b_4 and b_5 are the partial regression coefficients.

* F.E. Legates and F.L. Lush, A Selection Index for Fat Production in Dairy Cattle Utilising the Fat Yields of the Cow and her Close Relatives. Journal of Dairy Science, January 1954, Vol. XXXVII, p. 744-753.

509. The genetic improvement in fat production anticipated from a given intensity of selection depends on the magnitude of the correlation between the breeding value for fat production (G) and the index (I) or basis of selection. When the index values approximate a normal distribution and truncation selection is practised $(G \div G) = rIG \frac{z}{b} G$, where z is the height of the ordinate of the normal curve at the point of truncation, and represents the fraction of the population retained for breeding.

510. Increasing the number of daughters (x_3) greatly increases the efficiency of the index. This is of little practical concern, since few cows in the herd have daughters in milk when selection concerning those cows must be made, and these few generally have only one or two daughters.

511. Increasing the number of maternal half-sisters (x_4) does little to increase the efficiency of the index. But the number of paternal half-sisters can be large in many instances, and their influence can measurably increase the efficiency of the index, especially if the cow herself has only one record. When a cow has as many as three records, the new information provided by the relatives is limited.

512. Progress to be expected by using the index for selection would generally be about 1.10 to 1.15 times faster than by making selection on the cow's own performance alone. The authors pointed out that individual judgment cannot be replaced by an index deduced from records which at best are incomplete measures of practical merits, but subjective judgment can well be relegated to a lesser rôle than it plays now.

513. The index presented is only a beginning, but an index which would cover all situations and all pertinent characteristics would surely be unworkable because of its complexity.

514. At Ames, Iowa, a combined index for fat production and type has been elaborated. The performance is calculated as the difference between the cow's yield and the middle of the herd average. GP = the genetic ability = the cow's own performance + the performance of her relatives.

P = predicted production = $W_1P_1 + W_2P_2 + W_3P_3 + W_4P_4 + W_5P_5$;

P_1 = the cow's own performance ;

P_2 = the dam's performance ;

P_3 = the daughter's performance ;

P_4 = the maternal sisters' performance ;

P_5 = the paternal sisters' performance ;

W_1, W_2, W_3, W_4 and W_5 are weighting factors.

515. The factors found from these data were :

$W_1 = 0.18 - 0.23$; $W_2 = 0.12 - 0.14$; W_3 (one daughter) = 0.11, (two daughters) = 0.20, (three daughters) = 0.30 ; W_4 (one maternal sister) = 0.04, (two maternal sisters) = 0.05 - 0.10, (three maternal sisters) = 0.08 - 0.13 ; W_5 (one paternal sister) = 0.05, (20 paternal sisters) = 0.35, (90 paternal sisters) = 0.47.

516. Increasing the number of daughters (W_3) greatly increases the efficiency of the index. But since few cows in the herd have daughters in milk when selection concerning those cows is to be made, and these few generally have only one or two daughters, the daughters are of little practical concern. The number of paternal sisters (W_5) can also greatly increase the efficiency of the index, and this is of much practical value.

517. Most of the breeders are very much interested in type. That is the reason why much effort has been made for establishing a combined index for fat production and type. The conformation is classified in 5 classes which are broken down as follows in Iowa :

5 = E = Excellent :	90 - 100
4 = V = Very good :	85 - 90
3 = GP = Good plus :	80 - 85
2 = G = Good :	75 - 80
1 = F = Fair :	65 - 75
0 = P = Poor :	below 65

518. Within the classification the following characteristics are taken into consideration :

General appearance	until 30
Dairy character	" 20
Body capacity	" 20
Mammary system	" 30 (Udder, fore udder, rear udder, teats)

519. The variation in fat production is 22 times as great as the variation in type. With the use of the combined index the figures of the type must be multiplied by the factor 22.

520. At Ames, 3 times as much attention has been given to production as to type. The index itself is complicated to handle and therefore almost unworkable to the farmers.

521. Such indexes are, however, of very great interest in scientific research work, and for the breeder when the Breed Society provides facilities for computing them.

522. Some investigations about the correlation between transmitting ability for type and transmitting ability for production have shown $r = 0.18$ to 0.19 . Selection on the basis of the type alone should therefore automatically bring about some

genetic improvement in production. However, selection on type alone would require about 6 to 10 generations to obtain the improvement that selection on the basis of production would purchase in only one generation.

523. In practical breeding farmers pay attention to both conformation and production ability, and, where no milk recording is done, selection is made with the help of the pedigree only.

Selection of bulls and organisation of progeny-testing

524. The improvement of a dairy herd largely depends on the value of the method used for selecting the bulls.

525. The use of sires which have proved their ability to transmit a high milk yield to their progeny seems to be the most effective method, as is shown in particular by the work done at the Beltsville Experimental Station. Thus, the bulls used in artificial insemination centres in the United States are in most cases chosen by reference to their progeny; in addition, a national programme for the progeny-testing of breeding-bulls has been organised by a special division of the United States Department of Agriculture.

526. The system of progeny-testing used is based on a comparison of the daughter yield with that of their dams. The choice of young bulls may be based not only on the performance of the dam and grand-dams, but also on the performance of the paternal, and in some cases maternal half-sisters. The latter method is known as the "sib test" and constitutes a progeny-test of the parents. It is undoubtedly less satisfactory than a choice based on the quality of the bull's own progeny, if the same number of daughters or half-sisters are used and the same environmental conditions observed, but the sib test enables the breeding-value of the young bulls to be assessed as accurately as possible long before their daughters can be tested.

527. The official Sire-Proving Programme for bulls is based on an analysis of the information collected by milk inspectors, and transmitted first to the central office in each State, then to the specialised division of the Department of Agriculture in Washington. To realise the scope of the undertaking, it will suffice to say that the quality of more than 500 bulls is determined every month.

528. An extensive system of punched-card accounting facilitates analysis of the mass of statistical data collected. The results of the tests are published regularly in a Monthly Letter sponsored by the Dairy Herd Improvement Association, which seem to be very useful to breeders. Complete lists of progeny-tested bulls of all the dairy breeds raised in a country are

seldom available in Europe. However, such lists are now being published in a number of European countries. It may also be mentioned that in several European countries, punched-card systems for analysing milk recordings are now being installed. For Europe as a whole, however, the analysis of the data is naturally available only at national level, or often only in the associations responsible for the improvement of the various breeds.

529. The members of the Mission noticed, of course, the invaluable aid provided by punched-card accounting ; as the system is rather expensive to install and operate, they consider that it could only be used on a wide scale in Europe when the amount of work involved in progeny-testing was sufficiently large in the country concerned, and when the system could be used for other purposes as well.

530. When results are available for five dam-daughter pairs for a given bull, a provisional breeding-value is established and published in the Monthly Letter. It is finalised when the number of pairs rises to ten or more. The Mission pointed out that tests on five pairs would not seem fully reliable. Such evaluations are, it is true, regarded as tentative, but with a larger number of pairs the results would clearly be more significant.

531. In the view of J.L. Lush,* however, if the daughters of the bull being proved are kept in the same herd, any increase in the number beyond five will only slightly improve the accuracy of evaluation of the bull. For breeding-bulls used in artificial insemination centres, whose daughters are raised in different herds, or even in different districts, an increase in the number of pairs - they may, for example, be raised to 20 - noticeably improves the accuracy of the evaluation.

532. J.L. Lush also notes that the fixing of a minimum number of daughters is an arbitrary procedure and one liable to error. A decision must, however, be made on this point if an official testing programme is to be introduced and widely respected.

533. Accuracy in proving the bull is not the only factor to be considered in fixing the number. It must also be borne in mind that a much larger number of bulls than are actually needed must be progeny-tested, so that a selection can later be made among the tested sires. The reason for fixing the official number of dam-daughter pairs to determine the provisional value of the bulls as low as five is to enable a large number of young bulls to be tested very quickly.

* Proving Dairy Sires and Dams, Journal of Dairy Science, February 1955.

534. If, for instance, ten bulls were required, and they could sire 500 daughters, 20 bulls could be tested from 25 daughters, 50 from 10 daughters or 100 from 5 daughters. The first instance would give the greatest accuracy in estimating the bull's breeding value, but half the sires proved would have to be used for reproduction. In the other two instances, one-fifth or one-tenth of the total number would be chosen respectively, which would raise the degree of accuracy by which the bulls were selected.

535. The best number of daughters to take thus represents a compromise between the greatest possible accuracy in the evaluation of the sire and the need to test a sufficient number of bulls, as regional possibilities permit, to ensure a reasonably high standard of selection.

536. Another source of error in estimating the breeding value of bulls from their progeny must be sought in the adverse effect of environmental conditions on the yield of the daughters and their dams. As pointed out by J.L. Lush, it would be essential to lay down standard environmental conditions, to control environment as far as possible, and to correct the yields by relating them to standard conditions. Nevertheless the increased use of artificial insemination leads one to envisage the possibility of using progeny tests in varying random environmental conditions.

537. Some corrections are, in fact, made in sire-proving, so as to take into account duration of lactation, age and number of milkings. Differences between rearing conditions and feeding of the various dams and daughters are disregarded. In the same author's view, systematic enquiries should be carried out locally to study conditions in the various herds and thus collect the greatest possible amount of data which would subsequently facilitate the interpretation of milk recordings. He remarks, however, that studies of the relationship existing between feeding standards and other environmental conditions on the one hand, and yield on the other hand, have not yet advanced far enough for methods to be established whereby official associations or the D.H.I.A. could correct the results of the tests so as to bring them closer to the results which would have been obtained under standard environmental conditions.

538. However, in order to make better use of the data collected locally or by a State, the Federal Bureau is proposing to take into account the feeding of daughters and dams by establishing a feeding index based on T.D.N. units, and to allow for yearly differences by comparing the yields of daughters and dams with the average of their contemporaries in the same herd. Details of the system will shortly be published by Dr. J.F. Kendrick, Head of the Dairy Herd Improvement Investigation Division of the United States Department of Agriculture, in the "Journal of Dairy Science".

539. McGillard notes, however, that difficulties would arise in comparing daughters and dams with the average for the herd, especially in picking out their contemporaries and determining their average yield.

540. As previously pointed out, lactation is at present related to a lactation period of 305 days for a full-grown animal milked twice a day, and this therefore means making corrections for duration of lactation, age and daily number of milkings. The coefficients used for correction vary with the breed; for example, the yield of a Holstein-Friesian calving at 30 months is multiplied by 1.275. The coefficient is reduced to 1.131 and 1.077 respectively for lactation after calving at 3 1/2 and 4 years.

541. In taking into account the number of milkings it is considered that three milkings per day give 20 per cent more milk than two milkings. Actually, research work done in Europe has not given the same result, the increase being evaluated at 8 to 10 per cent for suitably fed cows.

542. It should be noted that these correction coefficients have a limited application. Because of the very way in which they have been established, they can be used only if simultaneously applied to a large number of animals; their use for a single animal or a few animals only introduces further errors. This fact needs to be emphasised in view of the small number of dam-daughter pairs required to assess the breeding value of a bull under the Sire-Proving Programme.

543. Furthermore, it is difficult to use identical correction coefficients in all areas for different populations. Local studies are therefore carried out, such as, e.g. the work being done at the State College of Agriculture at Cornell University, to analyse the effect on milk yield of the number of milkings, duration of lactation, age, year, and calving season, in particular. This research work is connected with a study of the daughters of bulls used by the New York Artificial Breeders' Co-operative. In view of the difficulties referred to above, several European countries use no corrective factor. They simply compare the yield of a bull's daughters at first lactation with the dam's yield at the same age. If this comparison is difficult to make because of widely different environmental conditions, it is not attempted. It is, however, important for the yields to be impartially analysed by competent experts.

544. The results of the official tests made in the United States are expressed by showing the difference between the yields of the daughters of the bull being proved and of their dam. The results for Guernsey bull No. 331805, for which the following data were published on 20th January, 1955, may be quoted as an instance:

	LACTATIONS	MILK	PERCENTAGE FAT CONTENT	BUTTER
15 daughters	31	8,314 lb. (3,771 kg.)	4.8	397 lb. (180.1 kg.)
8 "	12	8,495 lb. (3,853 kg.)	4.8	409 lb. (185.5 kg.)
8 dams	17	7,276 lb. (3,300 kg.)	4.8	351 lb. (159.2 kg.)
Difference		+ 1,219 lb. (553 kg.)	0	+ 58 lb. (26.3 kg.)

545. Of the 15 daughters covered by the enquiry, only 8 were born of officially inspected dams, and in the case of these 8 dam-daughter pairs, the daughters' superiority over their dams is evident. It corresponds to an extra 1,219 lb. (553 kg.) of milk and an extra 58 lb. (26.3 kg.) of butter.

546. In artificial insemination centres it is usual to post in front of each bull's box the yield of its daughters and their dams. Its breeding value is also often expressed by an index known as the "American Index", based on YAPP's index. For milk yield and fat content it can be expressed as follows :

American index = 2 x average yield of daughters - average yield of dams.

For the Guernsey bull referred to above, the milk yield would be expressed as follows :

American index = 2 x 8,495 - 7,276 = 9,714 lb.
(2 x 3,853 - 3,300 = 4,406 kg.)

547. In conclusion, it may be emphasised that despite its imperfections, the Sire-Proving Programme is an invaluable instrument. It can, of course, be improved and, as already mentioned, arrangements are now being made to allow for environmental differences in particular. It has the great advantage already of supplying an annual guide to the breeding-value of a very large number of bulls. The evaluation is possibly not made accurately enough as compared with the results obtained by other systems, but its technical influence on the improvement of the cattle population as a whole is perhaps greater than a more accurate annual proving of a small number of bulls. Its cost per bull is also relatively low. As it can probably be combined with artificial insemination, it will very likely be possible for proving programmes to be established in the near future which, though inexpensive, will enable the breeding-value of bulls to be more accurately estimated. Such programmes are in fact already applied on a more local scale in the United States by certain specialised animal production services. There is, for instance, the programme established

by the New York Artificial Breeders' Co-operative, working in co-operation with the experts of Cornell University (Ithaca).

548. The members of the Mission particularly appreciated the opportunity of studying at first hand the organisation of this vast plan for the progeny-testing of bulls of dairy breeds. The Mission will find it interesting to consider it in relation to the testing methods evolved in Europe, based sometimes on principles other than the comparison of dam-daughter pairs, as explained in Publication No. 2 of the European Association for Animal Production.

SELECTION IN BEEF CATTLE BREEDS

Some differences between the United States and Europe

549. In the United States, as in other countries, the genetic improvement of beef cattle has to be considered from two points of view : that of improving the rate of growth and economy of gain, and that of producing a type of cattle adapted to market requirements which will give carcasses of the requisite quality. There are substantial differences, however, between the requirements of the European market, which are inherently very varied, and those of the American market. Attention needs to be drawn to these differences because the problems involved in the genetic improvement of beef animals are closely related to demand on the regional markets and there are certain problems inherent in this question which have to be solved by regions where the markets are similar.

550. As a concrete example of this state of affairs it may be pointed out that :

1. Whereas most experimental work in the United States is done on baby-beef, many European markets have rather few animals of this type and we have no information on the comparative results obtained from baby-beef and those recorded for older animals.

2. Carcass evaluation in the United States differs considerably from that practised in most European countries, for two main reasons : the large amount of fat tolerated in the United States and the difference in the carving up and utilisation of the beef. Whereas the optimum measurements of the fat covering the eye-muscle in the United States are 14 to 15 mm. (0.552 to 0.591 in.), the measurements in Belgium, for example, do not exceed 5 to 6 mm. (0.197 to 0.236 in.). The methods of carving up carcasses in the United States and in Europe differ in many respects. In the United States the method of butchering carcasses is more industrial than that practised in the European countries.

3. Price ratings for the animals differ from those met with in a number of European countries. The following table shows how the animals are graded on the United States market and the price for each grade.

GRADE	PERCENTAGE OF THIS GRADE ON THE MARKET	PRICE \$
Prime	5	34
Choice	54	29
Good	35	25
Commercial	5	18
Utility	1	14

Ninety per cent of the animals fall within a price range varying from \$31 to \$22 per 100 lb. (45.36 kg.).

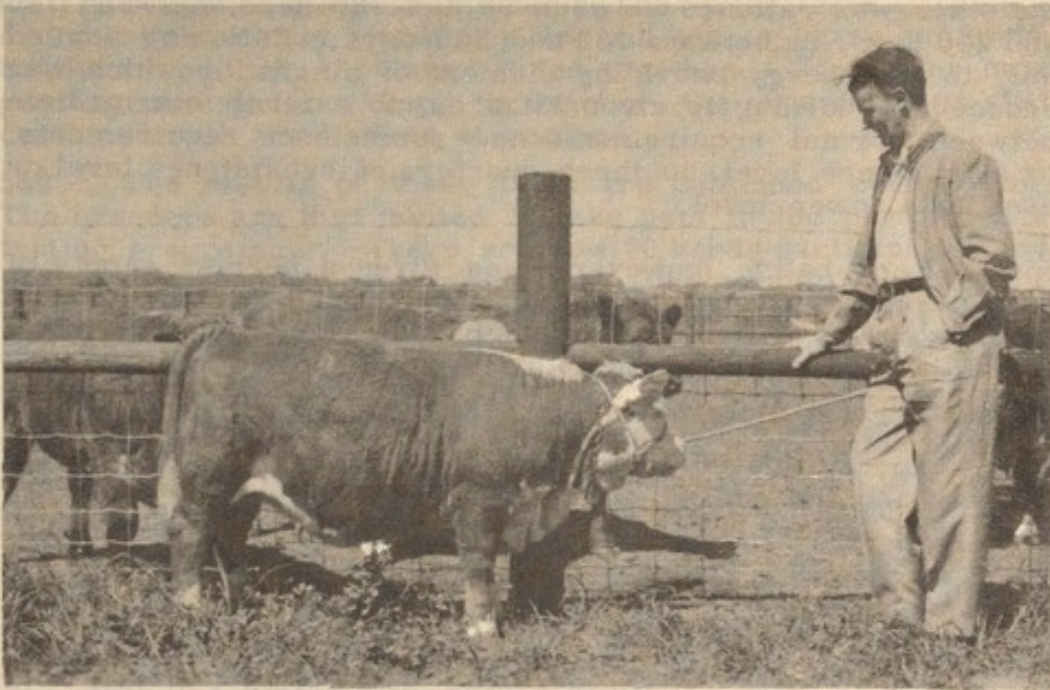
The table below gives the relative values of different cuts for "prime" and "choice" grades.

NAME		PRIME	CHOICE
Hindquarters 49 %	(Round	45 - 46	43 - 46
	(Loin	83 - 88	68 - 71
	(Flank	12 - 14	12 - 14
Forequarters 51 %	(Plate	9 - 11	9 - 11
	(Rib	59 - 61	48 - 49
	(Chuck	29 - 32	29 - 32
	(Brisker	28 - 30	28 - 30

4. Whereas the trend in many European countries is partially towards the production of dual-purpose cattle, United States circles have always made a practice of producing special types for beef and special types for milk. The situation in this respect, however, is changing and many universities and research stations are taking up the production of dual-purpose cattle. In view of the apparent confusion about defining the latter type of beast, the Mission considered it essential to ensure better understanding, that the idea of dual-purpose cattle as understood in Europe and actually produced there should be more clearly defined so as to facilitate, inter alia, international exchanges of view on the subject.

Research work and selection schemes in the United States

551. As already emphasised, the characters involved in the production of beef are essentially related to the way in which the animal is prepared for the market and to carcass quality. We will therefore outline here a few research programmes



Female dwarf cattle 14 months old and weighing 500 lb.

which the Mission was able to examine in both these fields. To begin with, however, reference might be made to the curious phenomenon of dwarf cattle (dwarfism), evidence of which we found at Ames (Iowa) in the Hereford breed. This particular type of dwarfism has become sufficiently common to constitute an economic problem. Generally, animals with this defect die before weaning, but some have lived for several years and we saw a dwarf cow which had produced a normal calf. J.L. Lush and L.N. Hazel consider that this form of dwarfism is recessive as compared with the normal development which is dominant. It has not yet been possible to distinguish phenotypically the heterozygotes from the normal homozygotes and it is recommended that the breeding animals be tested by their offspring, e.g. by crossing them with their own heifers, to distinguish which animals carry the lethal gene.

Study of growth and results of feeding

552. Much work is being done in the United States in this field. Monozygote twins are often used as material for experiments on growth and feeding. Any interruptions which occur during growth are examined in the light of their effects on the amount of feed required and on carcass and beef quality.

553. Two consecutive experiments on these lines were conducted by C.F. Winchester and Paul E. Howe on six pairs of steers, and then on six pairs of heifers and four pairs of steers, purebred or crossbred. One twin in each pair was given a normal ration throughout its growth and fattening period, while

the other was rationed between 90 and 180 days, between 120 and 240 days, or between 180 and 360 days. Rationing applied only to the energy-providing element of the ration which was reduced, according to circumstances, to a level intermediate between normal requirements and subsistence requirements, to subsistence level, to three-quarters of subsistence level or even to a lower level.

554. Each batch, however, was given a normal supply of nitrogenous products, mineral products and carotene. The animals were killed under comparable conditions at about 1,000 lb. (453.59 kg.) weight. These test showed that the feed coefficient evaluated over the whole growth and fattening period was slightly less in the case of the animals which had had their feed temporarily restricted, and that the composition of the carcass and the quality of the beef were not affected by this diet. The authors conclude that it is, nevertheless, preferable, if feed resources permit, to let young animals intended for fattening grow without interruption so that they can be sent to market as soon as possible, but if, as in winter-time, there is not sufficient food, it is not necessary to satisfy the animals' energy needs over a limited period completely - if this is economically hindersome - provided they get enough nitrogenous, mineral and vitamin foods.

555. Other studies are being carried out on adding special products such as oestrogenic substances to the food. The effects of feeding on the quality of the tissues, as on the bone structure, are being studied in several research stations. Finally, appetite, considered as an hereditary factor, is also being studied in nutrition experiments in which the animals are supplied with as much food as they like.

556. Studies of strains or lines which can be used to select animals for faster growth and satisfactory conversion of feeding stuffs are rarely made use of in stockbreeding, although tests which may prove successful are being carried out by some experimental stations.

557. This is being done at the Beef Cattle Research Station at Front Royal (Virginia) where a selection scheme is being operated to select animals by growth rate and feeding efficiency as well as by type.

558. Performance tests, for example, have been initiated to guide the selection of breeding animals. For a short time during their rearing, the young beasts of both sexes are put on a standard ration, the daily quantities of feeding stuffs consumed are checked, and the weight of the animals is noted every fortnight. Conformation is judged at the beginning and end of the test. The control period is six months for young bullocks commencing end September or beginning October, when they are weaned, and continuing throughout the winter in the byre. During this time the animals are fed separately. The young

heifers are given similar tests during the winter, from December or January onwards, until they are put out to graze in April. Unlike the bullocks they are all fed together. During the next grazing period, from April to October, the experiment is still continued with the heifers at pasture.

559. The results of these tests are published every year. The breeders are then invited to take part in the performance testing programme. There are now 70 herds participating and in January 1955 a special Board of Directors for Virginia's Beef Cattle Performance Testing Programme was set up. This Board consists of representatives from the Virginia Beef Cattle Association and the Animal Husbandry Department at the Virginia Polytechnic Institute. The results of the performance tests also produce data which will enable a sire-testing programme to be put into operation. It is considered a priori that from 10 to 30 offspring are required in order to judge a bull's breeding qualities. This material is also used for genetic research. As a result of the knowledge gained of the growth rate of bulls and their offspring it has been possible to evaluate the heritability of this character at 0.20 to 0.30. Overall evaluations of carcass quality are also made and an index is proposed which will take account of growth rate and carcass quality. Finally, comparisons are made of the carcass quality of the animal on the hoof (slaughter grade) and of its carcass grade.

560. Notwithstanding these observations, the Mission felt that the research work done on growth and the effect of feeding on beef production was less well co-ordinated in the United States than that done on other sectors of animal husbandry.

Study of carcasses

561. There are a large number of cattle slaughter stations in the United States and animal husbandry circles are interested in the problem of producing quality cattle for beef purposes. The equipment and resources of these stations give reason to hope that fairly soon the work being done on production of meat animals will reduce the gap between the selection of animals for meat and their selection for milk purposes.

562. In this connection, however, it should, as already pointed out, be noted that the studies made by United States specialists based on their own material and for the purposes of their own markets will not be so useful to European countries as those concerning milk, as the conclusions cannot be so easily transposed.

563. In Europe itself some markets are in a better position than others for finding a good use for second-quality beef. Similarly, there are some European markets which would never tolerate the quantity of fat acceptable in the markets of the English-speaking countries, particularly the United States, even though the tendency on those markets now is to reduce the amount of fat.

564. This reduction of the quantity of fat in carcasses is one of the main problems in the United States both for cattle and pigs. On this account specialists are paying more attention to the conformation of lean cattle and to the possibility of obtaining breeds or strains which can introduce intramuscular fat without this involving a large layer of covering fat.

565. The Mission noted with interest the attention which was being paid to judging carcass quality and to experiments for determining standard methods of appraisal. Work on similar lines is now being done in Europe. It would be useful if comparisons could be made between the methods used for this purpose in the various countries.

566. In the United States a good deal of work is being done on carcass appraisal at various stations, and it may not be inappropriate to mention here the measurements proposed at Beltsville for the grading of cattle carcasses :

This method of measuring beef carcasses is applicable to dressed beef that has been split through the centre. Measurements 1 to 10 inclusive, as well as measurements 32, a, b, c, d and e, 33 and 34 are taken on the split carcass. The other measurements are made after the sides are cut. A steel tape is used for taking all measurements except 9, 10, 23, 33, 34, 35, 36 and 37, for which a pair of calipers is used, and 11 and 12, which are taken with a metre stick. All measurements are taken in millimetres and with the carcass hanging from a hook in a normal position, neck down. The cuts are measured when lying in a normal position on a table.

Length

1. Body - from anterior edge of first rib to the lowest point of the aitchbone
2. Hind leg - from the lowest point of aitchbone to the highest point of hock joint (leg removed between first tarsal and the large metatarsal bones).

Depth at seventh dorsal vertebra

3. Thickness of flesh from lower edge of split breast bone (sternum) to lower edge of flesh below breast bone
4. Distance from lower edge of breast bone to upper edge of spinal canal
5. Distance from upper edge of spinal canal to outer edge of flesh above spinous processes.

Depth at first dorsal vertebra

6. Thickness of flesh from cartilage at end of first rib of sternum (manubrium) to lower edge of flesh below breast bone (sternum)

7. Distance from cartilage at end of first rib of sternum to upper edge of spinal canal
8. Distance from upper edge of spinal canal to outer edge of flesh above spinous processes.

Width of carcass

9. At shoulder - width from inside of carcass at first dorsal vertebra to outside of shoulder on a line parallel to the floor. Sum measurements of two sides of carcasses is recorded
10. At round - width from the highest point or aitchbone to outside of round on a line parallel to the floor. Sum of measurements of two sides of carcass is recorded.

Prime rib cut (Chicago style cut)

11. Distance from chine bone (ventral edge of 12th thoracic vertebra) to button (cartilage between 12th and 13th rib)
12. Sixty-one and one-half per cent of measurement number 11 (this is joint where prime rib cut is made)
13. Distance from chine bone (ventral edge of 12th thoracic vertebra) to end of rib (12th rib)
14. Distance from side of spinal canal to outer surface of the external fat on posterior side of 12th rib (tape held at right angles to the surface of the split vertebra)
15. Same as measurement 14 for anterior side of 9th rib
16. Same as measurement 14 for anterior side of 6th rib
17. Thickness of flesh from outer surface of lean at end of cut rib to outside edge of bone 12th rib
18. Same as measurement 17 for 9th rib
19. Same as measurement 17 for 6th rib
20. Thickness of flesh from outer surface of fat across "eye" (longissimus dorsi) muscle to inner edge of the head of the rib bone on a line parallel with split surface of vertebra, on posterior side of 12th rib
21. Same as measurement 20 for anterior side of 9th rib
22. Same as measurement 20 for anterior side of 6th rib.

Fore leg (Chicago style cut)

23. Distance from ventral (external tuberosity of radius) surface of radius bone to dorsal edge of knee joint (joint between fused 2nd and 3rd carpal bones and metacarpal tuberosity).

Brisket (Chicago cut)

24. Thickness of flesh from outer surface of lean at end of cut rib to outside edge of bone - 5th rib
25. Same as measurement 24 for 3rd rib
26. Same as measurement 24 for 1st rib.

Chuck (Chicago cut - 5th rib)

Chuck is cut from lower corner of 5th rib across shoulder joint (joint at head of humerus and scapula) through fat, lean and bone.

27. Thickness of flesh from outside of flesh to outside edge of rib bone - at end of 5th rib
28. Same as measurement number 27 at end of 3rd rib
29. Same as measurement number 27 at end of 1st rib
30. Length of neck from atlas joint to first thoracic vertebra, along the spinal canal (7th cervical vertebra)
31. Thickness of flesh between 3rd and 4th cervical vertebrae taken at right angles to surface of the split cervical vertebra across spinal canal bone, lean and to external edge of fat.

Round (before cutting from hind quarter)

32. Plumpness

- a) locate straight line from the lowest point of aitch-bone to highest point of hock joint with skewers
- b) locate point that is 60 per cent of the distance (a) from the highest point of hock joint or 60 per cent of measurement 2
- c) locate points on both sides of point (b) that are at right angles to line marked in (a). Use a square and allow it to follow the curve of the round
- d) measure the circumference of round at the three points located in (b) and (c) as fixed points
- d) Plumpness - $\frac{\text{Circumference} \times 100}{\text{Length } 2}$

33. Thickness of round from anterior to posterior edge through plane from points located in measurement 32 c)
34. Width of round from inside of round at point located in measurement 32 b) on a line parallel to floor.

Round (after cutting from hind quarter)

35. Distance from stifle joint (dorsal head of femur bone) to point where femur bone is cut in separating the rump and round.

Hind leg

36. Length of tibia from stifle joint (external condyle of tibia) to hock joint.

Short loin (cut Chicago style)

37. Length of short loin from anterior edge of first lumbar vertebra to centre of sixth lumbar vertebra
38. Length of "eye" (longissimus dorsi) muscle from outside edge of lumbar vertebra process to outside edge of "eye" muscle at division of fat and lean taken at the maximum length of muscle :
- a) across centre of 5th lumbar vertebra
 - b) across anterior 3rd lumbar vertebra
 - c) across anterior 1st lumbar vertebra
39. Width of "eye" (longissimus dorsi) muscle from top of transverse spinal process to external edge of fat taken parallel to spine of lumbar vertebra at the anterior articular process :
- a) at centre of 5th vertebra
 - b) at anterior 3rd lumbar vertebra
 - c) at anterior 1st lumbar vertebra
40. Thickness of fat over centre of "eye" (longissimus dorsi) muscle of loin from external edge of fat to the lean flesh at :
- a) posterior edge of short loin (5-1/2 lumbar vertebra)
 - b) center of 5th lumbar vertebra
 - c) anterior 1st lumbar vertebra.

Loin end (Chicago cut)

41. Maximum length of tender loin muscle (transversalis costarum) taken through the centre of the muscle located at anterior edge of cut
42. Maximum width of tender loin muscle (transversalis costarum) taken through centre of the muscle located at anterior edge of cut.

567. This work is followed up by an examination of the glands. Chemical analyses of the meat are also being made (determination of collagen and elastin contents, etc.). By using other kinds of physical tests, it has been possible to evaluate the tenderness of the various muscles of animals of both sexes and of different grades, and the members of the Mission had occasion to inspect apparatus designed for this purpose at the experimental station at Beltsville (Maryland).

568. Very detailed research work has been done to find simple criteria also for determining carcass grade, particular attention being directed to the study of the 9th, 10th and 11th ribs. Many of these studies are co-ordinated under a national scheme known as "Co-operative Meat Investigations".

Conclusions

569. At present American and European specialists alike are dealing with similar problems in the selection of breeding animals in the various beef cattle breeds. Schemes have been drawn up on both sides, at various levels, to check more particularly the growth rate and the quantity of feed consumed, as well as the composition of the carcass and the quality of the beef. Although most of such research work in the United States relates to the production of baby-beef animals, a type which is rather uncommon on many European markets, and although the method of carcass appraisal in the United States is quite different from that followed in Europe because of the larger proportion of fat tolerated and differences in cutting up, the members of the Mission nevertheless consider it most important for European specialists to keep in close touch with their American colleagues so as to try jointly to solve the complex problems involved in the genetic improvement of beef cattle breeds.

570. On the European side, the members of the Cattle Committee and of the Research Committee of the European Association for Animal Production have already decided, at their meeting in July 1955, to promote the co-ordination of research in this sphere.

AN EXAMPLE OF INTER-STATE CO-OPERATION

The North-Eastern States Regional Research Project on Fertility in Cattle

571. A striking example of inter-State co-operation is provided by the research programme which is being carried out in the North-Eastern States on the causes of reproductive failures in dairy cattle, and how these can be remedied.

572. Sterility and reduced fertility cause serious economic losses to dairy farmers. Dr. Asdell estimates that dairy farmers in New York State lose about \$20 million a year through sterility. In Pennsylvania, the annual losses amount to \$15 million, and in the United States, as a whole, at least \$250 million.

573. The number of cows weeded out for this reason is increasing yearly, though few animals have been slaughtered in the last few years for brucellosis. In herds subject to D.H.I.A. arrangements for inspection, sterility, as a cause of elimination, comes second to insufficient yield. In view of this state of affairs a number of dairy States drew up a research programme with the United States Department of Agriculture to see if the chief causes of sterility could be traced and alleviated.

574. In the North-Eastern States the work has been co-ordinated since 1st July 1948, through a regional research programme in co-operation with the United States Bureau of Dairy Industry under the Research and Marketing Act. Stock-breeders in those States, which contain 7,500,000 milk-cows, consider that reproductive failures are now one of the most important problems to be solved. In view of the importance of the scheme, other States such as North Carolina, South Carolina and Ontario, also decided to take part in it. The following bodies are thus co-operating in this field :

Connecticut Agricultural Experiment Station,
Cornell University (New York)

Agricultural Experiment Station

Delaware	"	"	"
Maine	"	"	"
Massachusetts	"	"	"
New Hampshire	"	"	"
New Jersey	"	"	"
North Carolina	"	"	"
Ontario Veterinary College	"	"	"
Pennsylvania Agricultural Experiment Station			
Rhode Island	"	"	"
South Carolina	"	"	"
Vermont	"	"	"
West Virginia	"	"	"
United States Department of Agriculture			
Dairy Husbandry Research Branch			
Animal Disease and Parasites Research Branch.			

Organisation

575. The causes of sterility and reproductive failures are many and complex, and research must accordingly be simultaneously pursued along different lines. It is therefore carried on the following fields :

1. Pathology,
2. Physiology, covering a study of the endocrine aspects of sterility,
3. Nutrition and stock management,
4. Genetics.

576. The programme entails co-operation between experts in these different sectors : pathologists, physiologists, nutrition experts, biochemists and geneticists.

577. A Technical Advisory Committee* with a chairman and a secretary has been appointed to co-ordinate the research work. The chairman is Dr. Asdell of Cornell University (New York). Sub-committees on nutrition, pathology and genetics are responsible for co-ordinating the work in their respective fields. The aims of each department concerned with the programme are defined every year. Reports on the progress of the work are then regularly prepared by the chairman for submission to the Committee, but each centre publishes its own results.

578. For the programme as a whole, the yearly allocation of funds is now planned as follows :

Pathology	36.9	per cent
Physiology	30.8	" "
Nutrition	26.3	" "
Genetics	6	" "

579. In each State funds are obtained from public and private sources, and are also supplied by Federal bodies.

580. As an example, the 1955 budget for the implementation of the programme in New York State is as follows :

Sources	Funds \$
State Government.....	65,000
Technical Advisory Committee.....	5,000
United States Department of Agriculture	1,500
Artificial Insemination Units	35,000
United States Public Health Department.....	4,500

The Technical Advisory Committee allocates the funds granted by the Federal Government, amounting to \$45,000 in all.

Results obtained

581. Disease is one of the chief causes of reproductive failure. Vibriosis is the most frequent cause, but brucellosis, trichomonosis and vaginitis also occur. A systematic study of farms made by a field laboratory in New York State brings out the fact that such failures can equally often be attributed to faulty stock management.

582. This study entails an analysis of reproductive performance and a schedule of feeding and management conditions for

* See the function and operation of the Technical Advisory Committees in the chapter on inter-State co-operation.

each farm. Tests are made of blood and vaginal mucus. A rectal examination of the genitals is made and sperm tests are carried out. Lastly, blood analyses are made to determine the ratio of carotene, vitamin A, protein, calcium, phosphorus and vitamin C in the plasma in relation to reproductive failures.

583. Following these observations, the attention of farmers was drawn to the need for letting at least 60 days pass after calving before re-mating the females and for having them served or inseminated at the correct time, the best results being obtained during the second half of the heat period, which averages eighteen hours, for checking the dates of successive heats to reveal abnormal cycles, and more generally, noting all factors which enable the operation of the reproductive system to be assessed : heat periods, dates of mating or insemination, dates of calving.

584. As regards the bulls used in artificial insemination centres, semen can be collected twice, every 8 days, over long periods. It has recently been shown that the number of spermatozoa produced per ejaculation is increased if the bull makes one or two false mounts before serving the artificial vagina.

585. From the nutritional angle, apart from the systematic blood analyses previously referred to, research is carried out to determine the influence of the feeding plan adopted for young animals on their later reproductive performance.

586. To this end 102 young animals were divided into 3 groups and made to follow feeding plans of different values until first calving. One lot (Group M) was fed at the upper level of Morrison's feeding standard, while the others received either a higher ration (Group H), corresponding to 140 per cent of normally accepted requirements, or a lower ration (Group L), providing only 65 per cent of those requirements. In the case of the latter group the ration was increased after the first calving and amounted to 120-140 per cent of T.D.N. requirements during first lactation.

587. Besides the quantitative calorific differences existing between the rations given to the three groups, the quality of the food and supplementary minerals and vitamins also varied.

588. It is still too soon to draw final conclusions from these trials and to judge, in particular, the influence of the diets on milk yield and number of matings or inseminations per conception. All the heifers were impregnated at about 18 months, and their weight at first calving naturally varied in inverse ratio to the feeding standard, but during first and second lactation the heifers in Group L increased their weight considerably, to the level of the animals in Group M.

589. The development of the genital organs was also checked and slaughterings were carried out in turn in the three groups

at 0, 16, 32, 48, 64 and 80 weeks. It has already been found that the feeding standard in early life affects the development of the reproductive organs. First heat occurs sooner with the better-fed animals. On an average, it occurs at 9, 12 and 18 months respectively in groups H, M and L. Macroscopic and histological studies show that the genital tract is fully developed and functions on first mating at 9 months in group H.

590. The same study applied to young males brings out the influence of the feeding plan on the age at which ejaculation first occurs ; this is 42, 50 and 54 weeks for groups H, M and L respectively. The total sperm production at comparable ages rises with the feeding standard. Underfed males are therefore available for reproduction later than the others.

591. In the physiological field the application of neuro-hormonal ovulation control was noted. From the genetic standpoint it was shown that the heritability and repeatability of the number of matings per conception and of the interval between calvings were very low.

Conclusion

592. The members of the Mission were keenly interested in the programme, which provides a further example of inter-State co-operation, and enables a given problem to be studied from every angle, so that a satisfactory solution can be reached on the local plane, while general conclusions can also be drawn.

INBREEDING AND CROSSBREEDING OF CATTLE

Introduction

593. The crossbreeding experiments carried out on cattle in the United States naturally aroused the immediate interest of many members of the Mission, especially as in the great majority of European countries any genetic improvement of livestock is still based on purebreeding with an increasingly wider use of progeny-test of the young bulls used for artificial insemination.

594. Keen interest was in fact shown in both :

the possibility of studying in detail the results of breeding experiments on animals with low fertility and a long interval between calvings on which very large amounts have to be expended for decades ;

the possibility of determining the value, under American stock-breeding conditions, of the methods used to get the maximum benefit from heterosis.

595. It was natural moreover that the Mission should take an interest both in the problems of inbreeding and those of crossbreeding, for, as Professor Lush pointed out, these are two complementary aspects of the same genetic phenomenon, and the two techniques are used concurrently both in vegetable production, for hybrid maize, and in animal production, for pig and poultry breeding.

596. We shall confine ourselves in this chapter to an analysis and discussion of these inbreeding and crossbreeding experiments carried out in the various universities and research centres visited by the Mission, on which sufficient documentary material was collected. Unfortunately, we were unable, except in one case, to see the effect of such experiments on current breeding practices.

Inbreeding experiments on dairy cattle carried out in the United States

Material on which the report is based

597. The members of the Mission collected information on the results of a lengthy experiment in inbreeding carried out on dairy cattle at the Beltsville (Maryland) Centre; they were able to study in great detail a research programme on inbreeding, minutely prepared on very comprehensive lines, which is now being applied at the Experimental Farm of the Dairy Department of the University of Wisconsin; lastly, they were given supplementary data on the same subject, especially on the effects of moderate inbreeding in a Holstein-Friesian herd in Iowa.

Definitions

598. It seems essential to start with a few definitions.

599. The term "inbreeding" is applied to any breeding method of mating two animals whose degree of relationship is closer than the average between random samples of the same breed. The definition of inbreeding is thus only relative. It may be pointed out that S. Wright has produced a coefficient which enables the degree of inbreeding for a given animal to be expressed in figures. The coefficient gives the percentage figures of reduced heterozygosis, or genetic variability, in an inbred animal.

600. It is usual to distinguish, although on very arbitrary lines, two types of inbreeding:

linebreeding, where the inbreeding coefficient is less than 15 to 20 per cent;

closebreeding, or heavy inbreeding, where the inbreeding coefficient is over 20 per cent.

Aims and effects of inbreeding

601. The aims of inbreeding are well-known. Its purpose is to produce animals of uniform phenotypical appearance and prepotent in the hereditary transmission of their characteristics. In this respect the two forms of inbreeding referred to above do not fulfil identical functions :

Linebreeding aims in particular at maintaining a high relationship coefficient between certain animals and an ancestor of outstanding quality, while avoiding a marked reduction in heterozygosis. The high relationship coefficient means that the inbred animals have a large number of genes in common with the founder of the line, and thus bear an actual phenotypical resemblance to it, without their genotype, however, becoming highly homozygous ;

Closebreeding serves mainly to reduce the heterozygosis of the animals produced. Consequently, the genetic variation of the breeding animals' progeny is limited, and homogeneity of the breeding values is thus achieved.

602. Inbred bulls are, in fact, used in practice - within the breed or outside it - either for topcrossing with unrelated females in mixed herds, or for linecrossing ; the production of inbred animals for use within the line is rarely an end in itself.

603. Inbreeding has often been accused of producing cattle with hereditary malformations because of the homozygotic action of undesirable recessive genes, and of very frequently causing a reduction in size, a drop in performance, more especially fertility, a lowering of the vitality and the constitutional soundness generally.

604. In the light of these preliminary explanations we will now describe the inbreeding experiments which we had occasion to study during the Mission.

Breeding stock and results of inbreeding in the experiments studied

Beltsville experiment *

605. The experiment began with fourteen cows of predominantly Jersey and Guernsey type, and four of predominantly Holstein type, which were graded with a registered Holstein bull, and then with seven males closely related to him ; the original bull was also mated with his own daughters. For seven generations of females thus obtained, recordings were made of performance, showing fertility, constitution, type, growth, milk yield, butter fat content and fat production.

* T.E. Woodward and R.R. Graves : Results of Inbreeding Grade Holstein-Friesian Cattle ; Technical Bulletin No. 927, October 1946 (United States Department of Agriculture, Washington, D.C.).

606. In this experiment the effects of inbreeding were considered in relation to two different factors: the degree of relationship reached by animals of successive generations - 25 per cent in F₁, 26.3 per cent in F₂, 32.4 per cent in F₃, 43.9 per cent in F₄, 44.7 per cent in F₅, 59.9 per cent in F₆ - and the number of generations obtained with inbreeding.

607. The authors tried to compare the performance of inbred animals with that of the outbred animals used for reference purposes.

Wisconsin experiment

608. The account of the Wisconsin experiment distributed to us, together with comments by the originator, Dr. Tyler, Head of the Dairy Department of the University, deserves to be very fully studied, as it is undoubtedly a model of its kind. We shall endeavour here to outline it briefly.

609. The original Holstein-Friesian herd was composed of animals of different strains, the females in a strain being the daughters or half-sisters of the male. Sires were mated with daughters as far as possible, and when this was quite impossible the sire was replaced by his son for the purposes of the experiment.

610. For the first calving the sixteen or twenty daughters or half-sisters of each original male were divided into three groups; one group of eight or ten was coupled with its sire or half-brother, while two other groups of four or five each were coupled with two bulls not related to them. Thus, from the original female stock of each strain, two F₁ groups of equal numbers were obtained, one inbred, the other outbred. For the second calving the mating programme was exactly reversed, so that each cow in a given strain bore one inbred and one outbred calf in succession. The proposed programme for the third and subsequent calvings of the cows in each strain will be devised so as to obtain about fifteen inbred daughters from the first generation and three inbred sons in each strain, with a good pedigree as regards yield and reproductive performance, so as to obtain also outbred bulls selected on the same basis, for use in private herds taking part in the experiment, and lastly, at least five outbred sons of each of the other two males.

611. The proposed mating plan for the progeny of the first generation has three principal aims:

to allow further inbreeding by coupling the male founders of the strains with their own inbred daughters (or failing this, coupling an inbred son with his near relatives);

to outbreed by coupling some sixty outbred heifers sired by the original bulls with as many males as possible, chosen at random in the artificial insemination centres, and repeat the

process with each generation, so as to obtain a reference group for environmental variations within the experimental herd (the outside bulls used must not be related to the animals in the herd, and must represent a varied sample of the bull population of the centres);

to make linecrosses between inbred animals of different strains.

612. Thus, the inbred females of the first generation in each strain will calve successively either inbred animals within the strain, or incrosses with each of the two males of two other strains. This is an essential point, for, as emphasised by the authors of the experiment, it will thus be possible to make comparisons between inbred and incrossed dams from a sufficiently large groups of heifers, classified by yield and reproductive performance.

613. It should also be emphasised that inbred and outbred bulls from the experimental herd will be used for comparative purposes in private farms, for topcrossing and for normal breeding.

614. Lastly, the mating plans proposed for later generations of females will be somewhat similar to those described above; they will make it possible to produce :

- close inbred animals ;
- incrosses (incrossing may involve two, three or even four strains) ;
- topcrosses in private herds ;
- outbreds for reference purposes.

Detailed comparisons will thus reveal the effects and the value of each breeding method.

615. An unusually large mass of information is also supplied by the authors of the experiment on the methods of preserving or eliminating females and males within the herd, their strictly controlled feeding, which is as uniform as possible (incidentally the animals will never be put out to graze, but will always be fed in the byre), and on the very strict check kept on the various stages of reproduction (puberty, heat, mating, gestation). Yields are expressed in terms of "a 305 days" lactation with compulsory observance, whatever the cow's yield, of a dry period of at least 42 days before each calving. The calves' weight at birth and their growth until maturity will be checked by weighing and measuring and systematically recorded ; a full analysis of the antigens in the blood will be made for each calf. Lastly, the authors propose to have each animal inspected for type at various ages by experts.

616. In a word, quite apart from the many related possibilities for research offered by such a wide field of experiment, the work that is being done in Wisconsin will allow conclusions to

be drawn on the effects of selection, combined with a method of stock management (inbreeding, outbreeding, incrossing and topcrossing) on the various characteristics and capacities of dairy cattle.

Iowa experiment *

617. This experiment, begun in 1930, the results of which were published in 1950, sought to determine the effects of moderate inbreeding, linked with selection for higher yield.

618. The system employed consisted in using the sons of cows with the best yield, and keeping them in service until they had at least eight daughters available for testing. The authors found that the coefficient of inbreeding thus rose by about 3 per cent per generation, or 1 per cent a year.

619. Very full performance recordings were kept for all the animals so that it was possible to calculate the correlation, in males, between certain characteristics and the coefficient of inbreeding.

Effects of inbreeding in the experiments studied

620. It now remains to study the effects of inbreeding in the experiments described.

Appearance of recessive genes

621. No recessive genes appeared during the experiments in Iowa, in Wisconsin, where the work is still in the early stages, or even in Beltsville, although a high coefficient of inbreeding had been reached with animals of the F₆ group (nearly 60 per cent).

Size and growth of the animals

i) Weight at birth

622. On this point the results seem to agree fairly well :

Nelson and Lush found a drop of $1/8$ lb. (57 gr.) in the weight of calves at birth for every increase of 1 per cent in their coefficient of inbreeding, the inbreeding of the dam having a slightly smaller influence on the weight of the calf at birth.

The first data from the Wisconsin experiment give a weight at birth 10 per cent lower for inbreds than for outbreds.

* R.H. Nelson and J.L. Lush : The effects of Milk Inbreeding on a herd of Holstein-Friesian Cattle ; Rep. from Journal of Dairy Science, March, 1950, Vol. XXXIII, No. 3, p. 186-193.

The results recorded at Beltsville were as follows :

GENERATION	WEIGHT AT BIRTH
F ₁	82 lb. (37.19 kg.)
F ₂	82 lb. (37.19 kg.)
F ₃	75 lb. (34.02 kg.)
F ₄	72 lb. (32.66 kg.)
F ₅	67 lb. (30.39 kg.)
F ₆ - F ₇	64 lb. (29.03 kg.)

The authors find that animals with a coefficient of inbreeding of over 50 per cent weighed about 15 lb. (6.8 kg.) less at birth than outbreds. Thus, inbreeding undoubtedly reduces the size at birth.

ii) Growth

623. Here again the data obtained by the various investigators agree :

Nelson and Lush observe that inbreeding flattens the growth curve, but allows it to extend over a longer period so that the size when full-grown is not affected.

This is confirmed by Tyler from the Wisconsin experiment : thus, at six months the weight of inbreds is 8 per cent less than that of outbreds ; at 18 months the difference is reduced to 5 per cent, and around 3 1/2 or 4 years to only 2 to 3 per cent (body measurements show the same trend).

Although the authors of the Beltsville experiment observe considerable differences in the weights of the animals in F₁, F₂, F₃, F₄ and F₅, which at 2 years are 1 113, 964, 952, 953 and 895 lb. (505, 437, 432, 432 and 406 kg.) respectively, they note that differences in weight between the various generations are smaller at one year than at birth, and smaller at two years than at one year. It is thus unanimously agreed that inbreds develop more slowly than outbreds.

Fertility

624. Tyler states that in Wisconsin inbred heifers reach puberty about one month later than outbreds, but this may be connected with the difference in weight at that age between the two types of animals.

625. The Beltsville investigators think that the number of generations of inbreeding has a more marked effect on fertility

than the degree of inbreeding ; after a certain stage in their experiment they noticed an alarming drop in fertility, which could be remedied by interrupting the inbreeding. Thus, when inbred cows were mated with unrelated males the average number of matings per conception was considerably lower than the number necessary in mating with related males.

626. Fertility does, therefore, ultimately seem to be affected by too heavy inbreeding.

Constitution, vitality

627. The Beltsville experiments showed a higher death-rate for inbred than for outbred calves, due probably to lack of resistance to infection in the former. Tyler reports an increased tendency to embryonic mortality in inbred cows, which does not, however, occur in the early stages of gestation.

628. It may, therefore, be concluded that inbreeding very often leads to a reduction in the general sturdiness of the animals produced.

Type

629. Nelson and Lush report that inbreeding has a slightly unfavourable influence on the animal type concerned.

630. One of the most striking results of the Beltsville experiment was the very characteristic bearing of inbred animals, marked by the shape of the head, the set of the ears, the gait and a general appearance of apathy.

631. Inbred animals thus seem to have a marked phenotypical appearance.

Antigenic factors

632. From this standpoint the Wisconsin experiment is very interesting ; though no artificial selection was made for this characteristic, an increase in homozygosis due to inbreeding could be observed.

Yield

633. Nelson and Lush found that there was, on an average, a very significant decline of 4.5 lb. (2.04 kg.) in fats for every increase of 1 per cent in the coefficient of inbreeding.

634. Tyler observed a 3 lb. (1.36 kg.) drop in the fat yield for every increase of 1 per cent in the coefficient of inbreeding, the reduction being due not to a fall in the butter-fat content, but to a decrease in the amount of milk produced.

635. The average yields of the different generations, as shown in the Beltsville experiment, were as follows :

GENERATIONS	FAT YIELD PER LACTATION
F ₁	457 lb. (207.3 kg.)
F ₂	446 lb. (202.3 kg.)
F ₃	431 lb. (195.5 kg.)
F ₄	388 lb. (176.0 kg.)
F ₅	412 lb. (186.9 kg.)
F ₆ - F ₇	297 lb. (134.7 kg.)

636. It will be noted that the fat yield was fairly well maintained up to F₄. The sharp drop which then occurs, especially in F₆ and F₇, can be attributed to the low hereditary value of the inbred male used to sire these generations. This is an important point to which we shall return later.

637. Lastly, the authors of the Beltsville experiment studied the uniformity of performance of each generation in conjunction with the reduction in genetic variability caused by inbreeding. They obtained somewhat diverse results : for milk yield, a sharp drop in variability in F₁, gradual decrease in variability up to F₅, and very marked heterogeneity again in F₆ in the most closely related animals ; a comparable trend in fat yield : for butter-fat content a drop in variability up to F₃, followed by an increase to a level which keeps constant through F₄, F₅ and F₆. We shall comment on these facts also.

638. Woodward and Graves, who analysed the Beltsville experiments, pointed out that a comparison made between the yields of 7 outbred daughters of 7 inbred dams and those of 11 inbred daughters (including, it is true, 6 daughters of the poorest inbred male used in making up F₆) of the same dams, showed that the performance of the former was, on an average, 11 per cent higher for milk and 16 per cent higher for fats.

639. In addition, Parker gave us figures for the comparative performance of inbred, linebred and outbred animals reared at Beltsville. The results are expressed as positive or negative deviations from an average.

TYPE OF ANIMAL	DEVIATIONS IN MILK YIELD	DEVIATIONS IN FAT YIELD
Outbred	+ 412 lb. (+ 186.9 kg.)	+ 25 lb. (+ 11.3 kg.)
Linebred . . .	- 7 lb. (- 3.2 kg.)	+ 4 lb. (+ 1.8 kg.)
Inbred	- 1 629 lb. (- 738.9 kg.)	- 39 lb. (- 17.7 kg.)

On the basis of these figures the author admits that there is a drop of about 2 lb. of fat for every 1 per cent increase in the coefficient of inbreeding.

640. Other interesting data are put forward by Parker. These enable a comparison to be made between 56 outbred females and 56 linebred females born of the same dams (of four different lines, shown as L₁, L₂, L₃, L₄). The yields are expressed in pounds of fat.

	L ₁	L ₂	L ₃	L ₄
Outbred	693 lb. (314.3 kg.)	828 lb. (375.6 kg.)	867 lb. (393.3 kg.)	890 lb. (403.7 kg.)
Linebred....	566 lb. (256.7 kg.)	821 lb. (372.3 kg.)	825 lb. (374.2 kg.)	841 lb. (381.5 kg.)

The influence of the line on the results of such a comparison can be clearly seen here.

641. It must, however, be finally admitted that, as all the authors agree, inbreeding usually leads to a reduction in yield, although the ways of expressing the drop in performance may vary widely.

Discussion of the results of the experiments studied

642. Inbreeding experiments can only be absolutely conclusive if outbred animals are produced side by side with each inbred generation as a standard of reference since any lasting change of environment, favourable or otherwise, in rearing the herds, in the course of an experiment which covers a number of years, tends systematically to favour or penalise the most closely inbred animals of the last generations. In this respect the Wisconsin experiment is absolutely unimpeachable, as not only will environmental conditions be kept as constant as possible throughout the investigation, but outbred animals will also be produced for reference purposes in every generation.

643. Furthermore, the performance recorded for a given animal generation should not be attributed solely to the breeding-value of the sire. This is not, for instance, the case with the F₆ animals in the Beltsville experiment since the authors admit that the sixth inbred bull used in the investigation was a very poor specimen. Here again the Wisconsin experiment is interesting, as each generation of inbred animals constitutes a representative group of animals from different lines, and each will produce a sufficient number of inbred bulls for further breeding.

644. These investigations show beyond a doubt that it is impossible, even after a thorough study of an animal's pedigree, to foretell the effects of inbreeding with it. Everything depends on the genotype of the foundation stock; thus, the appearance of recessive genes, as met with in other inbreeding experiments carried out in the United States - in California and New Jersey,

in particular - did not occur in the specific investigations which we studied (incidentally, inbreeding provides a means of revealing the presence of undesirable recessive genes in a male; if, for example, 23 sire-daughter matings are made, there are 95 chances out of 100 that all the recessive genes contained in a given bull will be brought out). In general, it is only above a certain coefficient of inbreeding that marked drops in performance are observed. It would be interesting to see whether the coefficient is the same for animals with varied levels of performance. We consider the observation made at Beltsville of the influence of the number of generations of inbreeding on the animals' capacities to be important. Which is better - to recommend moderate inbreeding up to a stated coefficient of kinship or to recommend closebreeding? Some think that too rapid inbreeding may tend to reduce the genetic variability on which selection can act, so that some genetic combinations will be entirely lost. Research into this point would be most useful.

645. It would be wrong to conclude from these studies that inbreeding leads to a considerable reduction in the variation of performance by the animals produced. It must be borne in mind that a large proportion of the variation in animal production is attributable to largely uncontrollable environmental factors. Even if complete homozygosis were obtained in an inbred animal generation, which is in fact impossible, there would probably still be considerable differences in their performance. A curious fact which should be noted and which will require further research is that it is often the least heritable characteristics - e.g. fertility, milk yield - which are most affected by inbreeding. Must one agree with Lush that the chief function of inbreeding is to reduce genetic variation through manifestations of dominance and epistasis, - a non-genetic additive part of the total genetic variation?

646. To conclude, this brief review has yielded few indications about the use of inbreeding as a preliminary to exploitation of heterosis through crossbreeding, within the breed or outside it. The Wisconsin experiment will be of very great assistance in this field too. Incrosses and topcrosses can, in fact, be compared with every possible scientific guarantee for inbreds and outbreds. The "nicking" which seems to occur between certain strains can also be studied.

Conclusions on the inbreeding experiments on dairy cattle

647. What is to be the final verdict on inbreeding in stockbreeding? Linebreeding is rightly recommended by Parker and McGillard. In this way an attempt is made to keep a high degree of relationship, either with a female of good yield or with a first-class bull. The wider use of artificial insemination makes it possible to apply this breeding method in many countries. For instance, a breeder will inseminate the original group

of females from the son of a first-class bull ; the females in F₁ from a second son of the same fine bull, and so on for several generations. In this way he will contrive to collect in his herd the greatest possible number of genes from the outstanding ancestor without unduly augmenting the inbreeding coefficient of his animals.

648. If incrossing or topcrossing improved performance in the matter of milk yield through heterosis, their commercial exploitation might be considered in certain herds by using the results of inbreeding carried out by other breeders. In this way the breeding of dairy cattle would finally fall into two stages :

first, the production of inbred breeding animals in breeding herds ;

secondly, their use for linecrossing in other herds with the sole aim of increasing the yield.

649. Stockbreeders would have to get accustomed to judging the inbred animals which they consider buying, less on the basis of their own performance than of the results they could give in crossbreeding. The results of the experiment should, however, be awaited before such a procedure is recommended, as the experimental stage is not yet concluded.

650. At all events, heavy inbreeding does not in practice appear to be an end in itself, and cannot justifiably be regarded as a breeding programme. If need be, sire-daughter matings can be made in a small herd to avoid buying another bull. It is not usually advisable to go any further.

651. Furthermore, inbreeding should always go hand in hand with intensive selection. Nelson and Lush speak with authority on this point. They consider that selection can counterbalance drops in yield due specifically to any inbreeding that increases by 2 per cent in each generation.

652. In any case, if performance in a herd deteriorates too much as a result of inbreeding, the only safe way of recovering the ground lost is to practise outbreeding.

Crossbreeding experiments on cattle in the United States

Material on which the Report is based

653. At Beltsville the members of the Mission collected material on two very important crossbreeding experiments, one on rotational crosses of specifically dairy breeds and the other on crosses of a dairy breed with Sindhi zebus.

654. They also studied with great interest another crossbreeding experiment which is being carried out at Purdue

University (Indiana) between dual-purpose breeds ; this experiment is unfortunately only in its initial stages.

655. In addition, they heard something of the crossbreeding experiments carried out on the experimental farm in Southern Minnesota, which may perhaps be the prelude to the creation of a dual-purpose breed.

656. The Mission visited a farm in Indiana which breeds and sells crossbreds to be used for breeding purposes in the Southern States.

657. We also received some additional reprints on crossbreeding in particular of beef cattle.

Aims and methods of crossbreeding

Crossbreeding is, firstly, an instrument of genetic research

658. We shall not stress this point unduly, but it should be noted that crossbreeding experiments have been carried out on domestic animals to study the hereditary determinism of certain characters, in particular milking ability. In analysing the variance of an F_2 , however, three series of obstacles are encountered.

much of the variance observed is not of genetic origin but is due to environmental factors which can more or less be controlled ;

the parent breeds are never pure in the genetic sense of the term ;

a very large number of genes are probably involved in most of the characters of our domestic animals.

Crossbreeding is a source of genetic variation

659. By crossbreeding it is possible to introduce into the gene complement of a breed new hereditary factors which were not there before and which may be important in animal production. Moreover, greater genetic variability means that further progress can be made in selection, particularly with characters of high heritability.

660. This technique may be used to improve a breed temporarily, to graft one breed on to another less productive one, or even to create a new one which is better adapted to climate conditions or to given economic requirements. Crossbreeding is also the only sound genetic improvement method when commercial herds have to be adapted quickly to abrupt changes in a market.

Crossbreeding engenders heterosis

661. The immense success of hybrid maize led scientists to think that crossbreeding of domestic animals might also produce heterosis. There is no need for us to discuss here the causes of heterosis, as these have been studied in previous chapters. We shall merely recall, before analysing the important Beltsville experiment, the essential experimental conditions for demonstrating the existence of heterosis.

In the first place, the crossbred and purebred animals must be bred and must produce in the same environmental conditions.

In addition, it must be possible to compare the crossbred genotype with the purebred genotype, and this implies a knowledge of the breeding value of the parents, in particular the sires, who, in the case of dairy production, have no phenotypic expression of this character.

662. Two possibilities are therefore recommended :

1. In producing crossbreds and purebreds, a sufficient number of males and females should be used in order to represent a random sample of their breed.

2. A small number of bulls from each breed is used for reciprocal crosses.

663. Actually there are various kinds of breeding methods which seek to produce heterosis. We have referred previously to the incrossing of inbred animals belonging to two different lines within the breed and to topcrossing between an inbred male and outbred females of the same breed.

664. In the same way there can be various kinds of crosses between animals of two different breeds :

Animals taken at random from two different breeds may be crossed ; this is crossbreeding, which can be done in various ways. In some cases animals belonging to several breeds are crossed.

Animals belonging to two lines in two different breeds may be crossed ; this will be specifically incrossbreeding.

Lastly, inbred males of a given breed may be crossed with outbred females of another breed ; this will be topcrossbreeding.

665. In fact, all these techniques are essentially comparable. The only difference is in the degree of average relationship between the mated animals (higher relationship coefficient between animals of the same breed than between animals of different breeds) and consequently in the degree of outbreeding practised. As a rule, the heterosis which may be expected from a mating will be the more intense the greater the genetic dissimilarity between the mated animals ; thus incrossbreeding should normally produce greater heterosis than incrossing.

Other aims of crossbreeding

666. To obtain a uniform F₁ : In some cases a uniform F₁ can be obtained by crossbreeding. If we assume a quantitative polygenic heredity for most of the characters of our domestic animals, we are entitled to expect a reduced variability in the first generation, apart from heterosis. This is very often what is actually found to happen.

667. To break a negative genetic correlation between two characters, one sought in the dam and the other in the progeny: This is a particularly important practical problem in breeding. If females of a dairy breed are often crossed with males of a beef breed, this is perhaps in order to break a negative genetic correlation which may exist between aptitude for milk production and aptitude for beef production. Thus, the crossbred utilises the good dairy ability of its dam while benefiting from the paternal genotype in respect of early maturity and conformation, not to mention the additional possibility of heterosis.

668. Taking things all in all, crossbreeding very often has several aims. It may very well be done to produce heterosis, obtain a uniform F₁ and break a negative genetic correlation between two characters, all at the same time. This is often the case for first generation crosses to produce animals sold for slaughter.

669. Ultimately, however, we must distinguish two different crossbreeding policies:

- i) to raise the genetic value of crossbred sires in order to permit future improvements;
- ii) to concentrate the benefits of crossbreeding in one generation, the products of which will be marketed.

Crossbreeding experiments in the United States

Crossing of dairy breeds at Beltsville *

670. The crossbreeding experiment on dairy breeds at Beltsville was certainly of the greatest interest to the members of the Mission.

671. This experiment, which started in 1939, was undertaken to test the value of crossbreeding in dairy production. The female foundation stock consisted of Holstein, Jersey, Danish

* M.H. Fohrman, R.E. MacDowell, C.A. Matthews and R.A. Hilder : A. Crossbreeding Experiment with Dairy Cattle ; Technical Bulletin No. 1074, February, 1954, United States Department of Agriculture, Washington, D.C.

Progress report of Results of Dairy Cattle Crossbreeding Experiment at Beltsville; United States Department of Agriculture, July 1st, 1954.

Red and Guernsey cows, which were crossed with proved sires (progeny-tested) of the Holstein, Jersey and Danish Red breeds.

672. The progeny-index of the sires used was critically examined; only one male is said not to have confirmed its previous performance.

673. Maintenance and feeding conditions were kept as nearly constant as possible throughout the experiment, the animals remaining in stall for the whole year. The production performances shown are those of cows milked three times a day for testing periods of 365 days during their first lactation.

674. The number of first generation animals derived from the crossing of two breeds and their average fat yield are shown in Table A.

Table A

BREED OF DAM	BREED OF SIRE					
	HOLSTEIN		JERSEY		DANISH RED	
	NUMBER	YIELD lb.	NUMBER	YIELD lb.	NUMBER	YIELD lb.
Holstein....	-	-	9	562 (254.9)	7	583 (264.4)
Jersey	9	623 (282.6)	-	-	5	598 (271.3)
Guernsey...	9	599 (271.7)	1	562 (254.9)	7	582 (264.0)
Danish Red .	6	549 (249.0)	2	585 (265.4)	-	-

Figures in brackets represent the equivalent weight in kilogrammes.

675. Table B shows the milk and fat yields and the butterfat content for first generation two-way crosses compared with their purebred dams.

676. Two-way cross F₁ females were then crossed with proved sires of the third breed in order to make a three-way cross: Jersey and Guernsey females were excluded from the experiment. The results of these three-way crosses are shown in Table C.

Table B

BREED COMBINATION *	NUMBER IN EACH GROUP	AVERAGE YIELD OF CROSSED				AGE		AVERAGE YIELD OF DAMS			AGE	
		MILK lb.	FAT		MONTHS	YEARS	MONTHS	MILK lb.	FAT		YEARS	MONTHS
			B.C. %	lb.					B.C. %	lb.		
Jersey-Holstein	9	12,320 (5,588)	4.61	562 (254.6)	2	2	2	13,108 (5,946)	3.51	458 (207.7)	2	3
Danish Red-Holstein . .	7	14,826 (6,725)	3.95	583 (264.4)	2	1	1	15,480 (7,022)	3.49	538 (244.0)	2	3
Holstein-Jersey	9	12,804 (5,808)	4.88	623 (282.6)	2	3	3	8,195 (3,717)	5.47	443 (200.9)	2	5
Danish Red-Jersey	5	12,475 (5,659)	4.78	598 (271.3)	2	1	1	7,361 (3,339)	5.69	419 (190.1)	2	3
Holstein-Guernsey	9	12,796 (5,804)	4.71	599 (271.7)	2	3	3	8,485 (3,849)	5.12	431 (195.5)	2	7
Jersey-Guernsey	1	10,653 (4,832)	5.27	562 (254.9)	2	2	2	8,052 (3,652)	4.51	363 (164.7)	2	0
Danish Red-Guernsey . .	7	13,143 (5,962)	4.43	582 (264.0)	2	1	1	8,758 (3,973)	4.95	428 (194.1)	2	9
Holstein-Danish Red . .	6	14,005 (6,352)	3.93	549 (249.0)	2	1	1	11,778 (5,343)	3.92	454 (205.9)	2	9
Jersey-Danish Red	2	11,515 (5,223)	5.08	585 (265.4)	2	5	5	13,209 (5,992)	4.01	531 (240.9)	3	1
All groups	55	13,039 (5,915)	4.53	586 (265.8)	2	2	2	10,540 (4,781)	4.55	455 (206.4)	2	6

* The sire is shown first.
 Figures in brackets show the equivalent weight in kilogrammes.

Table C

BREED OF DAM	BREED OF SIRE					
	HOLSTEIN		JERSEY		DANISH RED	
	NUMBER	YIELD lb.	NUMBER	YIELD lb.	NUMBER	YIELD lb.
Jersey- Danish Red ..	2	566 (256.7)	-	-	-	-
Danish Red- Jersey	9	632 (286.7)	-	-	-	-
Danish Red- Guernsey	6	562 (254.9)	-	-	-	-
Danish Red- Holstein	-	-	6	552 (250.4)	-	-
Holstein- Danish Red ..	-	-	6	587 (266.3)	-	-
Jersey- Holstein	-	-	-	-	6	602 (273.1)
Holstein- Jersey	-	-	-	-	13	576 (261.3)
Holstein- Guernsey	-	-	-	-	10	597 (270.9)

Figures in brackets show the equivalent weight in kilogrammes.

677. Similarly, Table D compares the yields of three-way cross females with their two-way cross dams.

678. The three-way cross females were again crossed with proved sires, either in order to start a second rotational three-way cross cycle or to produce a four-way cross from females derived from the Guernsey foundation stock. The progeny performances of only 6 out of the 8 combinations of 3 breeds previously obtained are known. These results are shown in Table E.

679. Table F compares the performances of these animals with those of their three-way cross dams.

Table D

BREED COMBINATION	NUMBER IN EACH GROUP	THREE-WAY CROSS DAUGHTERS			AGE		TWO-WAY DAMS			AGE	
		MILK lb.	B.C.%	FAT lb.	YEARS	MONTHS	MILK lb.	B.C.%	FAT lb.	YEARS	MONTHS
Holstein-Jersey-Danish Red	2	13,704 (6,216)	4.12	566 (256.7)	2	2	11,213 (5,086)	4.81	539 (244.75)	1	11
Holstein-Danish Red-Jersey.	9	14,393 (6,529)	4.40	632 (286.7)	2	2	12,695 (5,759)	4.85	616 (279.4)	2	1
Holstein-Danish Red-Guernsey	6	12,842 (5,825)	4.40	562 (254.9)	2	1	13,376 (6,067)	4.40	588 (266.7)	2	1
Jersey-Danish Red-Holstein	6	11,572 (5,249)	4.78	552 (250.4)	2	1	14,613 (6,628)	3.93	571 (259.0)	2	2
Jersey-Holstein-Danish Red	6	13,236 (6,004)	4.33	587 (266.3)	2	2	13,929 (6,318)	3.96	550 (249.5)	2	0
Danish Red-Jersey-Holstein	6	13,190 (5,983)	4.63	602 (273.1)	2	1	12,604 (5,717)	4.65	580 (263.1)	2	0
Danish Red-Holstein-Jersey.	13	13,360 (6,060)	4.34	576 (261.3)	2	2	12,766 (5,791)	4.89	622 (282.1)	2	2
Danish Red-Holstein-Guernsey	10	13,686 (6,208)	4.43	597 (270.9)	2	3	13,082 (5,934)	4.72	614 (278.5)	2	5
Total	58	13,361 (6,061)	4.44	588 (266.7)	2	2	13,114 (5,949)	4.58	596 (270.4)	2	2

Figures in brackets show the equivalent weight in kilogrammes.

Table E

BREED COMBINATION	BREED OF SIRE					
	HOLSTEIN		JERSEY		DANISH RED	
	NUMBER	FAT lb.	NUMBER	FAT lb.	NUMBER	FAT lb.
Danish Red-Jersey Holstein.....	5	603 (273.5)	-	-	-	-
Danish Red-Holstein- Jersey.....;	-	-	6	602 (273.1)	-	-
Danish Red-Holstein- Guernsey.....	-	-	2	591 (268.2)	-	-
Holstein- Danish Red-Jersey...	-	-	7	600 (272.2)	-	-
Holstein- Danish Red-Guernsey.	-	-	2	606 (274.9)	-	-
Jersey- Danish Red-Holstein..	1	590 (267.6)	-	-	-	-

Figures in brackets show the equivalent weight in kilogrammes.

680. Finally, the performances of the different generations may be summarised as shown in Table G.

Table G

GROUP	NUMBER	MILK lb.	FAT		AGE	
			%	lb.	YEARS	MONTHS
Foundation cows...	55	10,540 (4,781)	4.55	455 (206.4)	2	6
Two-way cross....	55	13,039 (5,915)	4.53	586 (265.8)	2	2
Three-way cross..	58	13,361 (6,061)	4.44	588 (266.7)	2	2
Progeny of three- way crossbreds..	23	13,176 (5,977)	4.58	600 (272.2)	2	3

Figures in brackets show the equivalent weight in kilogrammes

Table F

BREED COMBINATION	DAUGHTERS OF THREE-WAY CROSS DAMS				AGE		THREE-WAY CROSS DAMS			AGE	
	NUMBER	MILK lb.	FAT		YEARS	MONTHS	MILK lb.	FAT		YEARS	MONTHS
			B.C. %	lb.				B.C. %	lb.		
Holstein-Danish Red- Jersey-Holstein	5	13,863 (6,288)	4.35	603 (273.5)	2	1	14,701 (6,668)	4.45	649 (294.4)	2	0
Jersey-Danish Red- Holstein-Jersey	6	12,769 (5,792)	4.77	602 (273.1)	2	4	13,869 (6,291)	4.50	615 (279.0)	2	0
Jersey-Danish Red- Holstein-Guernsey	2	13,166 (5,972)	4.47	591 (268.2)	2	3	13,156 (5,968)	4.62	604 (274.0)	2	6
Jersey-Holstein- Danish Red-Jersey	7	13,166 (5,972)	4.59	600 (272.2)	2	4	14,429 (6,545)	4.41	634 (287.6)	2	1
Jersey-Holstein- Danish Red-Guernsey	2	12,677 (5,750)	4.78	606 (274.9)	2	1	12,506 (5,673)	4.31	531 (240.9)	2	3
Holstein-Jersey- Danish Red-Holstein	1	13,206 (5,990)	4.47	590 (267.6)	2	3	12,668 (5,746)	5.07	643 (291.7)	2	0
Total	23	13,176 (5,977)	4.58	600 (272.2)	2	3	13,987 (6,345)	4.48	621 (281.7)	2	1

Figures in brackets show the equivalent weight in kilogrammes.

681. The authors conclude that when proved sires are used for rotational crosses involving three or four breeds, there is a marked increase in yield in F1 (average level of heterosis = about 20 per cent), the effect of crossbreeding being to maintain this heterosis over the generations.

682. In studying the homogeneity of yields of foundation stock, two-way crossbreds and three-way crossbreds, by means of the standard deviation and the variance coefficient in these yields, the authors find that the variance is considerably lower in F1 but rises subsequently.

683. In this research work it has also been found that crossbreds had a high degree of persistence, which accounted for their heavy yields.

684. The order of breeds in the rotation seems to be a matter of indifference, according to the experimenters; the slight differences observed with the various breed combinations can in their opinion be attributed to the different breeding values of the sires used.

685. After completing their first lactation at Beltsville, most of the crossbreds were lent to private breeders so that their performances could be studied in normal working conditions. Most of the yields recorded are thus 2nd, 3rd and 4th lactations, of standard length (305 days) or less, of cows milked twice a day. Milk yields are not adjusted for age. They are shown in Table H.

Table H

GROUPS OF ANIMALS	NUMBER OF PERFORMANCES	MILK lb.	FAT		AVERAGE AGE		DAYS OF LACTATION
			B.C. %	lb.	YEARS	MONTHS	
2-way cross...	130	10,763 (4,882)	4.40	467 (211.8)	5	1	301
3-way cross...	115	11,270 (5,192)	4.27	480 (217.7)	4	4	298

Figures in brackets show the equivalent weight in kilogrammes.

686. The original feature of these experiments is that they have shown a new crossbreeding technique; many previous experiments had endeavoured to obtain F2 by crossing F1 crossbreds; Beltsville sought a method of continual crossbreeding whereby new genes from good tested sires could be introduced into each generation and a certain level of heterosis maintained. The idea that crossbred females can be successfully used for dairy production but not for breeding is not justified in the eyes of the Beltsville research workers who demonstrated that the progeny of crossbred cows from proved sires gave excellent milk yields.

687. This is a very important point which permits the authors of these experiments to recommend that dairy farmers using artificial insemination who are not specially interested in a given breed but aim solely at improving the productivity of their herds, should use the best bull available at the centre and should keep the females obtained for further crossbreeding without any risk.

Purdue experiment (Indiana)

688. The principal aim of this experiment is to see whether heterosis exists in crossbred dual-purpose cattle and whether it can be exploited commercially.

689. This experiment was only begun in 1951 with 20 cows and a bull from each of the three dual-purpose breeds : Red Poll, Danish Red, Milking Shorthorn. The milk and fat yields of the three foundation breeds were as shown in Table I.

Table I

BREED	MILK YIELD		FAT YIELD	
	lb.	kg.	lb.	kg.
Danish Red.....	8,910	4,042	331	150.1
Milking Shorthorn...	8,321	3,774	293	132.9
Red Poll.....	6,418	2,911	251	113.9

690. The cows were kept in the experiment for three lactations. The mating plan for obtaining F1 calves from the foundation stock is summarised in Table J.

Table J

BREED OF BULLS	BREED OF COWS		
	DANISH RED	RED POLL	MILKING SHORTHORN
Danish Red.....	30	15	15
Red Poll.....	15	30	15
Milking Shorthorn...	15	15	30

691. All the female progeny was kept and mated as follows :

purebreds were divided into two groups, in order to obtain $1/2$ purebred progeny and $1/4$ crossed with each of the other two breeds ;

crossbreds were mated with males of the third breed ;

foundation bulls were replaced in order to avoid inbreeding with purebreds ;

lastly, three-way cross females will probably be mated once to a male of each breed in succession.

692. It should be noted that progeny growth is tested periodically from birth and that the fattening performances of castrated males are carefully recorded. Table K gives a few of these fattening records:

Table K

BREED	NUMBER OF ANIMALS	AVERAGE DAILY GAIN DURING FATTENING PERIOD		AVERAGE DAILY GAIN SINCE BIRTH	
		lb.	GRAMS	lb.	GRAMS
Red Poll	8	2.03	921	1.79	812
Milking Shorthorn ...	9	2.21	1,002	1.99	903
Danish Red	9	2.26	1,025	1.89	857
Danish Red x Milking Shorthorn..	7	2.28	1,034	1.96	889
Danish Red x Red Poll	5	2.20	1,000	1.85	839
Red Poll x Milking Shorthorn..	9	2.27	1,030	1.89	857

693. Unfortunately, it is not known whether cows which were first mated pure were so mated for their three calvings, or whether, on the contrary, the other two calvings produced crosses with each of the other two breeds. The second alternative seems the more probable, since it would then be possible to compare dams between outbreds and crossbreds in the same environmental conditions and the experimenter himself told us that such conditions were not very good.

Crossbreeding experiments in Minnesota

694. On the experimental farm in Southern Minnesota, we saw crosses between Shorthorn-Jersey and Sindhi cattle, the Jersey being used to improve the butterfat content and the Sindhi zebu to provide interesting genes relating to butterfat content and heat tolerance. On these crossbreds, Brown Swiss was imposed; this secured a certain homogeneity of colour but did not increase the size of the calves; finally, the Dutch Pie Rouge was introduced for the latter purpose. The diversity of such a programme is rather astounding. It will admittedly secure an important genetic variation but will it lead to the creation of a dual purpose breed, tolerant of heat, with a good fat yield and yet heavy enough for beef production?

Sindhi-Jersey crosses at Beltsville *

695. The study of crossbreeding between European bulls and zebus was started in the United States because of the problem of adapting European breeds to the hot, damp regions of the Gulf of Mexico. The close inter-State co-operation achieved in the research done on this subject is directed by the Bureau of Dairy Industry. Work is proceeding both at Beltsville and in experimental stations in Louisiana, Texas, South Carolina and Georgia. Only the research work done at Beltsville will be discussed here.

696. In 1946, two Red Sindhi males and two females - zebu dairy breed - were imported from the Allahabad Research Institute, India. To begin with, the idea was to increase the stock of Sindhi animals, as far as inbreeding permitted (here it should be noted that the genetic variability which could be obtained with Sindhis was necessarily restricted because of the small number of animals imported).

697. The first crosses were made with Jersey, the predominant dairy breed in the Southern States. The idea of the crosses was to obtain the whole $1/8$ blood range possible between animals of the two breeds.

698. Since then, Sindhi-Holstein crosses have been made for comparison with their Sindhi-Jersey homologues. Table L gives the list of calves born from such crossings at Beltsville.

Table L

CROSSES (SIRE SHOWN FIRST)	BREED COMBINATION	NUMBER OF CALVES BORN	
		MALES	FEMALES
Crosses : Sindhi-Jersey			
S x J (F ₁)	1/2 Sindhi-1/2 Jersey	35	50
S x (S x J)	3/4 Sindhi-1/4 Jersey	13	26
J x (S x J)	1/4 Sindhi-3/4 Jersey	8	8
S x (S x S x J)	7/8 Sindhi-1/8 Jersey	4	3
S x (J x S x J)	5/8 Sindhi-3/8 Jersey	1	1
(S x J) x (S x J) (F ₂)	1/2 Sindhi-1/2 Jersey	5	5
(S x J) - (S x J) x J	3/8 Sindhi-1/4 Jersey	1	1
Crosses : Sindhi-Holstein			
S x H (F ₁)	1/2 Sindhi-1/2 Holstein	4	4
S x (S x H)	3/4 Sindhi-1/4 Holstein	0	3
	TOTAL CROSSBREDS	71	101

* M.H. Forhman, R.E. MacDowell and H.K. Douglas : Progress Report of the Sindhi Crossbreeding Experiment at Beltsville; United States Department of Agriculture, Agricultural Research Administration, Bureau of Dairy Industry, Washington 25, D.C. (R.D.I. -Inf.-128-Revised September 1953).

699. It will be seen that the number of crossbreds other than F₁ is relatively small. On the other hand, it was possible to compare first generation crossbred cows and purebred Jerseys, with conditions of upkeep and feed as nearly constant as possible, for 42 purebred Jersey cows gave 50 Jersey-Sindhi females.

700. The characters observed by the experimenters were : milk and fat yield, growth, physiological factors of heat tolerance.

701. Twenty-two Sindhi-Jersey females sired by two different Sindhi males have so far completed one or more lactations ; we were given their full performance together with that of their dams, but the results are not at present interpreted.

702. Very full particulars of the growth of crossbred females as compared with their dams have been recorded and are shown in Table M.

Table M

AGE	NUMBER OF PAIRS DAMS AND DAUGHTERS	AVERAGE WEIGHT in lb.		DAUGHTER/DAM RATIO IN PER CENT	AVERAGE WEIGHT in lb.	
		JERSEY DAMS	SINDHI-JERSEY DAUGHTERS		SINDHI FEMALES IN INDIA	FOUR SINDHI FEMALES BORN IN U.S.A.
Birth	37	58 (26.3)	65 (29.5)	112	43 (19.5)	43 (19.5)
6 months . . .	32	281 (127.5)	318 (144.2)	113	-	202 (91.6)
12 months . .	31	520 (235.9)	566 (256.7)	108	-	334 (151.5)
18 months . .	31	655 (297.1)	671 (304.4)	102	-	408 (185.1)
2 years . . .	26	824 (373.8)	855 (387.8)	104	447 (202.8)	-
3 years . . .	21	930 (421.8)	951 (431.4)	102	-	-
4 years . . .	16	1,019 (462.2)	1,038 (470.8)	102	-	-
5 years . . .	9	1,000 (453.6)	1,040 (471.7)	104	750 (340.2)	-

Figures in brackets show the equivalent weight in kilogrammes.

703. These results are rather surprising, for the purebred sindhis are smaller than the Jerseys. This is very definite evidence of heterosis. Similarly, a series of measurements showed that at 6 months the F₁ females were larger than the Jerseys (significance limit of 1 per cent) except in the length of the body. A comparison made during the first lactation showed, however, that the Jersey females were larger than the crossbreds (significance limit 1 per cent) except in the length of the head. Conversely to what has been found for inbreds, crossbreds probably grow much faster when young than purebreds; the rate of growth then slows down apparently until the body measurements of the purebreds become bigger, the weight at adult age being comparable.

704. The crossbreds also show many outward characteristics of the Sindhi, in particular the slope of the rump, the shape of the udder, the length of the head, the size of the ears and horns and the extent of the dewlap.

705. Very interesting bioclimatic studies have also been carried out at the Beltsville Station on the comparative heat tolerance of purebred Jerseys and Jersey-Sindhi crossbreds. The results are as follows :

there are no differences in the behaviour of Jerseys and crossbreds kept in normal conditions between 57° and 84°F.;

but after spending six hours in an air-conditioned room at a temperature of 105°F. and a hygrometric pressure of 34 mm., there was a noticeable rise in the rectal temperature of the Jerseys as compared with the crossbreds.

706. If the rise in rectal temperature indicates poor adaptation to difficult climatic conditions, it may be concluded that the crossbreds tolerate heat better than the Jerseys. This is true for all possible physiological states of a dairy cow - heifer stage, drying period, lactation at same production level.

707. Explanations have been advanced for this difference in adaptation and may be summarised briefly as follows : if the F₁ animals get rid of their excess heat more easily, it is not because they have a greater area of body per unit of weight than the Jerseys, for these areas seem quite comparable; neither is it a question of pulmonary ventilation; the authors think that the crossbreds can evaporate a larger amount of water at the surface of the skin than the Jerseys (an apparatus and a method for measuring this skin perspiration have recently been developed at Beltsville).

708. However that may be, there can be no doubt that the crossbreds tolerate heat better than the purebred Jerseys. But one important question is to know whether, as some think even in the United States, the yield loss in crossing is offset by the gain in heat tolerance; on the other hand, it is certain that the crossbreds are a better type of beef animal than the Jerseys.

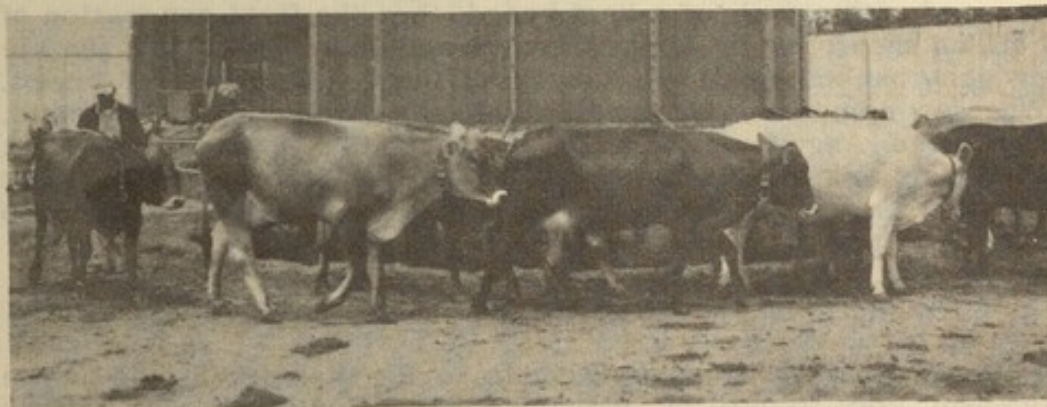
709. During our tour we were told of other crossbreeding experiments carried out in the Southern States between dairy breeds (Holstein and Brown Swiss in particular) and Red Sindhi. Incidentally, we also heard of crossbreeding for beef production between Brahman zebu and various beef breeds, e.g. Angus, Hereford, Shorthorn and Charollais, but, of course, had no opportunity of forming an opinion on these crosses.

Crossbreeding on an Indiana farm

710. We had occasion to visit an Indiana farm which sells crossbred breeding animals to be used for beef production in the Southern States of the United States.

711. Santa Gertrudis males are crossed with Angus or Red Poll females. (The Santa Gertrudis breed was created for the South and is the result of a cross between a Shorthorn and a Brahman zebu.)

712. In addition, this farm is trying at present to produce crossbred breeding animals to be used for dairy production in the Southern States. The aim is to obtain animals with fairly good dairy characters, tolerating rough fodder, adequately adapted to heat and with an adequate carcass quality. For this purpose, crossbred males (Jersey x Sindhi) from Beltsville University are crossed with Brown Swiss females. The phenotype of the resultant crossbreds is fairly homogeneous; it is planned to backcross them with Jersey or Sindhi; F₁ males will be used on females of the same generation but from different sires.



Crosses between (Jersey x Sindhi) males and Brown Swiss females

713. The purpose of this cross is in our opinion not clearly defined, unless it is to earn a profit for its promoters. The impression gained is that it is desired to provide possible buyers with crossbreds which will generate heterosis; but at the same time there seems to be a tacit move towards creating a breed with rather mixed characters for use in the hot coun-

tries of the South, since an attempt is undoubtedly being made to achieve a rather wide spread of genetic variation.

Crossbreeding for beef cattle

714. We were also told of two studies on crossbreeding for beef cattle.

715. One of these is concerned with the problem arising in the great plains of the North,* while the other aims at defining the breeding programme to be recommended for the States on the Gulf of Mexico.**

716. The first experiment is being carried out in Montana to study the possibilities of maintaining heterosis by using beef breed males and crossbred females ; this is a rotational cross between three breeds, as follows :

- 1st generation : Shorthorn male and Hereford females,
- 2nd generation : Angus male and F₁ crossbred females,
- 3rd generation : Hereford male and F₂ crossbred females.

717. Herefords were used as references in this experiment ; the conclusions are that with males the weight at weaning and at the end of fattening is always higher in crossbreds than with females ; weight and scoring at weaning and weight at 18 months are also higher in crossbreds, the reference purebred Herefords remaining the lightest until five years, when they were classed between the first and second generations of crossbreds.

718. The second series of studies recommends that in the Southern States a foundation stock of graded females should be crossed with a male of a beef breed, then the first generation of heifers should be crossed with a Brahman bull and the female progeny backcrossed with a male of the foundation beef breed. We also compared 1/2 breed (Angus x Brahman), 3/4 breed, 1/4 breed (Angus x Brahman), 5/8 breed, 3/8 breed (Angus x Brahman) and 1/2 breed (Angus x Afrikander) generations, but it would be going beyond the scope of this report to enter into details here.

Grading

719. Lecturing to purebreeders in the Western States on the present and future of purebreeding, Hodgson gave some interesting particulars of the comparison between registered herds and upgraded herds, i.e. in which an improved breed has been established by mating males with rather disparate females.

* Bradford Knapp Jr, A.L. Baker and R.T. Clark : Crossbred Beef Cattle for the Northern Great Plains ; Circular No. 810, April 1949, Washington, D.C. United States Department of Agriculture.

** A.L. Baker and W.H. Black : Crossbred Types of Beef Cattle for the Gulf Coast Region ; Circular No. 844, May 1950 - Washington, D.C. United States Department of Agriculture.

720. The D.H.I.A. results show that in a random sample from 17,900 performances on average per annum for registered cows and 14,800 performances on average per annum for graded cows, the average fat yield was 25 lb. (11.34 kg.) higher for registered cows between 1942 and 1952; Table N gives details of the results obtained.

Table N

(Random sample of D.H.I.A. data for 5 dairy breeds :
Ayrshire, Brown Swiss, Guernsey, Holstein and Jersey)

YEAR	REGISTERED COWS		GRADED COWS		AVERAGE DIFFERENCE IN FAT YIELD
	NUMBER OF PERFORMANCES	AVERAGE FAT YIELD lb.	NUMBER OF PERFORMANCES	AVERAGE FAT YIELD lb.	
1942	17,984	358 (162.4)	21,293	333 (151.0)	25
1943	14,851	355 (161.0)	13,527	330 (149.7)	25
1944	14,381	348 (157.9)	14,481	326 (147.9)	22
1945	14,077	355 (161.0)	10,877	331 (150.1)	24
1946	14,887	357 (161.9)	11,023	336 (152.4)	21
1947	17,055	359 (162.8)	13,793	333 (151.0)	26
1948	18,034	361 (163.7)	14,633	334 (151.5)	27
1949	18,518	368 (166.9)	19,854	345 (156.5)	23
1950	22,285	379 (171.9)	19,180	354 (160.6)	25
1951	21,751	379 (171.9)	18,719	354 (160.6)	25
1952	23,174	376 (170.6)	8,412	356 (161.5)	20
Average	17,909	365 (165.6)	14,800	340 (154.2)	25

Figures in brackets show the equivalent weight in kilogrammes.

721. Hodgson also says that the value of the additional yield is greater than the additional cost of feed. But the speaker himself limits the value of his comparison, for the registered cows were not producing in the same conditions as the graded cows.

722. Hodgson also reports the results of an economic survey carried out in 1951 in New York State on the same problem : comparison of registered and graded animals. The registered cows were found to have produced 44 lb. (20 kg.) more of fat, but they consumed more concentrates so that it was a moot point whether they were more economic : Hodgson affirmed that they were.

723. It may, however, be asked whether registered animals are genetically superior to graded animals or whether they are not simply better kept and better fed because they are tended by better breeders.

724. The conclusion is that graded cows are interesting from the production point of view. Hodgson therefore wonders whether closed Herd Books are not a mistake, since these animals could increase genetic variability to an interesting extent within the breed.

Discussion of the crossbreeding experiments studied

725. There is no doubt that crosses between European dairy breeds and zebus are extremely interesting ; it is equally certain that crossbreeding is a good means of giving cattle that are to be used in hot countries genes well adapted to hot climates. The Beltsville experiments have the merit of showing that the following limits had to be respected if adaptation and yield are to be smoothly combined : $\frac{3}{4}$ Sindhi blood - $\frac{1}{4}$ Jersey blood, and $\frac{1}{4}$ Sindhi blood - $\frac{3}{4}$ Jersey blood.

726. It would, in fact, seem reasonable to suppose that only the minimum of zebu blood compatible with good heat tolerance should be perpetuated in crossbreds, if the milk yield is not to be unduly affected. The adaptation of dairy cattle to hot countries constitutes a real problem for certain European countries with territories in tropical, sub-tropical, desert or semi-desert regions.

727. The technique of grading is well known and highly valued in many European countries. It provides a reliable and economic method of raising a common place and rather mixed cow population to a satisfactory level of production. Stock-breeders practising this "grafting" technique are very often advised, while improving their animals' stock of genes, to better the environmental conditions in which their herds are reared, to ensure, that, for instance, the feeding factor does not limit the phenotypical results of their cows' milk yield.

728. Crossbreeding undoubtedly leads to increased genetic variability in subsequent generations. This is precisely why it has been possible to evolve famous and technically interesting breeds in Europe. In the United States the Santa Gertrudis beef breed is a great success. Yet we felt that the few attempts we

saw being made to evolve a dual-purpose breed were being conducted on somewhat devious lines.

729. As for crossbreeding limited to the first generation, which is rather favoured in some European countries for the production of beef animals, we had no opportunity of seeing anything similar in the United States.

730. The crossing of dairy breeds to obtain heterosis is, in our view, the focal point of this report, as it has evoked a lot of controversy, both in Europe and in the United States. Some people - perhaps quite rightly - claim that the Beltsville experiments have not been carried out on absolutely strict scientific lines. Too few males were used for producing the different generations. It is a fact that only one Holstein bull and one Danish Red were used to beget the first crossbred generation ; this is certainly a very important point, as the success of the crossbreds born of the Holstein-Friesian bull might be attributed solely to its high genetic value. Some people go so far as to consider that purebred daughters of this bull, in the same environmental conditions, might have given as good results. Thus, the successful crossbreeding would be no more than a matter of successful selection. It must also be admitted that there were not enough reference comparisons between the crossbreds and purebreds of the same generation, reared in identical environmental conditions. In addition, the purebred dams used in the experiment as reference standards achieved their performance in other centres. Furthermore, the progeny of the proved sires gave no production at Beltsville, and this is clearly a source of error in assessing their intrinsic value.

731. Again, keeping an environment constant throughout an experiment lasting nearly fifteen years is not an easy matter. Even a slight improvement in environmental conditions over the years will favour the latter generations as compared with the original generation, which in the present case is the only purebred group in the experiment.

732. Lastly, to judge the performance of experimental animals on a standard lactation basis, with the help of certain corrective factors, may in some cases be fallacious.

733. The Beltsville investigators point out in reply that, if animals are picked from the herd at random for crossbreeding, there is no certainty that the specimens used are really representative of their breed ; apart from a few fixed racial characteristics, the genotype of American dairy cattle is in their opinion very heterozygotic. Thus, random selection of the foundation stock could not provide sufficient basic data for a proper study of the value of crossbreeding. The authors therefore thought the drawbacks of random selection could be overcome by selecting the original females more strictly and using males proved by the yield of their progeny.

734. Besides being a positive and irrefutable demonstration of heterosis, the Beltsville experiments provided conclusive proof that crossbred females could be used for reproduction under a specific programme of rotational crossing between several breeds. The breeding technique involved is very simple. The stockbreeder merely has to obtain semen from the best bulls of the different breeds available at the time at the Artificial Insemination Centre for his region.

735. To conclude, with such a breeding method, a method that is considered rather revolutionary in many European countries, further methodical research would have to be done on heterosis in dairy cattle. Other questions would need to be cleared up at the same time : e.g. is the degree of heterosis constant whatever the level of production of the animals crossed ?

736. In most European countries pure-line breeding has made it possible, by keeping a larger number of performance records, practising more artificial insemination and progeny-testing of young bulls in artificial insemination centres, to attain a very satisfactory, and in some countries even a remarkable, level of production. To upset a system solidly based on the work of a whole class of stockbreeders who have been selecting their cattle for years - though, admittedly with varying success - would obviously be a serious problem.

737. In point of fact, the merits of pure-line breeding and of crossbreeding will soon be apparent ; the two methods seem contradictory, but they can very well be carried on side by side (production of heterosis) or consecutively (crossbreeding giving a pure breed ; the pure breed making no further genetic progress, and having to be crossed).

738. All the members of the Mission were impressed by the enormous resources available to the American stockbreeder for solving the problems of the genetic improvement of dairy cattle. Thanks to the great mass of experience accumulated and the persistent efforts made it should be possible to devise breeding methods which will ultimately help to improve the productivity of American cattle.

BLOOD GROUPS IN CATTLE

739. The study of blood groups in cattle, although of very recent date (1940), has already led to applications which are of considerable practical interest. What is more, the theoretical importance of the studies made in this field is at least as great as the practical importance, since only the antigens, plus a few other rare characters - colour, in particular - can be followed to the level of the genes. They are therefore first-class material for the geneticist. After a brief review of the dis-

covery and identification of these antigens, we shall consider in greater detail the various possible applications of this new technique.

740. Although the work of Landsteiner drew investigators' attention as early as 1900 to the antigens carried by the red corpuscles in the human blood, it was not until about 1940 that L.C. Ferguson, C. Stormont and M.R. Irwin, working at the University of Wisconsin, were able to demonstrate the existence of similar factors in the blood of cattle. The search for these antigens was held up by the fact that there are no natural antibodies in cattle as there are in man. The antibodies can only be identified after a series of transfusions of blood from a donor animal to a recipient animal. In practice, four transfusions, each of one litre or less of citrated blood, have to be made at intervals of about a week to obtain a maximum percentage of antibodies in the serum of the recipient animal. Most generally, however, experience has shown that by using this procedure not just one but a series of antibodies is obtained.

741. All the antigens are carried by the red corpuscles, except antigen J which is free in the serum. If, after being carefully washed in an isotonic saline solution, red corpuscles carrying given antigens are placed in a serum containing at least one of the corresponding antibodies, hemolysis occurs. In fact, for hemolysis to take place fresh rabbit serum must be added to the serum.

742. The hemolysis test has been preferred by American investigators to hemoagglutination as being more sensitive (40 to 60 per cent of cells dissolved instead of about 30 per cent of cells agglutinated).

743. How are the antibodies to be isolated and the corresponding antigens then individually distinguished? The isolation technique involves lengthy, difficult and hazardous work. To minimise the work, related animals, i.e. animals which already have some antigens in common, are chosen. For example, blood is transfused from a heifer to her dam. As an individual secretes antibodies only for antigens it does not itself possess, the dam produces only a relatively small number of antibodies, those referable to the sire.

744. From this iso-immunised serum, by successive elimination of the various antibodies which it contains, a serum can be obtained containing no more than one antibody and reacting therefore only with one antigen. Such a serum is called a reagent. In practice, to purify the complex iso-immunised serum, a batch of animals is used which can be divided into two groups :

one group of animals whose red corpuscles are not dissolved by the immunised serum ; the animals in this group therefore have no antigens in common with the original donor ;

another group of animals whose red corpuscles are dissolved by the immunised serum ; the individuals in this group possess one or more antigens in common with the original donor.

745. The antibodies are then eliminated in turn with the red corpuscles of the individuals in the second group. By putting each of the latter's excess red corpuscles into the same serum in turn, the antibody or antibodies corresponding to the antigens which they possess are eliminated from the serum at each step. After a series of eliminations, the number of which is very variable moreover, the serum is left with only one antibody which can also be eliminated. The serum can then no longer react to any of the red corpuscles of the animals previously used to purify it.

746. The antigens thus isolated were denoted each by a letter of the alphabet, from A to Z and then from A' to Z'. At the present time more than forty antigens have been identified in the United States and some of these have been rediscovered by the various European laboratories studying the same question.

747. Once the reactive sera have been obtained it is a relatively simple matter to analyse the antigens in an individual. The red corpuscles to be tested are first of all washed in an isotonic saline solution and are then placed in suspension in the same solution at a concentration of 2.5 per cent. All that has to be done next is to bring together in a small test tube :

- 1 drop of the suspension of red corpuscles ;
- 2 drops of the reagent adequately diluted ;
- 1 drop of fresh rabbit serum, half diluted with saline.

748. The degree of hemolysis is measured by eye appraisal, a rating being given according to the percentage amount of red corpuscles dissolved. The readings are taken, at a temperature of 20 to 25° C. at regular intervals (from 2 to 18 hours). As the reagent, in an adequate dilution, can generally be used in 1/8 dilution, 80,000 individuals can be tested with 1 litre of reagent in an adequate dilution. The sera can also be kept easily, either refrigerated to -18° C. or at -5° to +5° C. Fresh rabbit serum is used as a complement source, as it generally possesses no natural antibodies corresponding to the antigens in cattle. It must, however, be tested beforehand.

Hereditary transmission of antigens in the blood

749. The many studies carried out in the United States indicate that the antigens in the blood of cattle are transmitted according to Mendel's laws, in most cases with complete dominance ; each antigen or group of antigens corresponds to a dominant gene and the absence of such antigens to a recessive gene. Homozygote individuals cannot, in general, be distinguished from heterozygotes.

750. The practical consequences are very important :

Every antigen distinguished in an individual exists in at least one of its parents, but an animal may very well not transmit all its antigens to an individual offspring ;

The number of antigens identified up to now - more than 40 - gives a number of different combinations, so that for practical purposes it can be taken that each individual can be characterised by its blood formula.

751. Actually, a few cases of pleiotropism and linkage occur to reduce the number of possible combinations very slightly, but without thereby diminishing the importance of antigen analysis in identifying an individual. Through a study of the phenomena of linkage between certain antigens it has been possible to identify 11 different independent blood group systems corresponding to 11 chromosomes. The following table gives a nomenclature of the different factors classified according to these systems (Z' was found in the zebu) :

Antigenetic factors of the different systems

Linkage groups											
A	B		C	F	J	L	M	S	Z	H'	Z'
A	B	A'	C	F	J	L	M1	S	Z	H'	Z'
H	G	D'	R	V	abs.	abs.	M2	U1	abs.	abs.	abs.
abs.	I	E'					abs.	U2			
	K	I'	W								
	O	J'	X'								
	P	K'	L'								
	Q	abs.									
	T										
	Y										

752. The problem is, in fact, complicated, for in certain cases it is possible for more than one antigen to correspond to only one gene, and there are some antigens which are always related to others. Take, for example, the mating of B G parents with individuals possessing neither B nor G. In their progeny there will be found, as the case may be, 50 per cent B and 50 per cent G, or B and G together in one group of progeny and neither B nor G in the other. Here we have two different types of B G individuals where in one type B and G behave as if they belonged to two separate genes, and in the other to one gene only. Similarly, K has never been found without B G and some of the progeny from the mating of a B G K individual with an individual not possessing these groups will have B G K while others will not.

Applications of blood group analysis

753. Apart from its great scientific interest, the discovery of antigenic reactions can be used for important practical purposes in stockbreeding. Thus, in the particular matter of checking of pedigrees, the examination of blood groups enables possible relatives to be eliminated, although it does not empower one to say that a given individual is bound to be a relative.

754. The method would seem to be indicated for identifying monozygotic twins in cattle in view of the importance of this material for many animal husbandry studies. Unfortunately, the incidence of anastomosis of the blood vessels is in such cases so high (90 per cent) that it detracts considerably from the value of using antigens for this purpose. It is, however, possible in most cases today to determine whether or not there has been any mingling of blood. On the other hand, antigens can be usefully employed for detecting free-martins at an early stage.

755. Furthermore, the problem of determining paternity might become extremely important if certain insemination centres adopted the technique of mixing sperm from two or more bulls. The first tests seem, moreover, to be giving very promising results. In the United States at the present time all bulls used in the artificial insemination centres have undergone blood group analysis.

756. Finally, in another sphere which is of great theoretical importance in cattle breeding, the study of the antigens in blood corpuscles will enable us to detect at the level of these genes the consequences of consanguinity in a herd, and, in a different field again, to study the origins, relations and evolution of the various racial groups.

757. Several European countries already have their own laboratories in operation or coming into operation and the use of this method is certainly bound to develop. Collaboration between the various States in this field would seem very desirable and easy to achieve.

VII

INTER-STATE CO-OPERATION

758. The Mission was much impressed by the teamwork evident at State, inter-State, and national level, which was particularly noticeable both between and within State experimental stations. Co-ordination of the methods used for improving animal production makes it possible, within the research plan, to solve local problems on a broader scale and afterwards to centralise the data obtained in order to reach general conclusions. It also allows, on the organisational side, for co-ordinated action to be taken at the different levels.

759. The agency mainly governing inter-State co-operation is the Agricultural Research Policy Committee. This Committee and its Sub-committees are appointed by the Secretary of Agriculture under the Research and Marketing Act of 1946. The aim of the Committee is to advise the United States Department of Agriculture on agricultural problems in the widest sense. The objectives vary from animal breeding and management to transportation of farm products, cold storage, etc. Each problem is dealt with by a special group. Thus 25 groups are created. Each group consists of 9 to 15 persons, representing the producers, the processors, scientists and, of course, officials of the U.S.D.A. attending the meetings.

760. The experts in the different fields are generally proposed by the organisations in that particular field or chosen by the U.S.D.A. for their expert knowledge.

761. The activities of these advisory groups may lead to the proposal or regulations and requirements or result in the recommendation of investigations and research programmes. This makes it possible for the U.S.D.A. to plan a programme of research for the coming financial year. The programmes may have a general or a regional character.

762. An example of an important programme with a general character is the Poultry Improvement Scheme ; programmes with a regional character are e.g. : the Regional Swine Breeding Laboratory in the Middle West and the Research Programme on Fertility in Cattle in the North-Eastern States.*

* See under the specific chapters dealing with Poultry, Swine and Cattle.

763. A substantial contribution to inter-State understanding is provided not only by the fact that financial aid is coming from various sources both from the participating States and the U.S.D.A. and private organisations or from the regular meetings of the technicians collaborating in the particular programme, but also by the fact that research workers are exchanged between one institute and another and special experts are called in to co-ordinate the work.

764. More than once the Mission came across situations in which the research workers employed on the same programme were paid by the State or the Federal Government or a special agency, but it was one team with one goal, i.e. to solve the problem with which they were confronted.

765. Another example of inter-State co-operation is the Dairy Herd Improvement Plan. This was discussed and formulated in the American Dairy Science Association. It was established on an entirely voluntary basis and has been accepted by all the States in the United States.**

766. Another interesting case of co-operation, not on a State basis, but between organisations, is the co-operation amongst the five Dairy Breed Societies. These have established common regulations regarding A.I., scoring and other specific herd-book regulations.

767. It is undoubtedly true that since the war co-operation in European agriculture, especially in the technical field, is developing. This is due, inter alia, to the activities of F.A.O. of which the European Agreement on Milk Butterfat Recording is an example. Partly through these activities the interest and need for a European Association for Animal Production was felt with the result that this association was founded in 1949. Later, O.E.E.C. encouraged programmes on a European scale, and the organisation of this mission to the United States was one of its activities. A definite arrangement for harmonious European co-operation has, however, not yet been reached.

768. Undoubtedly the E.A.A.P. offers possibilities for a basic discussion of European problems on animal production. It is a free organisation open to every country in Europe. The different aspects of animal production are entrusted to permanent committees such as the Committee on Research, on Cattle, on Pigs, etc. In these committees each country can be represented by three members, which enables producers, research workers and agricultural advisers to participate in its work.

769. It is no use to include the processor in this scheme, as is done in the United States. The free market all over the United States offers no difficulties in this field, the problem being a United States problem. Europe is still far from being a

* See paragraphs on Milk Recording, Chapter VI.

free market and this has its repercussions and limitations in the technical field.

770. If it is agreed that the E.A.A.P. offers a proper forum for discussions and advice on European problems in the field of animal production, it needs stronger backing than it receives today from official quarters. It is clear that the E.A.A.P. cannot play a rôle in European agriculture if it is not supported morally and materially by the official European authorities in the same way as the U.S.D.A. in the United States co-ordinates and supports in the Advisory Council all efforts to improve American agriculture.

771. For instance the programme for progeny-testing in beef production, which was accepted at the 1955 meeting of the E.A.A.P.* cannot be developed on paper only by sending outlines and circulars to the participating countries. It needs support and advice from experts who will visit the countries where the programme is accepted and developed, in the same way as Mr. Craft in the United States, for instance, is visiting the various States participating in the Swine Breeding Programme for the Middle West. This is the least that can be done. If financial support could be given for research in this field in the various countries the programme would, of course, develop much more quickly.

772. E.A.A.P. does not have the funds to enter into such a programme and it is hardly thinkable that as a private organisation it can find them. The final word will have to remain with various European authorities.

773. One difficulty in the way of European co-operation, which does not exist in the United States is the language problem. It is evident that efficient co-operation cannot be obtained if people do not understand one another. This understanding must go further and deeper than a reading knowledge of a foreign language. For while a reading knowledge is essential to a proper study of the results of research and planning in other European countries, it is also necessary for effective European co-operation to be able to express one's ideas in a foreign language and to understand foreign colleagues. Those interested in, or participating in European co-operation should, besides their own language, learn the use of at least one of the official languages employed by the various European organisations.

774. Authorities and organisations should therefore encourage young technicians and officials to take part in international courses and meetings on technical problems. This would amongst other things help to develop their speaking knowledge of foreign languages most frequently used at international level.

* See paragraphs on Selection for Meat Production, Chapter VI

VIII

SUMMARY

775. The members of the Mission which visited the United States to study the application of improved breeding methods to poultry, pigs and cattle, and inter-State co-operation, have returned confident of having achieved their aim. Many points undoubtedly have still to be elucidated, but there is now a very wide field of research available for deciding whether or not to apply to stockbreeding the new methods based on those successfully used for the production of hybrid maize or, more generally, methods involving crossbreeding.

776. There can be no question of differentiating on the score of value between pure breeding and crossbreeding. The two methods are not incompatible but complementary and the second presupposes the first. When the percentage of desirable genes in a given population is too low or, in extreme cases, non-existent, genetic improvement postulates crossbreeding. Many existing breeds have been created or improved by crossbreeding. The need also arose in the United States, where it led, for instance, to the creation of new pig breeds. Another point, however, is that, when desirable hereditary factors exist in sufficient proportion, selection for pure breeding can, by a judicious choice of breeding stock based on their own performance and that of their ancestors, relatives and progeny, ensure the progressive improvement of the population concerned.

777. Pure breeding is mainly relied upon in Europe for the improvement of the chief animal species. It facilitates the organisation of stockbreeding on professional lines, with or without State action, and makes it easier by laying down standards to provide guidance for stockbreeders.

778. This method may, however, lead in some cases to conditions of equilibrium, or to levels of improvement beyond which it is difficult to go. Such stages of improvement are noticeable particularly in egg production. The decline in the efficacy of selection is not incompatible with the existence of genetic variability, which can then no longer be turned to useful account by breeders for pure breeding. The genetic bases of

this phenomenon have been referred to in this report ; they are more particularly related to genetic interaction (epistasis) and over-dominance.

779. Other methods must then be employed to allow the creation, by crossbreeding, of new and more desirable genetic combinations. The success achieved in producing hybrid maize by inbreeding, followed by crossbreeding, should quite obviously induce experts to apply this method to animal genetic improvement. The method will, of course, be the more easy to apply if the reproduction rate of the species concerned is high and the interval between the generations short.

POULTRY

780. Poultry are thus ideal material. Here, we are no longer in the experimental stage, and hybrid chicks are produced on an industrial scale by this system. Yet much research still remains to be done in this sector. It is interesting to note that practical experience has often outstripped scientific experiment in the production of laying hens. The chief producers of hybrid chicks consider that their birds are more valuable as layers than those of ordinary commercial flocks.

781. The Mission's experts were, nevertheless, unable to get exact information on the comparative value of chicks produced by crossbreeding and those obtained from purebred flocks. The same applied to the relative value of crosses between inbred strains and more recent breeding schemes aimed at achieving heterosis. Detailed information would need to be obtained on recurrent selection and recurrent reciprocal selection. This last method, which consists in choosing the breeding birds in a strain on the strength of the quality of the progeny produced from crossing with another strain so as to evolve two breeds likely to give the best results when crossed, deserves special attention. Its application is not, moreover, limited to poultry, but can be extended, in particular, to pigs.

782. With regard to the production of broilers, opinions differ. Some consider that crosses between inbred strains give promising results, while others think that crosses of first generations of the normal market type, with no inbreeding, are preferable.

783. It should in any case be emphasised that inbreeding inevitably produces a high proportion of throwouts, and that the organisation of large concerns for producing hybrid chicks involves a big capital outlay.

784. The growing use of random sample laying tests was noted with interest.

PIGS

785. Much is being done to improve the economics of pig production, and to try to replace fat pigs by a leaner type better adapted to the demands of the present-day market.

786. With stock mainly consisting of breeds with a propensity to fat, and a few pork breeds, steps are being taken to improve fertility, rate of growth, index of consumption and quality of carcass.

787. New strains of the pork type, often intended for cross-breeding, are produced from local and improved strains. Their characteristics are fixed by inbreeding.

788. Working from these various pig types, the breeding plans are mainly based on the diagram for production of hybrid maize, so as to stabilise and then combine the required characteristics, while raising the level of performance through heterosis. Inbred lines are evolved and then crossed, the male progeny being sold as hybrid breeding boars to farmers, who use them in their herds on fairly complex systems of rotational breeding which enable them to make some use of the boars' female progeny for reproductive purposes.

789. Huge private concerns, which may be described as "breeder factories", turn out these hybrid boars and regularly supply farmers with male breeders. Here again their establishment entails very high investment costs. The pigbreeder is not nowadays fully responsible for originating breeding improvement schemes but on the other hand he benefits by the knowledge of the technicians who supervise these breeding centres.

790. When only the best inbred strains are used for suitable crosses the method has in American breeding conditions proved somewhat superior to the pure breeding method. Many lines have to be eliminated and new ones constantly produced. Pure-breeds must, of course, be preserved and gradually improved. Inbreeding depression occurs, particularly in regard to fertility and rate of growth, but these characteristics are subsequently improved by heterosis resulting from strain-crosses ; the less closely the parents are related, the more pronounced the heterosis. The various forms of this type of breeding have been studied in the report.

791. For carcass improvement there are no sure means of ascertaining whether inbreeding followed by crossbreeding is superior to purebreeding or not.

792. Much prior research, and large financial resources, will be required before the extension of these modern methods to pig-breeding in Europe can be considered. It is not, however, impossible that some of the methods will be applied later. Their practical results in the United States will be attentively followed.

CATTLE

793. While in Europe it is more usual to rear dual-purpose cattle, American breeders still favour specialised types. Some progress is, however, being made and, more especially at the research stage, the production of dual-purpose cattle is being studied at several centres. It would be well to have a clearer definition of the dual-purpose type in order to facilitate subsequent exchanges and discussion.

794. Improvement of beef cattle in the United States tends to be directed towards controlling rate of growth and food consumption, and towards systematic standardised carcass evaluation. Sire-proving tests are being carried out. The position here is similar to that which is tending to develop in Europe. It cannot fail to stimulate further efforts in this direction.

795. In the dairy-cow breeding sector note should be taken of the arrangements for milk testing which cover 5 per cent of all dairy-cows, or 1,400,000 head, on lines similar to those followed in Europe, based on regular visits to farms by a milk inspector. In addition, 500,000 cows are tested by their owners, who have analyses made by a specialised laboratory. This type of testing, although still unofficial, constitutes a first step towards official testing.

796. The information collected by the milk inspectors is forwarded to the Central Office in each State, and then to the Department of Agriculture in Washington. This procedure allows immediate, effective use of the data, and makes it possible to complement an extensive sire-proving programme. The yields of the bull's daughters and their dam are regularly published in a "Monthly Letter", which provides breeders with useful information. Five pairs of dams and daughters have to be checked before even a provisional breeding-value for the bull can be fixed; it becomes final with ten or more pairs. Corrections are made to the yield for age, duration of lactation and number of milkings. In spite of imperfections due mainly to the small number of dam-daughter pairs studied, and failure to observe the influence of environment on yield, this system provides an invaluable guide to the breeding value of a very large number of bulls.

797. Another source of improvement - artificial insemination - is being more and more widely used. It was developed through a competition between co-operatives and private undertakings and is well adapted to varying local requirements. The artificial insemination centres use mainly bulls chosen for the quality of their progeny.

798. Meanwhile, the Herdbook Associations are pursuing their own improvement programmes. These powerful organisations, working on the pure breeding system, naturally take a

reserved attitude to improvement plans involving crossbreeding, though they follow their development very closely.

799. Cattle improvement in the United States is still, in fact, mainly based on pure breeding :

a) Crossbreeding trials have, however, been carried out, both to give prompt satisfaction to the demands of some States which wanted to have more productive and sturdier milk-cows, and also to study the effects of heterosis. These effects are mainly apparent in the first generation, and are scarcely accentuated in the following generations unless the crossbred females are fertilised by a purebred, progeny-tested male. Rotational crossing must therefore be applied in order to secure heterosis.

b) The rather tardy rate of reproduction, the high cost of replacing the females, and the very low fertility rate restrict the application to cattle of the method used for the production of hybrid maize. Tests are, however, being made, and the experimental stage is still continuing. Inbreeding seems to have unfortunate effects on conformation and on butterfat production but this, of course, depends on the stock used. As the work continues it will be possible to say whether later crosses more than offset these tendencies.

c) Following the creation of beef cattle adapted to southern regions from crosses with improved zebu strains, efforts have now been made to create, in the same way, dairy breeds adapted to those regions.

INTER-STATE CO-OPERATION

800. As pointed out in the various chapters of this report, there are extensive programmes for co-operation between centres in the same State, between States, and at national level, which seek to co-ordinate the methods of improving animal production, and make it possible, in particular, to solve local problems experimentally in a wider context and then centralise the results so as to draw general conclusions. In the planning stage, such programmes ensure co-ordinated action at the various levels. The various examples cited in the relevant chapters provide evidence of this. Mention may be made of the Technical Advisory Committees of the Department of Agriculture, the Regional Swine Breeding Programme for the Middle West, the Regional Research Programme on Fertility in Cattle in the North-Eastern States, the Dairy Herd Improvement Associations (D.H.I.A.) and the Sire-Proving Programme. Reference may also be made to the excellent collaboration which exists between the various university services.

801. The parallel efforts made in Europe have been mentioned in a chapter dealing more particularly with inter-State

co-operation. At the present time, however, Europe has no organisation comparable to the Department of Agriculture in Washington and its lack constitutes a handicap. Such an organisation is, in fact, necessary to stimulate co-operation by drawing up programmes and, more directly, by providing technical and financial aid to those concerned. The closer the co-operation established between the various countries, the sooner will progress be made. The members of the Mission very much hope that exchanges of experts will become more and more common, and that programmes for European co-operation will be developed.

Annex I

MEMBERS OF THE MISSION *

CONVENER

Theodoor Rijssenbeek Netherlands

DEPUTY CONVENER

George Mann United Kingdom

Richard N. Thomsen Denmark

MISSION SECRETARY

Jacques Delage Associate Professor for Animal Husbandry,
Institut National Agronomique in Paris

AUSTRIA

Wilhelm Muller (3) Officer for cattle breeding,
Section Councillor,
Federal Ministry of Agriculture
and Forestry,
Stubenring, Vienna I

BELGIUM

Gilbert Kint (3) Animal Husbandry Adviser,
Ministry of Agriculture,
Ae Général-Méd. Derache, Ixelles

Claude Panier (3) Animal Husbandry Adviser,
Ministry of Agriculture,
rue du Parc, Namur

* The figures in brackets after the names refer to the sections into which the Mission was divided during periods of special study. The sections were : (1) Poultry, (2) Pigs and (3) Cattle.

DENMARK

- | | |
|---------------------|--|
| Holger Aersoe (3) | Secretary-General
of the Governmental Committee
on Animal Husbandry,
Ministry of Agriculture,
Copenhagen |
| Richard Thomsen (2) | Research Officer,
National Institute of Animal
Husbandry,
Rolighedsvej 25, Copenhagen |
| David Davidsen (1) | Adviser
of the National Committee on
Poultry Breeding,
Peter Bangsvej 191, Valby,
Copenhagen |
| Niels Jensen (2) | Teacher in agriculture on live-
stock breeding, anatomy and
nutrition,
Malling |

FRANCE

- | | |
|------------------|---|
| Paul Auriol (2) | Assistant on Breeding and
Genetics, Institut National de la
Recherche Agronomique,
C.N.R.Z., Jouy-en-Josas,
Seine-et-Oise |
| Jacques Poly (3) | Genetics Research Officer,
Institut National de la Recherche
Agronomique,
12 Ave du Parc, Vanves, Seine |

NETHERLANDS

- | | |
|--------------------------|---|
| Theodoor Rijssenbeek (3) | Director of Animal Production
Section, Ministry of Agriculture,
van Hogenhoucklaan 57,
The Hague |
| Dingeman Heijboer (1) | Officer in General Service of
State Poultry Advisory Service,
Wilhelminalaan 30, Zeist |
| Yme Kroes (2) | Government Adviser
on Pig Breeding,
Willemsplantsoen 6, Utrecht |
| Dirk C. de Ridder (3) | Secretary of the Cattle Breeding
Section, Agricultural Board,
Roomweg 27, The Hague |

NORWAY

Samson Berge (2)	Professor at the Agricultural College of Norway, Vollebekk
Arne Eskilt (1)	Senior Teacher at State Training School for Teachers to Smallholders, Hvalstad
Hans Tilrem (3)	State Adviser in Cattle Breeding, Trondheim

SWEDEN

Artur Hansson (2)	Head of Animal Breeding Institute, Wiad, Eltomta
Börje Olsson (3)	Secretary of the Swedish AI Association, Hallstaggård, Hallsta
Ole Venge (1)	Associate Professor, Royal Agricultural College of Sweden, Banergatan 16 C, Uppsala

UNITED KINGDOM

James Baker (2)	Assistant Provincial Livestock Officer, National Agricultural Advisory Service, Ministry of Agriculture and Fisheries, Elswick Hall, Elswick Park, Newcastle-on-Tyne, 4
George Mann (1)	Poultry Advisory Officer, National Agricultural Advisory Service, Huntingdone, St. Michaels, Tenterden, Kent

The cattle section was joined in the United States by Mrs. Brita von Koskull (Finland), who followed the studies under special arrangement by the F.O.A. (I.C.A.).

SECRETARIAT OF O.E.E.C./E.P.A.

Mr. B.L. Rowan	Head of Division for Productivity in Food and Agriculture
Mr. D. Thomsen and Madame V.C. Durand	Division for Productivity in Food and Agriculture

NORWAY

Samson Berge (3) was a Professor at the Agricultural University of Norway, Christiania, and a member of the Norwegian Agricultural Society.

Arne Eskin (1) was a Senior Teacher at State Training School for Teachers in Small-Schools, Christiania.

Hans Thrum (3) was a State Adviser in Cattle Breeding, Christiania.

Arne Hansson (2) was a Head of Animal Breeding Institute, Christiania.

Børge Olsen (2) was a Secretary of the Swedish Al-An Association, Christiania.

Ole Venge (1) was an Associate Professor, Royal Agricultural College of Sweden, Uppsala.

James Baker (2) was an Assistant Provincial Livestock Officer, Newcastle-on-Tyne.

George Mann (1) was a National Agricultural Advisory Service, London.

The cattle section was joined in the United States by Mrs. B. L. Rowan, who followed the members under special arrangement by the F. O. A. (I. C. A.).

Mr. B. L. Rowan was a member of the Division for Productivity and Agriculture, Food and Agriculture, United States.

Mr. D. Thompson was a member of the Division for Productivity in Food and Agriculture, United States.

Madame V. C. Durand was a member of the Division for Productivity in Food and Agriculture, United States.

Mr. B. L. Rowan was a member of the Division for Productivity and Agriculture, Food and Agriculture, United States.

Mr. D. Thompson was a member of the Division for Productivity in Food and Agriculture, United States.

Madame V. C. Durand was a member of the Division for Productivity in Food and Agriculture, United States.

Mr. B. L. Rowan was a member of the Division for Productivity and Agriculture, Food and Agriculture, United States.

Mr. D. Thompson was a member of the Division for Productivity in Food and Agriculture, United States.

Madame V. C. Durand was a member of the Division for Productivity in Food and Agriculture, United States.

Annex II

ITINERARY OF THE MISSION

- April 18th Left Paris.
- April 23rd Arrived New York City, New York.
- April 25th-29th Washington, D.C.
- April 25th :
Foreign Operations Administration.
- April 26th-29th :
1. Agricultural Research Centre, Beltsville, (Maryland), Dairy, Swine and Poultry Husbandry Branch.
2. United States Department of Agriculture - Dairy Herd Improvement and Sire Breeding Programmes Work ;
Animal Disease Prevention and Eradication or Control, and Research ;
Research Advisory Committee of the United States Department of Agriculture.
- May 2nd-7th Iowa State College of Agriculture and Mechanic Arts at Ames.
1. Breeding work on swine, poultry and cattle (beef and dairy).
 2. Visits to poultry-breeding enterprises which follow closely the genetic principles of hybrid seed corn production, utilising inbreeding and heterosis in producing baby chicks.
Visit to enterprise producing boars for use in rotational crossing plans intended to show the advantages of heterosis.
 3. Regional co-operation in swine breeding research - The Regional Swine Laboratory.

Note : See special itinerary for poultry section.

- May 9th-14th University of Minnesota - Institute of Agriculture - St. Paul.
1. Main concepts of swine breeding in Minnesota (development of new breeds - inbreeding and crossing inbred lines).
 2. Visits to swine, cattle and sheep farms.
- May 15th-21st University of Wisconsin at Madison
1. Reproductive physiology.
 2. Poultry, swine, dairy cattle, beef cattle, sheep and rats research, with emphasis on dairy breeding, including blood-typing work.
 3. Fur-animal research.
 4. Visits to Holstein-Friesian and Brown Swiss farms, dairy cattle experimental farm, Country D.H.I.A. Laboratory and East Central Artificial Breeders' Association.
- May 23rd-24th Purdue University, Lafayette (Indiana)
1. Work on animal genetics and on poultry, swine and cattle breeding and production, with particular emphasis on poultry work including the regional laboratory.
 2. Visits to enterprise producing incross boars for use in rotational crossing plans, farm, and American Breeders Service Bull Stud.
- May 26th-28th Ohio State University at Columbus
1. Discussion on the latest developments in the fields of genetics and breeding for poultry, swine and cattle (dairy and beef).
 2. Visit to the Jersey Cattle Club office, for the cattle section.
 3. Visit to experimental station (swine, beef and dairy cattle, sheep).
- May 31st-June 2nd 1. United States Department of Agriculture, and Foreign Operations Administration, Washington, D.C. - Review, discussion and recapitulation of the study in the various fields up to this date. Submission of the interim report.
2. Agricultural Research Centre, Beltsville (Maryland) - Review, discussion and recapitulation.

June 3rd	Visit to the Beef Cattle Research Station, Front-Royal (Virginia).
June 6th-7th	New York State College of Agriculture at Ithaca (New York) - Work at Cornell in the fields of genetics and breeding for poultry and dairy cattle, including artificial insemination, Regional Research Project of North-Eastern States on causes and prevention of reproductive failure in dairy cattle, and the New York Artificial Breeders' Co-operative Programme.
June 8th	Left New York City, New York.
June 9th	Arrived Paris.
June 10th	O.E.E.C. Headquarters. Round-table discussion of trip - Submission of preliminary report.

Special itinerary for Poultry Section
(May 8th-11th)

May 8th	Left Ames (Iowa) Arrived De Kalb (Illinois).
May 9th	Hybrid Seed Company, Sycamore (Illinois). Details of the genetics and breeding work involved in the production of hybrid chicks.
May 9th-10th (overnight)	Left De Kalb (Illinois) Arrived East Lansing (Michigan).
May 10th	Regional Poultry Research Laboratory, East Lansing (Michigan). Breeding poultry for resistance to leukosis and developments of the new techniques for breeding resistance in baby chicks by vaccinating hens.
May 10th-11th (overnight)	Left East Lansing (Michigan) Arrived St. Paul (Minnesota).



O.E.E.C. PUBLICATIONS

THE CONTROL OF JOHNE'S DISEASE IN CATTLE, SHEEP AND GOATS

204 pages (demy-8vo) \$2.00 12/- 600 Fr.fr.

METHODS OF TYPING AND CULTIVATION OF FOOT-AND-MOUTH DISEASE VIRUSES

110 pages (demy-8vo) \$1.00 7/- 350 Fr.fr.

THE CONTROL OF LIVESTOCK DISEASES IN EUROPEAN COUNTRIES

84 pages (demy-8vo) \$1.25 5/- 250 Fr.fr.

EUROPEAN GRASSLAND CONFERENCE

404 pages (crown quarto) \$1.50 10/- 500 Fr.fr.

PASTURE AND FODDER DEVELOPMENT IN NORTH-WEST EUROPE

180 pages (demy-8vo) \$1.50 8/6 420 Fr.fr.

AGRICULTURAL POLICIES IN EUROPE AND NORTH AMERICA

376 pages (demy-8vo) \$3.00 18/- 900 Fr.fr.

THE WRITTEN WORD IN AGRICULTURAL ADVISORY WORK

80 pages (demy-8vo) \$1.50 9/- 450 Fr.fr.

THE ORGANISATION AND RATIONALISATION OF SOIL ANALYSIS

200 pages (demy-8vo) \$2.00 12/- 600 Fr.fr.

THE AGRICULTURAL VALUE OF PHOSPHATIC FERTILISERS WHICH ECONOMISE IN THE USE OF SULPHURIC ACID

92 pages (demy-8vo) \$1.00 6/- 300 Fr.fr.

TO BE PUBLISHED

ORGANISATION OF CONTROL OF WARBLE FLY INFESTATION IN CATTLE

76 pages (demy-8vo) \$1.00 6/- 300 Fr.fr.

O.E.E.C. SALES AGENTS

ARGENTINA

Editorial Sudamericana S.A., Alsina 500,
BUENOS AIRES

AUSTRIA

Gerold & Co., Graben 31, VIENNA I

Sub-Agent :

GRAZ : Buchhandlung Jos. A. Kienreich,
Sackstrasse 6

BELGIUM

Librairie Encyclopédique, 7, rue du Luxembourg,
BRUSSELS

BRAZIL

Livraria Agir Editoria, Rua Mexico 98-B,
RIO DE JANEIRO

CANADA

The Ryerson Press, 299 Queen Street W.,
TORONTO

CUBA

La Casa Belga, O'Reilly 455, HAVANA

DENMARK

Ejnar Munksgaard Forlag, Nørregade 6,
COPENHAGEN

FINLAND

Akateeminen Kirjakauppa, Keskuskatu 2,
HELSINKI

FRANCE

Presses Universitaires de France, 108, boulevard Saint-Germain, PARIS-6^e

GERMANY

Deutscher Bundes Verlag, G.m.b.H.,
Bundeshaus, Schliessfach 137, BONN

GREECE

Librairie Kauffman, 21, rue du Stade,
ATHENS

INDIA

International Book House Ltd., 9 Ash Lane,
Mahatma Gandhi Road, BOMBAY I
Oxford Book and Stationery Co.:
NEW DELHI : Scindia House
CALCUTTA : 17 Park Street

IRELAND

Eason & Son 40-41 Lower O'Connell Street,
DUBLIN

ISRAEL

Blumstein's Bookstores Ltd., 35 Allenby Road,
TEL AVIV

ITALY

Libreria Commissionaria Sansoni,
Via Gino Capponi 26, FLORENCE

JAPAN

Maruzen Company Ltd., 6 Tori Nichome
Nihonbashi, TOKYO

LEBANON

Librairie Universelle, avenue des Français,
BEIRUT

LUXEMBOURG

Librairie Paul Bruck, 33, Grand'Rue,
LUXEMBOURG

THE NETHERLANDS

Wholesale agent :

Meulenhoff & Co. N.V. Importeurs,
Beulingstraat 2, AMSTERDAM

Principal retailer :

W. P. Van Stockum & Zoon,
Buitenhof 36, THE HAGUE

NORWAY

A/S Bokhjornet, Stortingsplass 7, OSLO

PAKISTAN

Mirza Book Agency, 9-A Shah Alam Market,
LAHORE

PORTUGAL

Livraria Portugal, Rua do Carmo 70, LISBON

SOUTH AFRICA

Van Schaik's Book Store Ltd., Church Street,
PRETORIA

SPAIN

Mundi Prensa, Lagasca 38, MADRID

SWEDEN

Fritzes, Kungl. Hovbokhandel, Fredsgatan 2,
STOCKHOLM 16

SWITZERLAND

Librairie Payot, 40, rue du Marché,
GENEVA

TURKEY

Librairie Hachette, 469 Istiklal Caddesi, Beyoglu,
ISTANBUL

UNITED KINGDOM AND CROWN COLONIES

H.M. Stationery Office, P.O. Box 569,
LONDON S.E.1

Branches at :

EDINBURGH 2 : 13a Castle Street
BIRMINGHAM 3 : 2 Edmund Street
BRISTOL 1 : Tower Lane
MANCHESTER 2 : 39 King Street
CARDIFF : 109 St. Mary Street
BELFAST : 80 Chichester Street

UNITED STATES OF AMERICA

O.E.E.C. Mission, Publications Office,
Suite 61, 2000 P. Street N.W.,
WASHINGTON 6, D.C.

VENEZUELA

Suma S.A., Calle Real de Sabana Grande 102,
CARACAS

Orders and inquiries from countries where sales agents have not yet been appointed may be sent to:
O.E.E.C., Distribution and Sales Service, 33, rue de Franqueville, Paris-16^e.

PRINTED BY THE O.E.E.C.
2, rue André-Pascal - Paris 16^e

No. 1689

PRINTED IN FRANCE

O.E.C. SALES AGENTS

ARGENTINA

Industria Argentina S.A., Avda. 500,
Buenos Aires

AUSTRIA

Carroll & Co., GmbH, H. VETTER,
Salzburg
GUST. F. FUCHSBERGER, Dr. A. FUCHSBERGER,
Innsbruck

BELGIUM

Librairie Encyclopédique, 7, rue de la Chapelle,
BRUXELLES

BRAZIL

Librairie São Paulo, Rua Mariz 15-3,
São Paulo

CANADA

The Ryerson Press, 399 Queen Street W.,
TORONTO

CHINA

Le Carré Sino, 17, rue de la Paix,
HONGKONG

DENMARK

Librairie Universitaire, Helsingør, 1,
COPENHAGEN

FINLAND

Maailman Kirjallisuus, Helsinki, 1,
HELSINKI

FRANCE

Librairie Universitaire, 17, rue de la Paix,
PARIS

GERMANY

Gustav Fischer Verlag, Stuttgart, 1,
STUTTGART

GREECE

Librairie Universitaire, 17, rue de la Paix,
ATHENS

HUNGARY

International Book House Ltd., 7, Ady Endre,
Budapest, 1,
Budapest
Oxford Book and Stationery Co.,
100, GAZDAR, Széchenyi Square,
BUDAPEST

IRELAND

Librairie Universitaire, 17, rue de la Paix,
DUBLIN

ITALY

Librairie Universitaire, 17, rue de la Paix,
ROMA

JAPAN

Librairie Universitaire, 17, rue de la Paix,
TOKYO
Librairie Universitaire, 17, rue de la Paix,
TOKYO

LEBANON

Librairie Universitaire, 17, rue de la Paix,
BEIRUT

LUXEMBOURG

Librairie Paul Bruck, 17, rue de la Paix,
LUXEMBOURG

THE NETHERLANDS

Librairie Universitaire, 17, rue de la Paix,
AMSTERDAM
Librairie Universitaire, 17, rue de la Paix,
AMSTERDAM
Librairie Universitaire, 17, rue de la Paix,
AMSTERDAM

NORWAY

Librairie Universitaire, 17, rue de la Paix,
OSLO

PANAMA

Librairie Universitaire, 17, rue de la Paix,
PANAMA

PORTUGAL

Librairie Universitaire, 17, rue de la Paix,
LISBON

ROMANIA

Librairie Universitaire, 17, rue de la Paix,
BUCURESTI

RUSSIA

Librairie Universitaire, 17, rue de la Paix,
MOSCOW

SPAIN

Librairie Universitaire, 17, rue de la Paix,
MADRID

SWEDEN

Librairie Universitaire, 17, rue de la Paix,
STOCKHOLM

SWITZERLAND

Librairie Universitaire, 17, rue de la Paix,
BERNE

UNITED KINGDOM AND CROWN COLONIES

Librairie Universitaire, 17, rue de la Paix,
LONDON

USA

Librairie Universitaire, 17, rue de la Paix,
NEW YORK
Librairie Universitaire, 17, rue de la Paix,
NEW YORK
Librairie Universitaire, 17, rue de la Paix,
NEW YORK

UNITED STATES OF AMERICA

Librairie Universitaire, 17, rue de la Paix,
WASHINGTON

VENEZUELA

Librairie Universitaire, 17, rue de la Paix,
CARACAS

PRINTED BY THE O.E.C.

Librairie Universitaire, 17, rue de la Paix, PARIS

No. 1587

PRINTED IN FRANCE

Orders and inquiries from countries where sales agents have not yet been appointed may be sent to
O.E.C., Librairie Universitaire, 17, rue de la Paix, PARIS

