AGRICULTURAL EXPERIMENTS AND THEIR ECONOMIC SIGNIFICANCE (II)

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INTRODUCTION

This paper discusses what economists want experimenters to do, and why, and criticises existing methods from the economists' viewpoint. The subject has received very little serious attention outside of North America and practically none, as far as I am aware, in Australia. The exception is a valuable critical survey, by Pearse, of the Department of Agriculture's experimental work in a large part of Western Australia.[1]

We are concerned in this paper only with certain types of agricultural experiments; namely (i) experiments which investigate physical input-output relationships (such as fertiliser, feeding and stocking rates) and (ii) where the technical data alone does not suffice to indicate an optimum.

EXPERIMENTS AND FARM MANAGEMENT

The purpose of the farm management worker is to plan optimum use of a set of farm resources, given the relevant price data and input-output data. The farmer sees this problem in simpler terms, in the question—"How can I get most net income from my limited land, labour and capital?" He should, and frequently does, think in marginal terms—"Would an extra bag of fertiliser per acre on my sown pastures return a better net profit than, say, additional stock, or purchased feed, or a larger area of fodder crop, or more fencing?"

The type of experimental data frequently presented, which compare three or four widely spaced rates of fertiliser, feeding or stocking, in terms of output per acre, or per head, is of limited value in solving his problem, even when translated into monetary terms. Firstly, it will be pure chance if *the* maximum profit rate per acre or per head happens to coincide with, or nearly coincide with, one of the experimental rates shown. Second, even if it does, this is generally not the information required to maximise farm income. Experimental design does not seem to recognise this fact, and experimenters concentrate their attention on locating the point of maximum profit per acre or per head, or even the point of maximum physical return.

The farmer usually does not have sufficient capital to reach this maximum profit point for all farm inputs—fertiliser, feed, stock, etc., which means that he faces the decision as to how far he should go in expenditure on each particular cost item. The answer is that he should

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[1] R. A. Pearse, "Economic Implications for the Design of Agricultural Research", unpublished M.Sc.Agr. thesis, University of Western Australia.

invest to that point, for each input, at which returns from the last (marginal) £ spent (the value marginal product) are approximately the same as for all other inputs.[2] In this situation it is the average net return *per £ spent,* not the net return per acre or per head, that it maximised. Because the profitability of each increment of fertiliser and of other inputs generally varies continuously and considerably through the range, what is needed is the complete story in the form of a response curve, which will enable the farm management worker or farmer to estimate the return per £ at any level of investment. The mathematical expression of these response curves — the regression equation of resource on product, is termed a production function.

Experimental data on the key input-output relationships in Australian agriculture are grossly inadequate at the present time, and very little of what are available are in the form required for solving management problems—the production function. Extension workers advising farmers on management problems make recommendations based largely on considerations of *technical* efficiency plus hunches, and agricultural investment proceeds in a thick fog of uncertainty.

There are two purposes agricultural experiments can serve. The more widely appreciated and spectacular is the discovery and demonstration of new techniques, such as the sub-clover superphosphate combination. The second purpose is the detailed follow-up work of estimating the response curves which show how the new techniques can best be exploited by farmers. If, from experimental data, we could obtain accurate information in the form of production functions, it would be possible to greatly increase the efficiency of our agriculture through better resource allocation *at the given level of known techniques.* Generally the aims of experimenters are too limited, from the economists' viewpoint. They seek to prove statistically significant relationships between X, Y . . ., rather than to specify that relationship quantitatively over a wide range of levels. Even those experimenters who claim a "practical economic approach" often seem content to address themselves to the vague question "Is this practice profitable?" rather than "What is the profitability of this practice at various levels in various combinations and situations?"

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[2] *The Marginal Concept*: The basic principle is that maximum net return per unit of fixed resource (e.g. per acre of land) is attained when the cost of the last (marginal) increment of variable resource (say 20 lb. of superphosphate) is just equal to the value of the marginal product, which is the additional yield resulting from the last increment. This is so because, until that point is reached, each increment of variable resource returns more than it costs, and so adds to net income per unit of fixed resource. Thus, at the optimum point, the marginal product multiplied by its price equals the amount of the last increment of variable resource, multipled by its price. Where Y is the product, X the resource, and P_y and P_x their respective prices,

$$\delta Y \times P_y = \delta X \times P_x, \text{ or } \frac{\delta Y}{\delta X} = \frac{P_x}{P_y}$$

Thus, at the optimum point, the marginal product, expressed as a rate of transformation of resource into product $\left(\frac{\delta Y}{\delta X}\right)$, must equal the resource-product price ratio. Since these price ratios change continuously, so does the optimum.

The farmer who uses many variable inputs and has limited capital (i.e. he cannot afford to invest to the optimum point for each input) will theoretically maximise his net return by equating their marginal productivities. If the last (marginal) £ spent on fertiliser returns him less than the last £ spent on feed, he would gain by adjusting expenditure until each returned the same at the margin.

The existing general approach, resulting in an experimental design comparing a very few treatment levels, under one set of conditions, encourages "extension dogmatism". Blanket recommendations of particular practices are made to a wide range of farmers at different stages of development and levels of intensity, with different limiting factors, quite apart from environmental conditions. A better role for extension, admittedly difficult to attain, would be that of presenting facts in a form which enables the farmer to locate his *own* optimum for his *own* conditions, rather than advocacy of particular practices. Some changes in experimental methods would facilitate this more enlightened extension approach.

The three main groups of problems encountered by the farm management worker, in using experimental results, are:

(1) Those arising from the lack of economic orientation in experimental design—in particular the absence of the production function approach.

(2) "Problems of inference", arising from the necessity of making inferences from experimental results to the farm situation.

(3) Problems resulting from considerations of risk.

THE PRODUCTION FUNCTION IN EXPERIMENTS

Inadequate appreciation by experimenters of the usefulness of production functions in farm management is one of the main reasons why, as Heady puts it, a large skeleton of theory exists on the production function, but little empirical flesh has been fitted to it.[3] The application of the marginal concept, such as in the use of production functions, is a pre-requisite to rational decision-making by farmers and extension workers, and most of the input-output data necessary for the calculation of production functions are best obtained from controlled experiments.

Although this paper is confined to the application of marginal analysis to individual practices, such as levels of feeding and composition of rations, production functions are also essential to indicate the appropriate production coefficients for use in farm budgeting and linear programming, in planning the optimum farm organisation.

The main reasons why a great deal of experimental data cannot be used to derive production functions can be summarised thus: *experiments are generally concerned with point estimates at wide intervals over inadequate ranges, economically important related variables are excluded and substitution relationships among inputs are seldom considered.*

Very few Australian experiments have been designed to produce mathematically fitted production functions, although a considerable number have gone sufficiently close to satisfying the requirements to enable useful curves to be derived. Pearse, in his survey of Western Australian research, found only two experiments of immediate usefulness from a farm management viewpoint, but an approximation of a production function could be "salvaged" from a half-dozen others.

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[3] E. O. Heady, "An Economic Investigation of the Technology of Agricultural Production Functions", *Econometrica,* Vol. 25, No. 2 (April, 1957) p. 249.

(a) Practical Application of Production Functions

Production functions can be used to derive graphs or tables which can be applied directly by farmers or extension men without any knowledge of production theory or calculus. In calculating an optimum fertiliser or feeding rate mathematically, we solve the regression equation for that value which equates the first derivative (marginal product) with the inverse price ratio. Graphically, this can be done very simply, as is shown in Figure 1. The only physical information needed by the farmer or farm management worker is the curve OA, which might be a fertiliser (or feed) response curve, showing yield responses above that achieved with no fertiliser. The cost line OB expresses the resource-product price ratio, so that the cost of the fertiliser rate below B on the horizontal axis equals the value of the yield opposite B on the vertical axis. The optimum point C on the curve is located by simply drawing as a tangent to the curve a line whose slope equals the price ratio, and is therefore parallel to OB. At this point the vertical line between the cost line and the curve (CF), representing the return to fertiliser above cost, is a maximum. Whenever prices changed, the farmer could quickly calculate the appropriate adjustment to his fertiliser rate, in contrast to the policy of following the perennial recommendation of the Department of Agriculture.

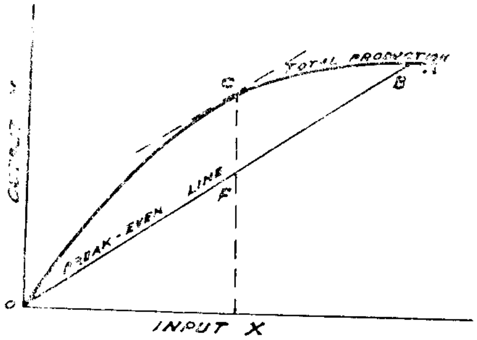

Figure 1: A Response Curve.

When two (or more) inputs interact, that is, are complementary, it becomes rather more complicated to consider them simultaneously. These relationships can be shown in three-dimensional "production surfaces". In the case of hay and grain in a feeding experiment or of nitrogen and phosphorus in a fertiliser trial, the farmer has two problems: deciding on the optimum *combination* of the two inputs—the optimum ration or fertiliser mix; and deciding on the optimum *level* of application—how much of the optimum mixture to use. Sometimes the composition of the optimum ration or fertiliser mix changes quite markedly according to the level of feeding or fertilising, so that these two problems must be considered simultaneously in selecting an optimum point on the production surface. From a multi-variate production function we can derive iso-product contours or isoquants (lines of equal product) which show the various combinations of the two inputs which will yield a given output. These isoquants express the substitution relationships between the two inputs. They can be thought of as contours around the hill of the production surface. Mathematically, the optimum level and optimum combination of nutrients are simultaneously attained when the partial derivatives for both nutrients are equated with the crop-nutrient price ratio for each.

If experiments provided multi-variate production functions, simple graphical methods of solution could be provided for farmers and extension officers.[4] Alternatively, the necessary information could be provided in tables, or on rotating slotted discs.

(c) The Experimental Requirements for Production Functions

The general procedure in most experiments of the type in which we are interested is that a limited number of treatments are compared. The effects are evaluated by replicating individual treatments and using analysis of variance to test the significance of the mean differences between treatments, the variation within treatments being measured against the variation between treatments. Whilst this procedure is well suited to the analysis of discrete phenomena (e.g. to crutch or not to crutch?) it is less appropriate to the analysis of continuous phenomena (e.g. how many cultivations, sprayings or units of feed, seed or fertiliser?).

To derive production functions, experimenters employ regression analysis to determine functional relationships, instead of analysis of variance to determine the significance of observed differences. Tests of significance are replaced by estimates of standard errors and fiducial probability. *This type of experimental design involves more treatment levels than are usually used, at fairly closely spaced intervals over a wide range, but less replications need be employed at each treatment level.*

It is difficult to generalise about the number of treatment levels needed, but it seems likely that in fertiliser experiments a *minimum* of four to five rates is required to establish a satisfactory production function. Paschal and French point out that with less than four or five rates the number of degrees of freedom is small and the estimates of the variability of the experimental data about the function are likely to be very large.[5] Where the soil is of low fertility, seven or eight rates may be needed if the yield increments are not to be too great. Leaving aside exploratory trials, most Australian experiments on feeding, fertiliser and stocking rates, etc., use insufficient treatment levels. Usually the fertiliser or feed increments used are very large.

It is desirable that both the upper and the lower regions of the curve be fully characterised. In many Australian experiments very considerable yield increases are attained right up to the maximum rates used. The lower regions are important for those farmers restricted by capital, uncertainty, tenure or other factors. A grazier with limited funds must face the problem—would it be more profitable to apply 4 cwt. of fertiliser per acre on 100 acres of pasture, 2 cwt. on 200 acres or 1 cwt. on 400 acres? Usually the marginal returns at these low levels of input are much higher than the average returns from the optimum application —a point seldom highlighted in published experimental results. For

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[4] *Economic Analysis of Fertiliser Use Data* (ed. Baum, Heady and Blackmore), Iowa State College Press, Ames, Iowa, 1956, p. 153. Also *Profitable Use of Fertiliser in the Midwest,* Wisconsin AES Bulletin 508 (1954) p. 25.

[5] J. L. Paschal and B. L. French, *A Method of Economic Analysis of Nitrogen Fertiliser Experiments on Irrigated Corn,* USDA Technical Bulletin 1141, 1956, p. 61.

example, in a superphosphate experiment on wheat at Balaclava, South Australia, the net return from the first 56 lb. per acre, at representative current prices was approximately £4.8.0d. per £ invested, whereas the average net return at the rate nearest the apparent optimum (168 lb. per acre) was only £1.17.0d. per £ spent.[6]

Many experimenters will look askance at the suggestion that some replications be sacrificed for an increased number of treatment levels.[7] In situations where a large variance is expected replication is generally essential for accuracy. However, the number of treatment levels is more important, and the number of replications less important, in the regression analysis approach, than in the traditional analysis of variance approach. In the latter, replication is required not only to attain accuracy, but to permit its measurement. In the regression analysis approach, a certain minimum number of treatment levels are required, whether replicated or not, to derive a curve of even moderate accuracy, and accuracy can then be further improved either by increasing the number of treatment levels, or by increasing the replications.

In experimental situations where there is a large variance, an unreplicated or lightly replicated regression approach may result in very large standard errors about the curve, whereas a heavily replicated comparison of only two or three treatment levels may give quite significant statistical differences. The analysis of variance method is statistically superior in such situations. However, one could argue that disguising a wide "scatter" of results within the average of numerous replications is less satisfactory than attacking some of the causes of excessive variance by doing larger, more complex and carefully controlled experiments, yielding production functions. With experimental resources limited, this would mean fewer experiments, but each experiment would be much more useful for farm management. In many Australian experiments two or three additional treatment levels, compensated for by one less replication, could have yielded a useful production function with little or no increase in the size of the experiment.

Relationships and factors of economic importance are frequently omitted from consideration. In particular, there is little consideration of substitution relationships between inputs. Although factorial experiments allowing for the measurement of interactions between fertiliser nutrients are becoming more popular, usually there are insufficient treatment levels to allow accurately-based recommendations on the optimum fertiliser mix or feed ration at various levels.

Heady and Olson point out that "the mere fact that nutrition books include a procedure to convert all feeds to a common T.D.N. basis, a supposition of constant substitution rates regardless of proportions, is an indication that the concept (i.e. the substitution problem) is not fully recognised. Another bit of evidence is that ration recommendations are most frequently in terms of 'a fixed combination of feeds', an

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[6] Based on yield responses quoted in A. R. Callaghan and A. J. Millington, *The Wheat Industry in Australia* (Sydney: Angus & Robertson; 1956) p. 98.

[7] An alternative devised to avoid discarding all replications in a factorial design is to discard treatment combinations unlikely to be important and to replicate the remainder. For an example, see Heady, Pesek and Brown, *Crop Response Surfaces and Economic Optima in Fertiliser Use,* Iowa AES Research Bulletin 424, March, 1955.

implication that this *one* ration is least costly and most profitable and that feeds do not substitute at all (or are all limitational in nature)".[8]

A knowledge of substitution rates can often yield significant savings in the cost of the fertiliser or feed mix required for a given output. In animal feeding, it is known that there is a shift in nutritional needs from proteins to carbohydrates as animals mature. Thus the composition of the optimum ration would change. In the case of pig-feeding, for instance, relatively less protein concentrate and more grain would be required as the pig approached market weight. A knowledge of the substitution relationships of concentrates and grain at various stages, as well as the feed-gain data, is thus required. An experimental procedure providing such information is illustrated by Heady.[9] On the assumption that pig farmers would change their ration three times, he computes three multi-variate production functions for the 34-75 lb., 75-150 lb., and 150-250 lb. weight ranges.

Contrast a pig feeding experiment in Western Australia quoted by Pearse in which only one rate of substitution was tried (1 gallon of skim milk for 1 lb. of wheat) and there was no variation in the ration according to stage of growth.[10] A common fault, Pearse found, was that rations were fed for the same period and their effectiveness and profitability measured by the live weights reached. The correct procedure for valid comparison would have been to derive isoquants, which would involve bringing all pigs to the same live weight and comparing the feed requirements. Due to the increased feed required per pound of gain as the animal matures, this procedure would have shown the inefficient rations to be even worse than the published figures suggested.

Substitution relationships are not the only factors of economic importance frequently left out of account. When a number of alternatives are being compared, many of the inputs related to the levels of the experimental variables, such as labour, are ignored. If one rate of input, or one method, involves more labour (or other costs) than another, it is helpful if this is recorded. Some of the outputs are also frequently neglected, such as the residual effects of fertiliser, and the quality effects of fertiliser and feed.[11]

In grazing trials using cattle and sheep, one of the factors frequently left out of account is the stocking rate, which is usually fixed at the same level for each treatment. This means that the differences between treatments are being measured entirely in terms of higher output per animal. Except in the case of the egg-feed relationship, diminishing returns to feed are such that "luxury feeding" is probably inefficient. In the case of Merino sheep, some experimental results suggest that the output of wool per unit of feed at maintenance levels of feeding is approximately 40 per cent. higher than at a high nutritional level.[12]

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[8] E. O. Heady and R. O. Olson, "Mighell on Methodology", *Journal of Farm Economics,* Vol. 35, No. 2 (May, 1953) pp. 275-6.

[9] E. O. Heady *et al., New Procedures in Estimating Feed Substitution Rates and in Determining Economic Efficiency in Pork Production,* Iowa AES Research Bulletin 409, 1954.

[10] Pearse, *op cit.,* pp. 201-3.

[11] For examples of the possible importance of these neglected factors see Paschal and French, *op. cit.*

[12] K. H. Ferguson, H. B. Carter and Margaret H. Hardy, "Comparative Fleece Growth in Sheep", *Australian Journal of Scientific Research,* Series B, Vol. 2 (Melbourne: C.S.I.R.O. and Australian National Research Council; 1949). This experiment, which resulted in an equation relating wool growth rate, nutrient intake and wool-producing capacity, is an Australian example of the type of experimental design needed by farm management workers.

Within quite broad limits, you can get the experimental results you want according to the stocking rate you set. Thus there is a strong case, in grazing trials, for treating stocking rate as an experimental variable in a functional design, even if this involves considerable sacrifice of replications.

A requirement which often presents some difficulty in experiments designed to provide production functions is the (to some extent) arbitrary choice of the mathematical functions to which the data must be fitted. This choice of functions will be largely dictated by the extent to which the characteristics of the function conform to the relevant biological laws, and by the efficiency of the estimates they provide.[13]

(d) Qualifications

The above argument does not imply that regression analysis should replace analysis of variance in all agricultural experiments of the type being discussed. The traditional approach is more appropriate in the large amount of local exploratory work which must often precede a well-organised production function experiment, and also where there is good evidence of a near-linear input-output relationship over a wide range, or fairly constant substitution rates. Furthermore, as far as multi-variate production functions are concerned, it must be admitted that if the number of variables simultaneously studied is increased to two or three, each at a sufficient number of levels, the number of plots needed increases very sharply, especially where the degree of variance necessitates considerable replication.

The production function approach has a rather wider and easier application in the United States than in a predominantly extensive grazing agriculture like Australia's. One reason for this is that it is not practicable for farmers to closely control or measure the quantity and quality of one of the most important farm inputs—pasture.

Finally, problems of inference are very considerable for some types of experiments, and in these cases, making the same large errors of inference with more precise data amounts to small progress.

PROBLEMS OF INFERENCE FROM EXPERIMENT TO FARM

The results of an experiment relate to a particular set of experimental conditions which will differ from the conditions ruling on any particular farm. In practice extension officers are largely left to make subjective judgments, based mainly on observation under practical conditions, when inferring from experimental results to actual farms.

There are two approaches to these problems of inference:

(a) We can make adaptation of experimental results less necessary, by bringing experimental conditions (e.g. management, animal quality) closer to commercial conditions. Experimental results might then be more directly applicable to farms under average

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[13] For some discussion of various functions used by experimenters, and their economic significance, see Heady (1957) *op. cit.* and J. C. Redman and S. Q. Allen, "Interrelationships of Economic and Agronomic Concepts", *Journal of Farm Economics*, Vol. 36, No. 3 (August, 1954) p. 454.

or representative conditions, but the problem would still exist of adapting the results to unrepresentative farms.

(b) We can investigate the effects of varying the conditions. This is most accurately done by further experiments, involving co-ordinated research programmes. Second, extension workers can encourage, supervise, and collect the results of more *farmer* "experiments". The results of an imperfectly run farmer experiment may be more useful for that farmer and his neighbours than rule-of-thumb adjustment of research station results. Thirdly, farm surveys and related methods of estimating input-output relationships may also be of some assistance in estimating "adjustment factors", i.e. quantitative estimates of the extent to which particular experimental results should be adjusted to allow for differences between experimental conditions and a particular set of farm conditions. Surveys and farm records are used occasionally as alternatives to experiments, to calculate production functions.[14]

RISK

A farmer needs to know, not only average relationships, but their variance in order to take account of the degree of risk. It is of little assistance to the farmer to be told that a particular result is "significant at the five per cent. level". What he and the extension man need, in a convenient form, is a probability distribution of the response functions and some knowledge of the main factors responsible for the variation.

An indication of the probable degree of spread in results if the experiment were repeated *under similar conditions* can be obtained by computing "confidence limit" curves around the response curve, which delineate the area in which a given percentage of repetitions would fall.[15]

The variation in results *when conditions differ,* especially the weather, is likely to be much greater than variation within the experiment. More repetitions are needed, from which to establish a pattern of responses between seasons. In a dry season farmers fertilising to the optimum rate for "average" seasons may suffer very heavy losses on their fertiliser expenditure, unless residual effects are very important. If such seasons are at all common, sacrificing the chance of the usually small rates of additional profit accruing to increments near the optimum may be a perfectly rational adjustment to risk and uncertainty. On the other hand seasonal variations may alter the optimum rate quite drastically without greatly affecting the return to fertiliser over that range.[16] A farmer who is not in a position to take a large risk would like to know what are the percentage chances, in any one year, of his losing money on the particular investment being considered. Experiments can be organised to yield such information, but the cost is considerable.[17]

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[14] A number of examples are quoted and commented on in Einar Jensen *et al.*, *Input-Output Relationships in Milk Production,* USDA Technical Bulletin 815, 1942, pp. 6-7.

[15] For examples, see Paschal and French, *op. cit.*

[16] For example, see J. McCann, "Fertiliser Trials in Sandhills in the Northern Mallee", *Victorian Journal of Agriculture,* Vol. 54, Part 1 (January, 1956) p. 12.

[17] See R. J. Hildreth, "Influence of Rainfall on Fertiliser Profits", *Journal of Farm Economics,* Vol. 39, No. 2 (May, 1957) p. 522.

JOINT RESEARCH

One of the earliest and most elaborate agricultural experiments ever carried out to derive production functions was a co-operative effort by economists and dairy scientists, in 1942.[18] Since then, joint research projects of this type have been growing in popularity in the United States. A good deal of this recent work has been inspired by Heady at Iowa.[19] The rationale for this inter-disciplinary co-operation has been the fact that almost all managerial decisions in agriculture embrace more than one field. For many problems joint research offers a more realistic and comprehensive approach, since each specialist involved is made aware of relevant principles, problems and findings in related disciplines.

To a considerable extent the problems we have been discussing are, fundamentally, liaison problems. The lack of economic orientation in experiments is largely due to a shortage of economists sufficiently informed in statistical, agronomic and other principles and a lack of knowledge of the principles of production economics on the part of experimenters.

CONCLUSIONS

It is suggested that more attention should be paid by experimenters to the requirements of the farm management worker, and particularly to his requirements relating to production functions. Australian agricultural economists need to be more vociferous and specific in making those requirements known to agricultural experimenters and administrators. In so doing they will be attacking barriers to communication which largely stem from the indoctrination received by specialists in any field during their period of training. The incorporation of more production economics training into agricultural science courses at our Universities is one long-term measure which is already under way. As an immediate step the organisation of joint research projects, involving statisticians, economists, agronomists and livestock officers, can play an important role, particularly in providing local examples of the type of experiment required. Experimenters' interest in this subject would be stimulated by a critical collation or stocktaking of experiment work in each State, of the type presented by Pearse for West Australian research.

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[18] Jensen *et al.*, *op. cit.*

[19] Some examples have already been quoted of joint experiments at Iowa on fertilisers (7) and pork (9). This approach has also been used in feeding experiments on broilers, turkeys and cows. For a list of references see E. O. Heady (1957—*Econometrica*) *op. cit.*, p. 250.

DISCUSSION

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It cannot be denied that few of the results of agricultural research and experimentation—except clear cut procedures such as "optimum time to drench", variety of sugar cane, etc.—can be translated to the farmer in economic terms. The adoption of new techniques is therefore seriously impeded.

It is not felt that this can be corrected by simply urging experimenters to rearrange their methods of experimentation. The problem is deeper than that.

Firstly, agricultural education at University level in Australia is largely a science course without direct contact with applied, more particularly applied whole-farm, problems. A recent trend in Australian Universities to become involved in applied research would appear to be an effort to remedy this situation, but it must not be pursued at the sacrifice of fundamental teaching and research, or the last state of the patient will be worse than the first.

Secondly, education, research and extension are separate entities. Both of the latter are staffed with graduates who are not necessarily appreciative of whole-farm problems, but are none-the-less eminently capable of being so, if guided, because of their scientific training.

Since the activities of research and extension are unco-ordinated, graduates entering research establishments tend to follow specialised lines, whilst those entering extension services are regarded by their employers as being unpractical and so lose any encouragement to retain contact with scientific thought and development. Moreover, the latter rarely remain long enough in one environment to pursue a continuous experimental programme.

Thirdly, much of the work quoted was in categories and situations where widely applicable input-output relationships could be fairly readily delineated; for example, the use of commonly used feeding stuffs for animals, or the application of fertilisers to well-known crops in large areas of uniform soil and climate with identical farming pattern between farms. In areas where the soils, climate, past history of fertiliser and cropping procedures and other factors vary, the task of delineating a *line* is greatly magnified, even for readily measurable crop. For pasture, the most difficult crop to measure, and yet the most important, the delineation of an input-animal output relationship to cover wide areas would appear colossal. It would also require closer co-operation between plant and animal men, traditionally jealous of poaching on one another's territory. On all this must be imposed the Australian situation of low reliability of rainfall. Most of the quoted work was for *crops* in areas where soil moisture is adequate at the commencement of every season.

None of the foregoing lessens the necessity for such information—it probably heightens it. I cannot agree with Dr. Skerman that fundamental work should be temporarily shelved to allow of more of this type of applied work—particularly at Universities. I believe, however, that much more can be done by some re-arrangement of present experiments, and that there is scope for greater efficiency of use of the scientifically trained extension workers.

A recent decision of the American Society of Mechanical Engineering was that if engineers were provided with more technical and clerical assistance, professional men could be freed for more creative work. This applies with immensely greater force to the agricultural scientist on extension work.

As Mr. Lloyd says, long repetition and heavy replication will make such experimentation unsatisfying and unrewarding. The tendency already is for the agricultural scientist to retreat from the directly applied field because of these and other reasons such as the complexity ot the problem, shortage of equipment and assistance. As an alternative he has the more satisfying and higher rewarding channels, such as experimentation into individual facets of less immediate agricultural application.

It is felt that all of the above factors have the effect of discouraging that type of experimentation which the economist believes could provide suitable data on which to base economic recommendations to the farmer.