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AGRICULTURAL EXPERIMENTS AND THEIR ECONOMIC SIGNIFICANCE*

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1. SUMMARY

More attention should be paid to designing agricultural experiments so that they yield more useful information about the profitability of particular practices at different levels, and/or in combination with other practices, under varying sets of farm conditions. The difficulties facing the farmer or farm management extension worker in applying this information to particular farms also merit more consideration.

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The aim of farm management is to plan optimum use of farm resources, given the relevant price and input-output data. Controlled experiments are the best source of much of the input-output data needed, but Australian experiments are seldom designed specifically to meet this need.

The more spectacular function of experiments is to discover and demonstrate improved agricultural techniques. The value of the follow-up work, of showing how farmers can make the most profitable use of those techniques, is not sufficiently appreciated, and even where it is, the experimental methods used are often faulty, from the economist's viewpoint.

The problems faced by the farm management worker in using such experimental data as are available fall into three groups:

(1) *The main problem is the lack of economic orientation in experimental design. In particular the production function approach is seldom adopted.* Generally, experimenters concentrate their attention on locating the point of maximum profit per acre in, say, a fertiliser trial, or the point of maximum profit per head in a feeding experiment. However, these points are seldom located with much precision, because too few treatment levels are employed. Even if the maximum profit rate per acre or per head happens to coincide with one of the experimental rates chosen, this is generally not the information required by a farmer to maximise farm income.

The farmer usually lacks sufficient capital to reach the point of maximum profit per acre or per head for all farm inputs—fertiliser, feed, stocking rate, etc., so that he faces the decision as to how far he should go in expenditure on each cost item. In this situation it is the average net return per £ spent, not average net return per acre or per head, that should be maximised. This involves equating marginal products, which requires the application of price and cost data to a response curve, such as a Mitscherlich curve.

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 is inadequate both in quantity and form, and agricultural investment proceeds in a thick fog of uncertainty, based largely on considerations of purely technical efficiency plus hunches. The traditional approach is to compare a few treatment levels employing analysis of variance based on replications. The production function approach requires more treatment levels, more closely spaced and over a wider range than is generally used but less replication is needed. The results are subjected to regression analysis and estimates of standard errors to provide confidence limits.

Relationships and factors of economic importance are frequently omitted from consideration. For instance, substitution rates between inputs at various levels are seldom measured and constant substitution rates are often implicitly assumed without justification. The farmer is frequently faced with the dual problem of deciding the optimum *combination* of two inputs—the optimum ration or fertiliser mix, as well as the optimum *level* of the mixture. Where the optimum combination varies with the level of application, the simultaneous solution to such problems requires multi-variate production functions, which are rarely available.

In grazing trials, within quite broad limits, you can get the experimental results you want according to the stocking rate you set. Yet the rate of stocking is seldom treated as an experimental variable in a functional design.

The fact that the data required for farm management is not more frequently sought by experimenters reflects limited aims and a pre-occupation with technical rather than economic efficiency. It is not sufficiently appreciated that to know a principle or relationship in general terms is inadequate from a farm management viewpoint; it needs to be known in quantitative terms over a range of situations. Many experimenters seem to be addressing themselves to the vague question "Is this practice profitable?" rather than to the question "What is the profitability of this practice at various levels and in various combinations and situations?"

(2) The farm management worker also faces *problems of inference* in transferring the experimental results to farm situations which differ from the experimental conditions. In practice, extension officers are largely left to make subjective judgments, based mainly on observation under practical conditions, when making recommendations involving the application of experimental results to actual farms.

There are two approaches to this problem.

First, we can, to a certain extent, select experimental conditions similar to the commercial conditions most commonly found. One frequently finds experiments conducted on unrepresentative soils, using high grade animals and superior levels of technical management. Some departures from commercial conditions are deliberately chosen in order to maintain controls—*e.g.*, very thorough cultivation to control weed growth. Nevertheless. the idea that the experiment farm should, in all its activities, demonstrate "the best methods", sometimes results in an unfortuante confusion of aims.

Second, further investigations can be undertaken to investigate the effect of varying some of the experimental conditions. This is most accurately done by an integrated long-term research programme, involving a series of comprehensive experiments—an expensive solution involving fewer but larger experiments. Further investigations can also take the form of farm surveys and supervised farm records, and the organisation of, and collection of results from, more "farmer experiments". Such information can provide "adjustment factors"—quantitative estimates of the extent to which experimental results must be adjusted to allow for differences between experimental conditions and a particular set of farm conditions.

(3) Because of considerations of *risk*, the farmer needs to know not only average relationships, but their variance. When data on variance is published, it is usually in a form which is of limited value. Replication through space and time is necessary to give estimates of inter-locational and inter-seasonal variability.

To a considerable extent the deficiencies of experiments, as outlined above, are the result of poor liaison between the scientific disciplines—a shortage of economists suffiicently informed in the agronomic and statistical principles, and a lack of knowledge of the principles of production economics on the part of experimenters. One method of overcoming the problem is through *joint research*. Co-operative planning and interpretation of experiments by agronomists, economists, statisticians and animal husbandry specialists is becoming increasingly popular in the United States.

2. INTRODUCTION

This paper discusses what farm management economists want experimenters to do, and why, and criticises existing methods from the economist's viewpoint. It is concerned with the questions:—(1) How should experiments be organised to yield information about the profitability of particular practices at different levels, and in combination with other practices, under varying sets of farm conditions, and (ii) what are the difficulties facing agricultural extension officers in interpreting this information and applying it to actual farms?

Whilst the main concern is to present the economist's viewpoint, a secondary aim is to inform economists of some of the problems facing experimenters in providing the required data. This subject has received very little serious attention outside of North America and practically none, as far as I am aware, in Australia. One exception is a valuable critical survey, by Pearse, of the Department of Agriculture's experimental work in a large part of Western Australia, from the viewpoint of the first of the above two questions.[1]

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

Agricultural experiments can have considerable significance for agricultural policy, but this discussion is restricted to their implications for farm management.[2]

3. EXPERIMENTS AND FARM MANAGEMENT

A useful approach to this subject is to consider the purposes of farm management extension and of agricultural experiments.

The function of the farm management worker is to plan the optimum use of the resources on a farm, given the relevant price data and input-output data.[3] The farmer formulates 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?"

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

[2] For some policy implications, see E. O. Heady, *Economics of Agricultural Production and Resource Use* (New York: Prentice-Hall Inc., 1952), p. 124.

[3] The term *farm management worker* in this paper means a "general practitioner" in agricultural science who is also an economist to the extent that he uses the tools of production economics. At the present time most Australian extension workers are "specialists" (agronomists, veterinary officers, etc.) with little or no economics training, and the term will be used in that sense. They are normally concerned with a few aspects of resource use rather than with considerations of overall priorities.

The type of experimental data frequently presented, which compare three or four widely spaced rates of fertiliser, feeding, stocking, etc., in terms of output per acre, or per head, is of limited value in solving these problems, 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 generally ignores 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 point of maximum profit per acre 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 spend to that point, for each input, where returns from the last (marginal) £ spent (the value marginal product) are approximately the same as for all other inputs.[4] In this situation it is the average net return per £ spent, not the net return per acre or per head, that is 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 production—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

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[4] *The Marginal Concept*—At this stage, a few words on the marginal concept will clarify this paper for non-economists present. 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, multiplied 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 $\frac{\delta Y}{\delta X}$, 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 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. It is within this second field, which includes most agricultural experiments, that the production function approach discussed later can be usefully incorporated. 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.

The first type of research is concerned with finding new and higher production surfaces, or mountains ; the second type is concerned with charting the mountains we have already discovered. The farm management worker is concerned to show the farmer the highest point he can reach on the known terrain, given his limited climbing resources. The researcher into new techniques aims at lifting the farmer on to a higher mountain by the helicopter of scientific discovery. Four points can be made:—

(i) To a certain extent these are competing ends. Rational choice in allocation of limited experimental resources requires a full appreciation of the value of alternative uses. A better appreciation of the usefulness of accurate surveying, which is the main aim of this paper, may put in a new light the practice of leaving farmers to wander uncertainly in the foothills while we look for uncharted Everests.

(ii) To a certain extent these two ends are complementary. The usefulness of new discoveries is limited by lack of accurate knowledge of input-output relationships, which contributes to their slow and inadequate adoption.[5]

(iii) Most of the surveying of known terrain that is carried out could provide information more useful for farm management workers if some different methods were adopted, with little or no increase in the total experimental resources used.

(iv) A fuller appreciation of the second purpose of experiments strengthens the case for an increase in the experimental resources available for allocation between the two ends.

Generally the aims of many experimenters are too limited to allow experimental data to be of maximum value for economic analysis and decision-making. These aims are generally limited to showing that there is a statistically significant relationship between X and Y, rather than specifying that relationship quantitatively over a wide range of levels.

[5] For an example of the importance of this form of uncertainty, see M. A. Anderson *et. al.*, *An Appraisal of Factors Affecting the Acceptance and Use of Fertiliser in Iowa,* 1953, Iowa Agricultural Experiment Station Special Report No. 16, 1956.

It is not sufficiently appreciated that to know the principle or relationship in general terms is very inadequate; it needs to be known in quantitative terms under a variety of conditions, since the farm manager has the job of choosing between or compromising on many "principles" leading in alternative and sometimes in opposite directions.[6] 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?"

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—experiments are usually designed without much regard to economic interpretation.

(2) "Problems of inference", arising from the necessity of making inferences from experimental results to the farm situation. On any particular farm, the conditions will differ from the experimental conditions.

(3) Problems resulting from considerations of risk.

4. 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.[7] The case for incorporating the production function into experimental design can be summarised as:—

(i) The application of the marginal concept, as in production functions, is a pre-requisite of rational decision-making by farmers and extension workers.

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[6]As illustration, take the recently reported general advice given by a senior extension man—"Get rid of your old ewes; maybe they do give higher lambing percentages, but they cut less wool". Knowledge of these principles in general terms is obviously no basis for dogmatism. There is little satisfactory quantitative information on the relationship of age and breeding performance, and there appears to be no experimental data indicating the relationship of age to the feed-wool transformation rate (wool cut could only be used as the sole indicator where there was unlimited availability of feed per animal).

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

(ii) Most of the input-output data necessary for the calculation of production functions are best obtained from controlled experiments.

(iii) Thus agricultural experiments of the type we are discussing must be designed so as to yield production functions, if they are to be of maximum value in decision-making.

Although this paper is confined to the application of marginal analysis to individual practices, such as levels of feeding and composition of rations, it is very important to mention that production functions are essential to indicate the appropriate production co-efficients for use in farm budgeting and linear programming, in the wider problems of 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 has 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.

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 (at this stage, the curve DE and the percentage probability scale can be ignored). The only physical information needed by the farmer or farm management worker is the curve OA, which might be a fertiliser 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 perennial recommendations of Departments of Agriculture.

The variation through time of resource-product price ratios in agriculture is considerable. Even in the case of wheat, which has for many years been covered by price stabilisation schemes, the quantity of wheat equal in net value to 1 cwt. of superphosphate (delivered) has varied from 2 bushels in 1938-39 to ¾ bushel in 1947-48 and 1⅓ bushels in 1957-58 (New South Wales prices).

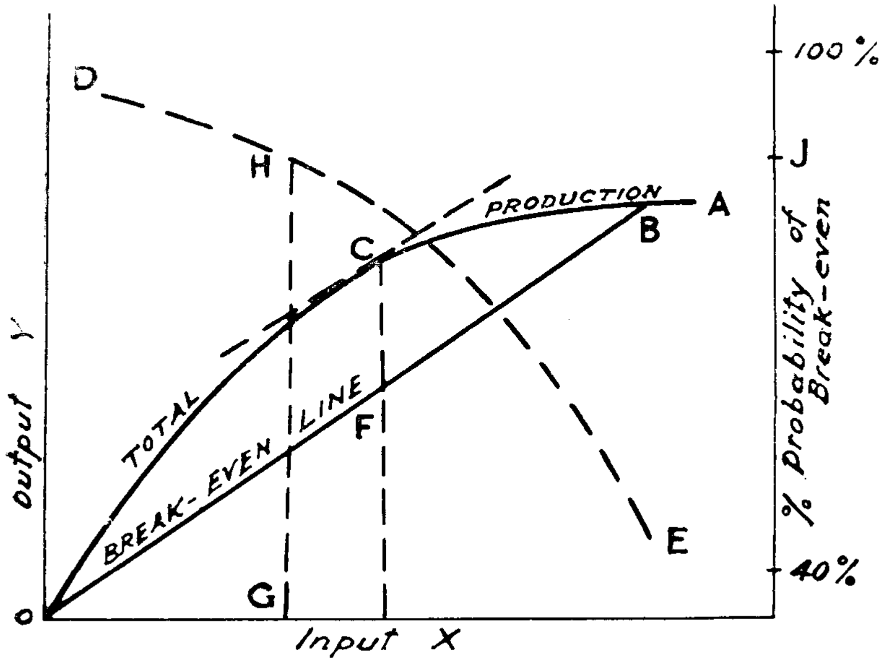

Fig. 1. Probability of Break-even Result

Experimenters should note that the maximum net return per unit of fixed resource is not necessarily the optimum for any particular farmer. The "optimum" will vary from farm to farm, according to the marginal return from other investment opportunities, so that experimenters are not justified in assuming that they need only aim at exploring the area on the curve around the point of maximum net return, even with stable prices. The maximum will be the same as the optimum in the case of ample funds, with no risk or tenure problems.

The case of two (or more) inputs which must be considered simultaneously because of interactions (economists refer to this as complementarity) is rather more complicated. These relationships can be shown in three-dimensional "production surfaces". In the case of hay and grain in a feeding experiment or of nitrogen fertiliser and superphosphate 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.[8] 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.

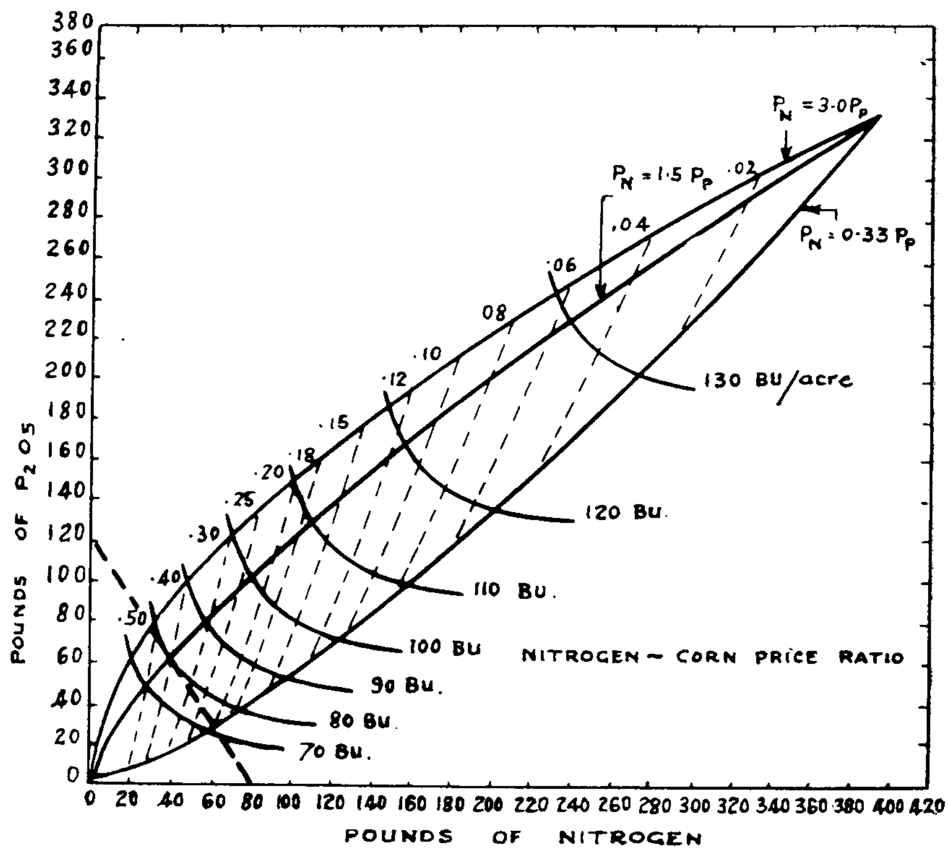

Fig. 2. Yield Isoclines and Isoquants for Corn on Ida-Monona Soil, Iowa Optimum Rates are indicated by dashed lines representing the Nitrogen-Corn Price Ratio

Source: Adapted from William G. Brown, "Practical Applications of Fertiliser Production Functions", Ch. 10 in *Economic Analysis of Fertiliser Use Data* (ed. Baum, Heady and Blackmore), Iowa State College Press, Ames, Iowa, 1956, p. 153.

[8] In the case of fertilisers, substitution need not take place as a chemical process in the plant, but where the availability of one nutrient affects the response to the other nutrient, substitution occurs in the sense that various combinations can be substituted to give the same yield.

A simple method of graphical determination is shown in Figure 2, which illustrates a multi-variate production function of nitrogen and P_2O_5 on yields of corn.[9] The seven curves marked 70 to 130 bushels are the isoquants explained above. The three curves marked—

$$P_n = 0{\cdot}33\ P_p,\ P_n = 1{\cdot}5\ P_p,\ P_n = 3{\cdot}0\ P_p$$

are termed isoclines (or expansion paths). They can be thought of as optimum fertiliser-mix curves, which show how the optimum fertiliser-mix varies as fertiliser application increases, as a result of interaction. They do this by connecting the points of equal slope (*i.e.*, equal marginal rates of substitution) on the isoquants (i.e., at various levels of yield).[10]

Along the isocline marked—

$$P_n = 1{\cdot}5\ P_p,$$

1 lb. of nitrogen produces the same as 1.5 lb. of P_2O_5 (the marginal rate of substitution is 1.5) so that when the nitrogen price is 1.5 times the P_2O_5 price, the optimum combination should be on this isocline (equating the marginal rate of substitution with the price ratio).

Brown illustrates the application of this useful chart in the price situation where corn is $1.00 per bushel, nitrogen $0.15 per lb. and available P_2O_5 $0.10 per lb. Since the fertiliser price ratio is 1.5, the farmer follows the line—

$$P_n = 1{\cdot}5\ P_p,$$

but how far does he go? In this case, the nitrogen-corn price ratio is 0.15, so he goes up until he reaches the dashed line marked 0.15. This point illustrates the optimum application (267 lb. per acre), the optimum mixture and the expected yield, with ample funds.

For the case of restricted funds, let us assume that the farmer can afford only $12 worth of fertiliser per acre. The "restricted" optimum can be located by drawing a line from 120 lb. on the P_2O_5 axis to 80 lb. on the nitrogen axis. Any point on this line would represent $12 worth of fertiliser at the given prices. The intersection of the straight line with isocline marked—

$$P_n = 1.5P_p$$

at about 60 lb. of P_2O_5 and 40 lb. of nitrogen is the best that can be done with $12 worth of fertiliser per acre.

For a sharefarmer on half-shares but paying for all the fertiliser, the relevant nitrogen-corn price ratio would be—

$$\frac{0{\cdot}15}{0{\cdot}50} = 0{\cdot}30.$$

His optimum (with ample funds) would be only 58 lb. of nitrogen and 81 lb. of P_2O_5.

An even simpler graphical method of computing the optimum combination and quantity of two inputs is shown in Figure 3. Fertiliser responses are affected by seeding rates and *vice versa*. This chart locates the optimum

[9] This figure was derived from formulae obtained from an experiment by Heady, Pesek and Brown (*Crop Response Surfaces and Economic Optima in Fertiliser Use*, Iowa AES Research Bulletin 424, March, 1955). Although very elaborate (114 plots) the methods it illustrates are applicable to considerably smaller experiments. For the sake of clarity, only three isoclines are included here of the eight computed.

[10] Only in the case of straight-line isoclines would it be correct to make the assumption, implicit in many feeding and fertiliser trials and recommendations, that the optimum combination is the same for all yield levels.

fertiliser rate and seeding rate simultaneously. A slightly more complicated graph could cover three inputs. To derive the graph requires calculus, but to use it a farmer needs only short division. Simple tables can also be used, and these could be further simplified by arranging the data on rotating slotted discs which can be issued to farmers.

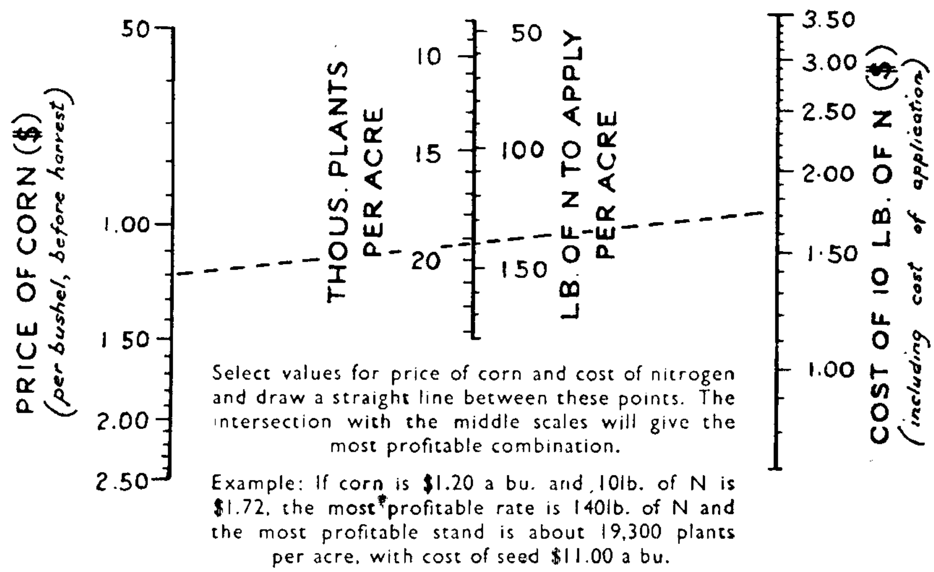

Fig. 3. Most Profitable Combination of Nitrogen Rates and Corn Plants per acre

Source: "Profitable Use of Fertiliser in the Midwest", *Wisconsin AES Bulletin* 508 (1954) p. 25.

So far we have mentioned *factor-product* relationships (marginal products) and *factor-factor* relationships (substitution rates). A third important group are the *product-product* relationships which show the quantities of two or more products that can be produced in various combinations from a given set of factors. As an example, results from rotation experiments can be most usefully expressed in the form of product-product relationships, using the same concepts discussed above.

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, experiments 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 the case of fertiliser experiments a *minimum* of four to five rates is required to establish a satisfactory production function.[11] 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 increments used are very large. Rates of nil, 1 cwt. and 2 cwt. per acre may be used in an area where almost all farmers use between 1 cwt. and 2 cwt., so that the crucial area is accurately specified only at its limits.

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 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 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 8s. 0d. per £ invested, whereas the average net return at the rate nearest the apparent optimum (168 lb. per acre) was only £1 17s. 0d. per £ spent.[12] Over that part of the curve where the marginal productivity is changing rapidly, as in this case, 56 lb. increments are too large.

Many experimenters will look askance at the suggestion that some replications be sacrificed for an increased number of treatment levels, *especially in situations where a large variance is expected.*[13] It is obvious that some 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 analysis variance approach. In the latter replication is required not only to attain accuracy,

[11] 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. See 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.

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

[13] In some overseas production function experiments, an alternative devised to avoid discarding all replications in a factorial design is to discard some treatment combinations unlikely to be important and to replicate the remainder. For an example, see Heady, Pesek and Brown, *op. cit.*

but to permit its measurement. In the regression analysis approach, a certain minimum number of treatment levels is required, whether replicated or not, to derive a curve of even moderate accuracy, and accuracy can then be further improved by increasing the number of treatment levels.

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 experiments.

Relationships and factors of economic importance are frequently omitted from consideration. In particular, there is inadequate 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. (Total Digestible Nutrients) 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 implication that this *one* ration is least cost and most profitable, and that feeds do not substitute at all (or are all limitational in nature)".[14]

It may be argued that TDN tables are designed only as rough guides, but they are not always used as such. Redman quotes a good example of their misuse in a residual method of determining the TDN obtained from pasture.[15] The method assumes constant rates of substitution and disregards the law of diminishing returns.

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

This article was in answer to one by Mighell, who claimed that feeding standards and recommendations *do not* assume perfect substitutability between grain and roughage. Mighell also discussed some limitations on the practical importance of substitution relationships. See R. L. Mighell, "What is the Place of the Equal Product Function?" *Journal of Farm Economics*, Vol. 35, No. 1 (February, 1953), p. 29.

[15] J. C. Redman, "Problems and Possible Solutions in Determining Input-Output Relationships in Agricultural Enterprises", *Journal of Farm Economics*, Vol. 36, No. 5 (December, 1954), p. 1027.

The latter point—ignoring the law of diminishing returns, is also illustrated by the general form of feeding recommendations for dairy cattle. The recommendation that cows be fed a certain quantity of concentrates per gallon of milk produced assumes a linear relationship between feed and output, which is quite unjustified on the experimental evidence available. When a relationship such as this is not known the assumption that it is linear can often be misleading.[16] The general rule in feed-product relationships is for diminishing returns to feed, except in a few cases such as the egg-feed relationship.[17]

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 protein to carbohydrates as animals mature. Thus the composition of the optimum ration would change, so that, 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.[18]. 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.[19] 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, especially labour, are ignored. If one rate of input, or one method,

[16] Redman and Allen point out that Liebig's "Law of the Minimum" implies that yield is a linear function of the minimum factor up to its limit in quantity, and that this early concept has had much influence on thinking in agronomy. The concept holds that the yield of any crop is governed by any change in the quantity of the scarcest (minimum) factor and that as the minimum factor is increased the yield will increase in proportion to the supply of that factor until another factor becomes the minimum. This law also denies the possibility of factor substitution. See 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.

[17] See P. L. Hansen and R. L. Mighell, "The Economics of Input-Output Relationships in Feeding for Egg Production", *Agricultural Economics Research*, Vol. 4, No. 1 (January, 1952).

[18] 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.

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

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.

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. 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.[20] Within quite broad limits, you can get the experimental results you want according to the stocking rate you set. Thus there appears to be 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.[21]

Qualifications

The above argument does not imply that regression analysis should replace analysis of variance in 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-organized 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

[20] 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. Experiments at Armidale (Chiswick) in New South Wales and at Ruakura in New Zealand also suggest the importance of stocking rate, though one must remember that the additional sheep required for higher stocking rates involve higher costs and higher risk, and that higher stocking may, at certain levels, reduce the total forage available over a period. The Armidale and Ruakura experiments compared only two or three different stocking rates over two to four years, and feed was limited in terms of acres, not intake.

See R. Roe, W. E. Southcott and H. N. Turner, "The Effects of Stocking and of Continuous and Rotational Grazing on Pasture and Sheep Production" (unpublished), and C. P. McMeekan, *Grazing Management and Animal Production*, Paper No. 12, International Grassland Conference, New Zealand, 1956.

[21] 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.

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 areas such as the United States and Europe 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.

5. Problems of Inference from Experiment to Farm

The fact that research resources can usually cover only a limited number of the numerous important variables in any particular problem means that:—

(i) There will be a large group of unstudied factors, the "experimental conditions", making up a unique complex which will differ, often markedly, from conditions on particular farms. Amongst the experimental conditions will be factors which are controlled (fixed at a certain level) but often at levels different to the farm level, and factors which are unmeasured, unspecified and uncontrolled, so that they differ from farm conditions to an unknown extent.

(ii) There will be an unexplained residual, within the experiment, resulting from the uncontrolled or imperfectly controlled factors mentioned above, and from errors of measurement. The unexplained residuals in experiments may bear little or no relation to the unexplained residuals in a farm situation.[22]

In practice extension officers are largely left to make subjective judgments, based mainly on observation under practical conditions, when making recommendations involving the application of experimental results to actual farms. Not infrequently, the task is made unnecessarily difficult by the fact that the experimental conditions that *can* be measured or described, such as climatic and weather conditions and soils, are not specified in the experimental report (at least, not in sufficient detail) to allow farmers or extension officers to relate a particular situation to the experimental conditions. We can never completely avoid the necessity of using subjective experience in this problem of inference, but there are a number of ways in which the area of objectivity can be enlarged.

Two such approaches to problems of inference can be distinguished:—

(*a*) Make adaptation of experimental results less necessary, by bringing experimental conditions closer to commercial conditions. This relates to the point made by G. L. Johnson, who refers to "the

[22] For elaboration of these two problems, see E. R. Swanson, "Problems of Applying Experimental Results to Commercial Practice", *Journal of Farm Economics*, vol. 39, No. 2 (May, 1957), and the following discussion of Swanson's paper by G. L. Johnson.

necessity of randomising such important variables as slope, weed infestation, managerial practices, etc., *over ranges appropriate for farm conditions*".[23] Experimental results might then be more directly applicable to farms under average or representative conditions, but the problem would still exist of adapting the results to unrepresentative farms.

(*b*) Further investigation into the effects of varying the conditions. This is most accurately done by further experiments, involving co-ordinated research programmes. 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 experimental results should be adjusted to allow for differences between experimental conditions and a particular set of farm conditions.

Swanson suggests that in applying experimental results to a particular farm, extension workers should take the precaution of varying the production co-efficients over what is believed to be a relevant range and noting the effects in a linear programming (or budgeting) model.[24]

Duplicating Farm Conditions

Most experimenters appreciate that experiments are much more valuable for extension if they use the type of animals, soils, etc., and, as far as possible, the levels of technical management which are commonly found in the populations to which the results are to be applied. Nevertheless, one frequently finds experiments conducted on unrepresentative soils, using high grade animals and superior levels of technical management.

Soil-type and fertility status will often differ greatly between the experiment farm and any particular commercial farm. On some New South Wales experiment farms, experiments are being conducted on soils quite a-typical of the areas for which the results are most urgently required. In one extreme case the whole of the experiment farm is located on a soil quite unique in the area. Siting experiments on private farms in the area can overcome this problem, and this is sometimes done. However, with elaborate experiments, difficulties in supervision and the positioning of equipment often make this solution impracticable.

The level of technical management is one of the most important of the experimental conditions within the experimenters' control. For example, fertiliser responses on experiment farms have been shown to be generally considerably higher than in supervised experiments on surrounding farms where the farmer is responsible for the cultivation and some other phases of the experiment.[25] In Virginia, Plaxico and Loope have shown that a superior manager with unlimited capital could profitably use 800 lb. of fertiliser per acre under stated conditions; a poor manager could use only 500 lb.[26] Survey results and published statistics on yields are consistent with

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[23] G. L. Johnson, *ibid*, p. 393.

[24] E. R. Swanson, *op. cit.*, p. 385.

[25] Paschal and French, *op. cit.*, p. 45.

[26] J. S. Plaxico and K. E. Loope, "Economic Factors Affecting Fertilisation Practices", *Virginia Farm Economics, No.* 41, 1955.

the general opinion that there is a similar management differential in Australian experiments. Rule-of-thumb adjustment for this factor is one reason why some departmental recommendations in New South Wales are below the optima indicated by experimental data.

Some of the departures from commercial conditions are deliberately chosen by experimenters in order to provide controls. Virgin country is sometimes selected for plot trials in order to eliminate as variables the effects of earlier treatments. Similar reasons sometimes prompt the adoption of an above-average level of cultural efficiency in controlling weeds, diseases and insects. Nevertheless, the idea that the experiment farm should, in all its activities, demonstrate "the best methods", sometimes results in an unfortunate confusion of aims.

Sometimes *the animals used* on experiment farms are genetically superior to the average for the district. In some cases this is apparently the result of the policy of seeking to combine research with studs and with winning prizes at shows.

It is desirable that as far as possible experimenters should recognise some of the common limitations on farms. For instance, Willoughby, at Dixon Experiment Farm, in his experiments on fodder conservation of improved pastures in a situation of extreme seasonality of pasture growth, has measured his results directly in terms of wool and meat, using a *set stocking rate* throughout the year. This is in recognition of the fact that flexible stocking rates are not practicable on commercial farms in the area. Many experimenters in similar situations have not been so realistic. Whilst total annual forage production is certainly important enough to be measured, the quantity which can be directly utilised is the vital factor for the farmer.

Further Investigations

Co-ordinated Experiment Programmes

A frequently debated issue is that of simple versus complex experiments. We can, at extra expense, incorporate into experiments as experimental variables some of the more important factors in the experimental conditions. For example, at Wisconsin management was treated as an experimental variable in a fertiliser experiment, and two response curves were published, one for the current level of yield—influencing practices and another for an improved level.[27] But before we co-ordinate research to the extent necessary to explore the role of the experimental conditions, we must consider the problem of whether experimental resources are best used to fully explore a few problems or to partially explore a larger number of problems. Furthermore, what levels of confidence—*i.e.*, how many replications will we settle for? The "economics of experiments"—of choosing between alternative research priorities and methods is shrouded in uncertainty, but a few general observations can be made.

[27] *Profitable Use of Fertiliser in the Mid-West,* North Central Regional Publication No. 54, University of Illinois A.E.S. Bulletin 508, 1954, p. 21.

For instance, there seems to be little point for farm management purposes, in striving for great accuracy in a particular experiment if there is reason to believe that repetitions of the experiment in other locations and at other times will give very variable results. In such situations the sacrifice of some plot replications enables the inclusion of more variables and/or more replications in time and space.[28] Published studies of inter-year and inter-soil variations are rare in Australia, but it is clear from a casual inspection of unpublished data from experimental farms in New South Wales that such variations are very wide for some types of experiments, particularly fertiliser trials.[29]

On the other hand, one of the main reasons why many New South Wales experiments are of such limited value, from the viewpoint of economic interpretation, is the lack of accuracy resulting from inadequate experimental materials and equipment. There is no scope for talking about *reduced* accuracy in a situation where, say, lack of efficient drying apparatus, or scales for animals, prevents accurate measurement of yields, or where lack of fencing or watering facilities, or even lack of grazing animals, prevents increments of feed, in, say, fertiliser or pasture variety trials, being properly measured in terms of output of milk, wool, etc. In these cases, less experiments of more accuracy and comprehensiveness would be of more value to farm management workers.

In the case of experiments involving pasture and forage crops, there is a particular need for experiments to be more comprehensive, to the extent that they take the production process through to the final product, as a grazing trial. Plot experiments measuring forage yield are much cheaper and obviously appropriate in the exploratory stages of a forage investigation, but the difficulties of forage evaluation are such that estimates of profitability really require measurement in terms of final product (such as wool, meat or milk) rather than the intermediate product—feed.

Farm Observations

Farm experiments, farm surveys and supervised farm records can provide assistance in meeting problems of inference by suggesting "adjustment factors". For instance, a controlled experiment might indicate that the sowing of an acre of improved pasture of specified variety, establishment method, fertiliser treatment, etc., on a particular soil type, would increase wool cut per acre by 20 lb. to 30 lb. Information derived by the above methods might suggest that the increase under farm conditions ranged from

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[28] Twenty years ago, Yates pointed out that the use of single replications in factorial designs need not involve the sacrifice of estimates of error, since some of the high-order interactions can replace the replicates for this purpose. He recommended the use of single replications in the above circumstances. See F. Yates, *The Design and Analysis of Factorial Experiments* (1st edition; Harpenden, England: Imperial Bureau of Soil Science, 1937), p. 27.

[29] For an overseas example of such a study, see *Georgia Experiment Station Bulletin* 424, in which experimental data indicated that the optimum nitrogen applications with ample funds varied from 31 lb. to 90 lb. per acre through seasons. For an Australian example, somewhat less precise, see J. McCann, "Fertiliser Trials in Sandhills in the Northern Mallee", *Victorian Journal of Agriculture*, vol. 54, Part 1 (January, 1956), p. 12.

15 lb. to 20 lb. A farm management worker who used the former figure in a budget, without any correction for the inference problem, would achieve a very questionable result.

Farmer "Experiments"

As mentioned earlier, extension workers are forced to rely on observations and experience in adjusting experimental results to what might be expected on particular farms. This method might be developed on a systematic basis by a more methodical collection of the results of farmer "experiments", to use the term loosely. The number and quality of farmer experiments can be increased and improved by extension men in the field, and this is a very desirable form of extension in itself, since it encourages farmers to work out their own problems. We should not be too optimistic about the results which could be achieved by extension workers giving farmers some supervision and a little informal training in experimental methods. (A little of this is already being done.) However, in some fields, where problems of inference are very considerable, the results of a badly run farmer experiment may be more useful for that farmer (and perhaps for some surrounding farmers) than the rule-of-thumb adjustment of results from a properly conducted experiment under very different conditions.

Farm Surveys and Supervised Farm Records

As an example of the survey approach, Odell, in estimating the productivity of some Illinois soils, used farm observation to show that when treatment and soil conditions were as comparable as possible for a certain type of soil, crop yields under farm conditions were 80 per cent. to 90 per cent of crop yields under experimental conditions.[30] Rust and Odell used multiple curvilinear regression analysis of observations on 700 Illinois farms in relating crop yield to weather conditions and methods of management.[31]

Surveys and farm records have frequently sought relationships between production, income, etc., on the one hand, and broad groups of inputs such as "working capital", on the other. However, in the absence of suitable experimental data, surveys have also been used to derive production functions for individual inputs.

In the United States, farm surveys and supervised records have been used to derive feed-milk production functions.[32] Clark and Bessel in the United Kingdom used supervised farm records over a period of years to derive, *inter alia,* marginal product curves for purchased feedstuffs and nitrogen fertiliser and the substitution relationships (isoquants) between these two

[30] R. T. Odell, "The Productivity of Dark, Till-Derived Soils in North-eastern Illinois", *Agronomy Facts,* University of Illinois College of Agriculture, January, 1956.

[31] R. H. Rust and R. T. Odell, "Methods used in Evaluating the Productivity of Some Illinois Soils", *Soil Science Society of America Proceedings,* Vol. 21, No. 2 (March-April, 1957).

[32] 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.

inputs at various levels of output.[33] The disadvantages of these methods, particularly lack of controls and difficulties of measurement, are partially offset by the large number of observations. It is generally agreed that for many types of input-output problems, farm surveys and supervised farm records do not provide a satisfactory alternative to controlled experiments, but they can play a very useful complementary role which is insufficiently exploited.

Long-term rotation experiments pose special problems in the difficulty of maintaining controls over many years and in the fact that rapid changes in varieties and techniques can make the experimental results obsolete before they are obtained. Farm surveys, using purposive samples of soil-types, varieties, etc., and involving careful measurements and observations of a large sample, represent an alternative approach providing somewhat less accurate cross-sectional data, but providing it much more quickly.

6. RISK

The variance of experimental results has important farm management implications connected with adjustments to risk. A farmer's willingness to take risks will often play a large part in decisions he makes on practices suggested by experiment results. To take the extreme case, the fact that a recommendation derived from experimental data would have been very profitable in the long run would be poor consolation to a farmer who went bankrupt in the short run. *A farmer needs to know, not only average relationships, but their variance.*

On occasions, data which would give the farmer some indication of variability are hidden by the publication of results as averages only. But when data on variance are published, it is often of very limited value; it is of little assistance to the farmer to be told, for instance, 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 curve and some knowledge of the main factors responsible for the variation.

Variability Within the Experiment

As a result of uncontrolled factors and experimental errors the observed differences between treatments will be only estimates of the "true" differences. If the experiment is so organised that a production function curve can be derived, that curve will be only an estimate of the "true" curve. If the experiment were repeated a number of times under similar conditions other curves would be obtained, and if they were very different, we would not have much confidence in any of them for farm management purposes.

In an experiment aimed at providing a production function, an indication of the probable degree of spread in results if the experiment were repeated can be obtained by computing "confidence limits". The upper and lower confidence limit curves around the response curve delineate the area in which a given percentage of repetitions would fall.

[33] J. Clark and J. E. Bessell, *Profits from Dairy Farming,* Bulletin No. 7 Imperial Chemical Industries Ltd. Central Agricultural Control, London, 1956.

Paschal and French have computed 67 per cent. confidence limits for a number of fertiliser experiments and used them to discuss the variability within the experiments in terms directly useful for farm management workers.[34]

Variability under Differing Conditions

Above, we were envisaging theoretical repetitions of experiments under *similar* conditions, and the resulting variance. The farmer is more concerned with the variation in results when conditions differ. This is likely to be much greater than the variability within the experiment.

An experiment is a single observation from the population with which it is concerned. The extension man must draw inferences from this sample to another sample. Generally speaking, there are too few repetitions to establish a pattern of responses. Replications within one year have obvious limitations.

Weather conditions are one of the major factors contributing to risk. In a dry season farmers fertilising to the optimum rate for "average" seasons may suffer 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. In other cases, bad seasonal conditions may reduce the optimum rate quite drastically without involving heavy losses for farmers fertilising at heavier rates.[35] Experiments can indicate whether small or large risks are involved in fertilising to the average-season optimum.

A farmer who is not in a positon to take a large risk would like to know what are the percentage chances, in any one year, of his losing money (i.e., failing to break even or better) on the particular investment being considered. Using the results from fifteen experiments having a common fertiliser rate (120 lb. per acre), together with rainfall data, Hildreth arrived at an equation expressing profits as a function of rainfall, the value of forage and the cost of fertiliser.[36] From this equation he computed the minimum rainfall necessary to "break even", and from rainfall records estimated for twenty-five locations, the simple probability of the 120 lb. rate being profitable in a given year.

This approach could perhaps be further developed, to illustrate the ideal requirements (which admittedly would be expensive to meet). The pooled data from a series of experiments replicated through space and time would give the distribution of responses *for each rate*. On the basis of this distribution we could estimate, for a number of price situations, the probability of the response equalling or exceeding the break even point for each rate.

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[34] Paschal and French, *op. cit.*

[35] For example, see McCann, *op. cit.*

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

We might then be able to tell a farmer that in say nine years out of ten, it is probable that a particular level of input, say of fertiliser or feed, would at lease pay for itself.[37]

The information might be presented graphically, as in Figure 1, in which case OA will not be a true production function but a hybrid, since other things (*e.g.*, seasonal conditions) will be deliberately allowed to vary as the relationship between X and Y is studied. The cost line OB, expressing the cost of input in terms of output, could be called a "break even" line, since the yields indicated along that line would be required to offset the additional costs. The curve DE indicates the percentage probability of the break even level of output (or better) being attained at various rates of input. For instance, the probability of a break even result using rate OG, is indicated by point J. This is obtained by reading off on the right vertical axis the probability of point H on DE above G.

7. 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.[38] Since then, joint research projects of this type have been growing in popularity in the United States. A good deal of this work has been inspired by Heady at Iowa.[39] 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.

Specialisation is a valuable aid to efficiency, but it is often true that it is only by the "integration" of research that the full benefits of specialisation can be reaped.[40] Johnson has written of "The hybrid vigour resulting from working jointly on production problems with representatives from the physical sciences . . ." [41] After considering the respective aims of the agronomist and the economist in experiments he concludes that "where they are not complementary, they are at least not in sharp conflict." [42]

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[37] Hildreth's approach to rainfall allows reference to a period as long as the rainfall records are available, but estimates of general variability could refer only to conditions ruling over the series of experiments, and these may not be representative of the long run variability.

[38] Jensen, *op. cit.*

[39] Some examples have already been quoted of joint experiments at Iowa on fertilisers (9) and pork (18). This approach has also been used in experiments using broilers, turkeys and cows. For a list of references see E. O. Heady, *op. cit.*, (1957—*Econometrica*), p. 250.

[40] H. C. Trelogan, "The Integration of Economic Research and the Problems Encountered", *Journal of Farm Economics*, Vol. 36 No. 5 (December, 1954), p. 841.

[41] G. L. Johnson, "Major Opportunities for Improving Agricultural Economics Research in the Decade Ahead", *Journal of Farm Economics*, Vol. 36 No. 5 (December, 1954), p. 832.

[42] G. L. Johnson, "Designing Experiments to Study Profitability"; Ch. 2 in Baum, Heady and Blackmore (eds.)—*Economic Analysis of Fertiliser Use Data*, (Iowa State College Press; 1946), p. 30.

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 barriers of communication--a shortage of economists sufficiently informed in the statistical, agronomic, etc., principles and a lack of knowledge of the principles of production economics on the part of experimenters.

For experiments to be of maximum value in farm management, liaison within research must be accompanied by effective liaison between research and extension.[43] A co-operative study of agricultural problems was recently commenced in the Southern Tablelands of New South Wales, involving extension officers as well as a wide range of research specialists. Even at this early stage, the value of an organised two-way flow of information between research and extension workers has been illustrated.[44]

8. 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 agricultural economics training into agricultural science courses at our Universities is one long-term approach to the liaison problem discussed here. As an immediate step the organisation of joint research projects 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.

[43] For a discussion of this point see H. C. M. Case and D. B. Williams, *Fifty Years of Farm Management* (Urbana, Illinois: University of Illinois Press, 1957), p. 355.

[44] See *Regional Research and Extension Study—Southern Tablelands, N.S.W., Report No.* 1, *Outline of the Project*, 1957, issued by the N.S.W. Department of Agriculture—CSIRO Joint Planning Committee.