PROCEEDINGS

of the

WESTERN FARM ECONOMICS ASSOCIATION

Thirty-Third Annual Meeting

August 23-26, 1960

Stanford University
Stanford, California

SUGGESTED METHODS OF THE ANALYSIS OF EXPERIMENTAL DATA RELATING TO PRODUCTION ECONOMICS

By

William G. Brown

Oregon State College

It is the objective of this paper to present certain methods which appear promising for production economic analysis of experimental data. While for deductive purposes it may conveniently be assumed that the relevant production coefficients are known, in reality these coefficients may be known only within wide limits. At least one purpose of the agricultural experiment stations is to conduct research leading to improved estimates of the production coefficients as well as to devise new technology resulting in coefficients which are improved from an economic viewpoint. In either event, estimation of the production coefficients is logically implied. Since economic considerations are crucial in the interpretation and use of production coefficients, the production economist does have an opportunity and obligation to see that the estimates of these coefficients are economically meaningful.

When production coefficients can be estimated, these coefficients should provide valuable information for firm analysis. Yet in practice, there may be considerable divergence between the production relationships estimated experimentally and the production information actually needed by the farmer in his decision-making environment. Therefore, there is a great need and opportunity to meet this problem by altering the analysis to make it more appropriate to the actual decision-making situation. If the production coefficients can be estimated and utilized in a more realistic decision-making framework, then the value of firm analyses by budgeting or programming techniques can be enhanced.

It is beyond the scope of a single paper to discuss all the many possibilities in applying production economics to experiment station data. However, two areas will be briefly considered, fertilizer-yield relationships and problems in animal nutrition. The interactions between fertilizer-yield relationships and optimum crop rotations have been treated in Mr. Pawson's study. The following section concerned with fertilizer production function estimation is intended to pertain to a specific problem so that duplication of Pawson's paper does not occur.

Plant Nutrient-Yield Relationships

Some of the early work in the estimation of yield-fertilizer production surfaces was based upon results from single experiments.[1] While production

---

[1] For example, Cf. E. O. Heady, J. T. Pesek, and W. G. Brown, "Crop Response Surface and Economic Cptima in Fertilizer Use," Iowa Agricultural Experiment Station Research Bulletin 424, 1955.

relationships and economic optima can be specified for a single experimental location and year, any recommendations based upon such a limited sample would have to be formulated with extreme care.

It is possible to take the "average" production function calculated from data over a number of years. It has been shown that the average production function would be the "best" single estimate for maximizing profit over time if there were no "advance information" as to the type of response to expect in a particular year.[2]

Actually, of course, the amount of soil moisture at seeding or when fertilizer is applied often gives a clue as to how favorable the response to fertilizer would be at harvest.[3] However, in addition to soil moisture factors, it would also be desirable to incorporate soil test measurements into the fertilizer-yield production function. Then, the yield response for a farmer's field with a given soil test could, supposedly, be predicted more accurately by substituting that field's particular soil-test measurements into the general yield predicting equation.

An interesting and promising approach to this problem has been suggested by Hildreth.[4] His model is appropriate if a given amount of nutrient in the soil replaces a proportionate amount of nutrient added artificially. This assumption appears reasonable and greatly simplifies the problem.

Considering the case of a single nutrient, say nitrogen, Hildreth would regard yield as a function of a variable which is the amount of nitrogen added plus some constant times the amount of nitrogen originally in the soil. Initial nitrogen in the soil would be measured by a soil test and nitrogen added would be recorded in the usual manner. The constant, which can be regarded as the rate at which initial nitrogen in the soil substitutes for added nitrogen, is, of course, unknown and must be estimated. In symbols:

$$(1)\quad y = f(x) + u$$

$$(2)\quad x = n + \lambda w$$

2/ W. G. Brown and M. M Oveson, "Production Functions from Data Over a Series of Years," Journal of Farm Economics Vol. XL, No. 2, May, 1958, pp. 451-457.

3/ Cf. F. Orazem and R. B. Herring, "Economic Aspects of the Effects of Fertilizers, Soil Moisture and Rainfall on the Yields of Grain Sorghum in the 'Sandy Lands' of Southwest Kansas," Journal of Farm Economics, Vol. XL, No. 3, August, 1958, pp. 697-

4/ C. G. Hildreth, "Possible Models for Agronomic-Economic Research," Fertilizer Innovations and Resource Use, Edited by E. L. Baum, E. O. Heady, J. T. Pesek, and C. G. Hildreth, Iowa State College Press, Ames, Iowa, 1957, pp. 176-186.

when y = yield

x = total nitrogen in the soil

n = nitrogen added

w = initial nitrogen

u = a random disturbance

λ = an unknown factor of proportionality

If Equation (1) is of a curvilinear form (as would be expected due to diminishing returns), then it is not possible to estimate the production function parameters by straightforward least squares procedures and still maintain the condition expressed in Equation (2). However, Hildreth does present certain techniques for obtaining maximum likelihood estimates of λ.[1] After λ has been estimated, the other parameters of the production function can be easily estimated by ordinary least squares techniques.

With the availability of modern electronic computers, Hildreth and others have suggested that it should be feasible to assume a number of values for λ, then calculate the error sums of squares of regression for the various assumed λ values. By graphical or other means, the approximate error minimizing value of λ could be selected. This kind of procedure should be feasible even if considering a number of plant nutrients.

Incorporation of measures of soil characteristics into yield-fertilizer predicting equations has been retarded by difficulty in adequately measuring many of the important variables. In this respect, the field of plant nutrition may be more difficult than animal nutrition. At least for animals, the total quantity of nutrient consumed or available for consumption is more easily measured or controlled.

Problems of Time and the Economics of Animal Nutrition

Early economic research with animal feeding experiments involving two or more feed inputs employed the traditional production economic theoretical framework, using such concepts as isoquants and isoclines.[6] While the traditional static framework provided a logical starting point, certain difficulties are encountered when it is used for animal feeding problems which do not arise in some other areas, such as for specifying optimum fertilizer rates. Ordinary static procedures are appropriate for most fertilizer problems since fertilizer can be dumped onto the ground in practically any desired amount in a short time. But for production situations where time is required for additional input of factors, time needs to be integrated into the analysis.

---

[5] Ibid.

[6] For example, Cf. E. O. Heady, R. Woodworth, D. N. Catron, and G. C. Ashton, "New Procedures in Estimating Feed Substitution Rates and in Determining Economic Optima in Park Production," Iowa Agricultural Experiment Station Bulletin 409, Ames, Iowa, 1954.

Selection of optimum feed inputs for farm animals often falls into the class of production situations requiring a more dynamic approach. Restrictions imposed by the animal stomach may cause the ordinary "least-cost" ration to be nonoptimum when the cost of time is considered. For example, a more costly ration may be preferred to the so-called least-cost ration if it permits the desired marketing weight to be attained sooner.

Of course, other research workers have recognized the problem of varying time requirements for different rations. In some studies, time has been predicted as a function of the consumption of specified feeds.[7] It was thereby not only possible to predict the length of time required for the animal to consume a given ration, but also to compute least-time rations. Although this method quantified some elements of the problem, it did not integrate time and static marginal productivity. Least-time, least-cost, or some intermediate combination of ration could be selected, but such a choice would be arbitrary.

To appraise the suitability of traditional procedures in production economics, it should be recalled that these procedures were designed to provide correct answers to two related questions: (a) What is the cheapest combination of factor inputs for obtaining a given output, and (b) what is the optimum level of output?

Questions (a) and (b) are answered by determining how far to go on the isocline, according to relative factor and product prices. But rather than answering questions (a) and (b) which ignore time, answers should be sought for two different questions:

(c) Given a limited, fixed time for the production process in a subperiod of production what would be the most profitable combination of factors to use?

(d) What is the optimum length of time for the subperiods of production, considering the longer over-all production period?

Question (d) can be handled by first calculating the answer to (c) for various subperiods and choosing the most profitable in relation to the longer over-all period. The optimum factor inputs can then be computed for a given time period by combining the factor time requirements with the production function. That is, output or product is estimated as the usual function of the various feed inputs. Then, the rate of input for one factor is expressed as a function of the input of the other factor and time. With the rate of input imposed as a condition upon the production function, the most profitable input combination may be specified for any length of feeding period. The optimum length of feeding period can then be computed by simple budgeting.[8]

---

[7] Ibid.

[8] For more detail, Cf. W. G. Brown and G. H. Arscott, "A Method for Dealing with Time in Determining Optimum Factor Inputs," Journal of Farm Economics, Vol. XL, No. 3, August, 1958, pp. 666-673.

To summarize, the main idea in dealing with time is to be able to predict the quantity of each feed input which will be consumed during a specified length of feeding period and for a specified feed combination. Thus, for each feed combination, the amount which can be consumed by the animal is substituted into the regular production function where product is the usual function of the factor (feed) input. Then, the value of product for various feed combinations and lengths of feeding period can be compared and the most profitable length of feeding period and feed combination can be selected.

It is of interest from the viewpoint of economic theory that when time is integrated into the analysis, the optimum factor combination is directly affected by the product price. In traditional production economics, the optimum combination of factors to achieve a given product is not affected, since the isocline equations are independent of the product prices.

Improving the Inferential Value of Animal Production Functions

Again (as for fertilizer-yield relationships) the desire of the cooperating economist and production specialist is to obtain results or predictions which will have the widest possible application. One approach is to cast the production function, not in terms of specific feed inputs, but rather in terms of measurable attributes of all feed inputs, such as energy, protein, or other important feed characteristics.[9] This approach has given promising results with broilers, allowing both the selection of the most economical feed ingredients and optimum ration specifications.[10]

With broiler weight expressed as a function of calories of energy and pounds of protein consumed, the predicted broiler weight and value obtainable from feed with various protein-energy specifications can readily be computed as shown in Figure 1. Likewise, the amount of these feeds of specified quality which would be consumed in given lengths of time can also be predicted, being a function of the protein and energy content as well as the length of feeding period. Thus, the weight and value of broilers producible from rations of different quality can be predicted for given lengths of feeding period.

On the cost side, we have employed linear programming to select the cheapest combination of feeds and feedstuffs to meet the protein,[11] energy,

---

[9] An early use of this technique was made by A. G. Nelson, "Input-Output Relationships in Fattening Cattle," Journal of Farm Economics, Vol. XXVIII, No. 2, May, 1946, pp. 495-514.

[10] W. G. Brown and G. H. Arscott, "Animal Production Functions and Optimum Ration Specifications," Journal of Farm Economics, Vol. XLII, No. 1, February, 1960, pp. 69-78.

[11] Our intent has been to keep protein quality constant by requiring the recommended minimum amounts of the important amino acids per pound of protein.

and mineral specifications. Thus, again the most profitable quality of ration and length of feeding period can be selected from the alternatives considered.

There has been no difficulty in locating the approximately maximum profit point on the protein-energy production surface when following this procedure. However, in some of Arscott's recent broiler experiments some feed ingredients have not given the same result that would be expected, based upon present estimates of feed specifications such as protein, amino acids, and minerals. For example, a ration with cottonseed meal as the main protein source has not given as good results as has a ration meeting the same specifications but with soybean meal as the chief protein source.[12] These discrepancies may be more important for broilers than for most other farm animals.

Suggested Models for Future Research With Beef and Dairy Animals[13]

Each class of farm animal involves particular problems in predicting economically optimum feed rations. For example, the selection of optimum steer fattening rations requires not only a consideration of time as for broilers but also requires that the effect of ration on beef quality be considered. However, these considerations can be incorporated into the analysis by using principles similar to those already discussed.

Many commercial beef feedlot operators weigh their cattle every month. Since the experimental animals were also weighed periodically, we decided to try a model which would predict the expected beef gain for the next feeding period, based upon the feed to be fed and the performance of the animals in the preceding feeding periods. Of the various equations fitted to the data, the more important variables were retained in (3):

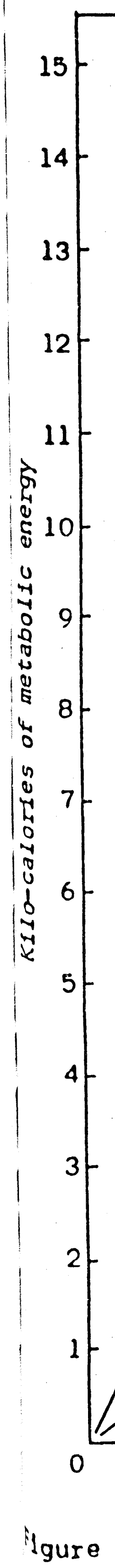
$$(3) \quad Y = f(X_1, X_2, X_3, X_4, X_5) - u$$

where Y = the average gain in weight per animal for feeding period i

---

[12] A report will be prepared soon regarding these effects and following up the work reported in "Animal Production Functions and Optimum Ration Specifications," Journal of Farm Economics, Vol. XLII, No. 1, February, 1960.

[13] A few ideas which seem promising are sketched out in this section. Examples of beef analyses are presented solely for illustrative purposes. A complete report will be prepared in cooperation with D. C. England, Department of Dairy and Animal Husbandry, Oregon State College, who was in charge of the beef steer experiments. A description of part of the data can be obtained from the following: D. C. England, N. O. Taylor, "Results of 1957-58 Milton-Freewater Beef Feeding Experiments, Circ. of Information 596, Oregon State College, Corvallis, Oregon, January, 1959.



igure

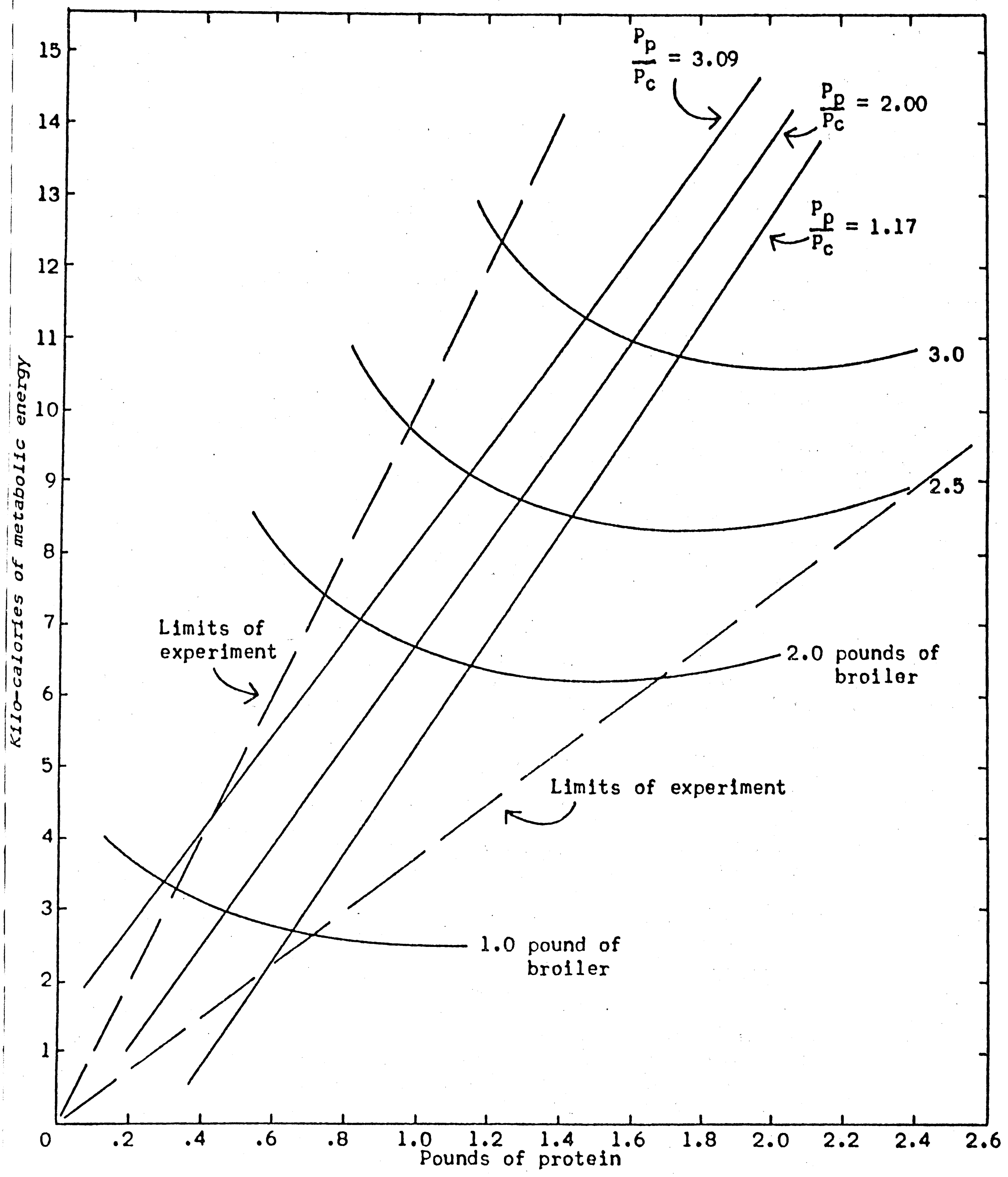


Figure 1. Calory-Protein Production Surface with Traditional Isoquants and Isoclines.

X_1 = the average net energy in therms consumed per animal during period i 14/

X_2 = the average weight per animal at the beginning of feeding period i times X_1

X_3 = the ratio of net energy to dry matter of the ration to be fed in period i times X_1

X_4 = the average ratio of net energy to dry matter of the rations fed before feeding period i times X_1

X_5 = the ratio of the immediately preceding period's gain to the net energy consumed in the preceding period times X_1

u = a random disturbance

Other logically justifiable variables were tried, such as interactions with different roughage sources and a curvilinear relationship for X_3. However, these variables were dropped because the experiments were not suitable for detecting these effects.

It should be noted that X_2 allows diminishing returns as the feeding period progresses and the animals become heavier. This hypothesis appears sensible and the variable X_2 is very highly significant, along with X_1, when fitted to the data.

Variables X_3 and X_5 were statistically highly significant. However, X_5 is deleted for making the predictions shown later. 15/ Variable X_4 was retained for logical reasons, although statistically nonsignificant at the 5% level. With the deletion of X_5 the predicting equation was (4).

$$(4) \quad \hat{Y} = 0.18075X_1 - 0.000226X_2 + 0.4400X_3 - 0.1295X_4$$

where the symbols are the same as for (3).

14/ Computed by multiplying published net energy values of the particular feeds times the quantity of these feeds consumed.

15/ Variable X_5 had an unexpected negative sign, the reason being that the animals were not uniformly shrunk before each weigh period. Thus, an animal with a heavy fill one month tended to make less apparent gain the following month. Thus, X_5 was a variable which more nearly reflected "fill" than a measure of animal efficiency. Nevertheless, if fill could be controlled by uniformly withholding animals from feed and water for a short period before each weighing, it is thought that such a variable could greatly increase the accurancy of the predicted gain for the next feeding period. Also, such a variable might be useful in predicting milk output since milk production can be accurately measured.

Energy consumption per animal was fitted to a model similar to equation (3).

(5) $X_1 = f(T, Z_1, Z_2, Z_3, Z_4, Z_5) + u$

where X_1 = average therms of net energy consumed per animal during feeding period i

T_i = the number of days in feeding period i

Z_1 = the average weight per animal at the beginning of feeding period i times T_i

Z_2 = the ratio of net energy to the dry matter of the ration to be fed in period i times T_i

Z_3 = the average ratio of net energy to dry matter of the rations fed before period i times T_i

Z_4 = the proportion of roughage consisting of alfalfa hay in period i times T_i

Z_5 = the ratio of the immediately preceding period's energy consumption to the number of days in the preceding period times T_i

u = a random disturbance

Since variable X_5 was dropped from Equation (3), Z_5 is deleted from (5) for simplicity. The coefficients of the equation were then as follows:

(6) $\hat{X}_1 = -11.05T + 0.00925Z_1 + 27.55Z_2 - 5.45Z_3 + 1.79Z_4$

Energy consumptions were predicted more accurately by Equation (6) than were beef gains by Equation (4). The standard error of estimate for (6) is about 20 for an average energy consumption of around 320, or an average deviation of only about 6% of the mean predicted value. However, for Equation (4) the standard error of estimate is about 12 pounds which is about 20% of the average predicted value. While the 12 pound deviation is substantial, it should be remembered that a variation of 1.5 gallons of water in the paunch of an animal between weighings could cause this much variance. Under these experimental conditions it was concluded that the gain-predicting model gave satisfactory results.

Utilization of the Beef Model

Two uses of the preceding type of beef model are possible, (1) ex ante or for decision-making during a feeding operation and (2) a retrospective or ex post analysis of experiments. For decision-making, the model should include variables similar to X_5 and Z_5 fitted to data obtained from specially designed experiments. Thus, it might be possible for the feedlot operator to utilize the past performance of a lot of animals to predict their gains and feed conversion during the next feeding period.

The second use, *ex post* analysis, would be to estimate optimum feeding practices under various assumed price and feeding conditions. For example, it is possible to reconstruct performance by first estimating the energy intake from Equation (4) by assuming a given initial size of animal and a given type of feed. Then by substituting the predicted energy consumption into (6), the predicted beef gain is obtained. This gain in turn is added to the initial weight of the animal to obtain a new total weight to use in predicting the energy consumption of the second period from Equation (4). This energy intake is again substituted into (6) to predict the second period beef gain. Thus, the model alternates from energy intake to gain, to energy intake to gain, etc.

Energy consumption and gain predictions are shown in Table 1 for four different types of rations, (1) low, (2) medium, (3) high concentrate, and (4) starting with low concentrate and working to higher levels. These projections can be accepted only with reservations since these figures are extrapolated somewhat beyond the range of the experimental data, especially for the ratio of net energy to dry matter of 0.7.

Predictions for the same rations of Table 1 are graphed in Figure 2. The higher ratios of net energy to dry matter give more efficient energy conversion than the lower ratios, perhaps due to the much higher rate of energy intake for higher energy rations[16] with a correspondingly lower maintenance requirement.[17] It is of interest that the ration with increasing energy to dry matter gave greater efficiency than a comparable energy ration fed "straight through." Thus, the more efficient use of a limited amount of grain would be to feed it sparingly at first and then to increase the gain percentage of the ration as the feeding period progresses. This is an opinion held by some successful cattle feeders.

While the above conclusion seems consistent with recommended feeding practices, such a relationship cannot be deduced from an ordinary production function model. However, additional variables can be added to the function to reflect the "carryover" effect from the kind of feed fed in previous periods.[18] Such models will need testing with additional data before they can be properly evaluated.

---

[16] An extrapolation of energy consumption beyond the experimental feeding period of about 260 days soon overestimates the feed consumption. Variable Z_1 in Equations (5) and (6) should be fitted over a longer time period.

[17] A net growth model in which maintenance requirements were subtracted from total energy intake was fitted to the data results did not appear satisfactory. A study of maintenance requirements is presented by S. Brody, *Bioenergetics and Growth*, New York: Reinhold Publishing Corp., 1945, esp. pp. 470-483.

[18] An interesting procedure has been used by G. W. Dean, "Consideration of Time and Carryover Effects in Milk Production Functions," Contributed Paper presented at the American Farm Economic Meeting, Ames, Iowa, 1960.

TABLE 1. Predicted therms of energy consumption and gain per animal from four different rations

TABLE 1. Predicted therms of energy consumption and gain per animal from four different rations with initial steer weights of 450 lbs.

		Ration Number I /a			Ration Number II /b		
Length of Feed. Per.	Total Days on Feed	Pred. Net Energy Consmp. Per Period	Predicted Beef Gain	Pred. Total Beef Wt. /e	Pred. Net Energy Consmp. Per Period	Predicted Beef Gain	Pred. Total Beef Wt. /e
30	30	125	29	479	191	51	501
30	60	133	30	510	205	52	553
30	90	141	31	541	220	53	606
30	120	150	32	573	234	54	660
30	150	159	33	606	249	54	714
30	180	168	33	639	265	54	769
30	210	177	34	673	280	54	823
30	240	187	34	707	295	53	876
30	270	196	35	742	309	52	928
30	300	206	35	777	324	51	979
		Ration Number III /c			Ration Number IV /d		
30	30	257	76	526	125	29	479
30	60	279	78	604	150	35	515
30	90	300	79	683	174	41	556
30	120	322	79	761	200	47	603
30	150	344	78	839	228	53	655
30	180	365	76	915	257	58	713
30	210	387	74	989	288	63	777
30	240	407	71	1060	320	68	845
30	270	427	68	1128	254	73	918
30	300	446	64	1192	388	76	994

/a A net energy-dry matter ratio of 0.5 is assumed for Ration #1. This ratio would correspond to 17.926 lbs. pea vine silage to one lb. of concentrate. (Pea vine silage was assumed to have a net energy value of 0.116 per pound with 25.9% dry matter. The concentrate had a tabulated net energy value of 0.688 with 89.2% dry matter.)

/b Net energy-dry matter ratio of 0.6 which would correspond to 3.8782 lbs. pea silage per pound of concentrate

/c Net energy-dry matter ratio of 0.7 corresponding to 0.9740 lbs. silage per pound of concentrate.

/d For Ration #4 it is assumed that the net energy-dry matter ratio starts at 0.5, then increases by 0.02 for each period.

/e Predicted gains and total weights may not check exactly because of rounding for this table.

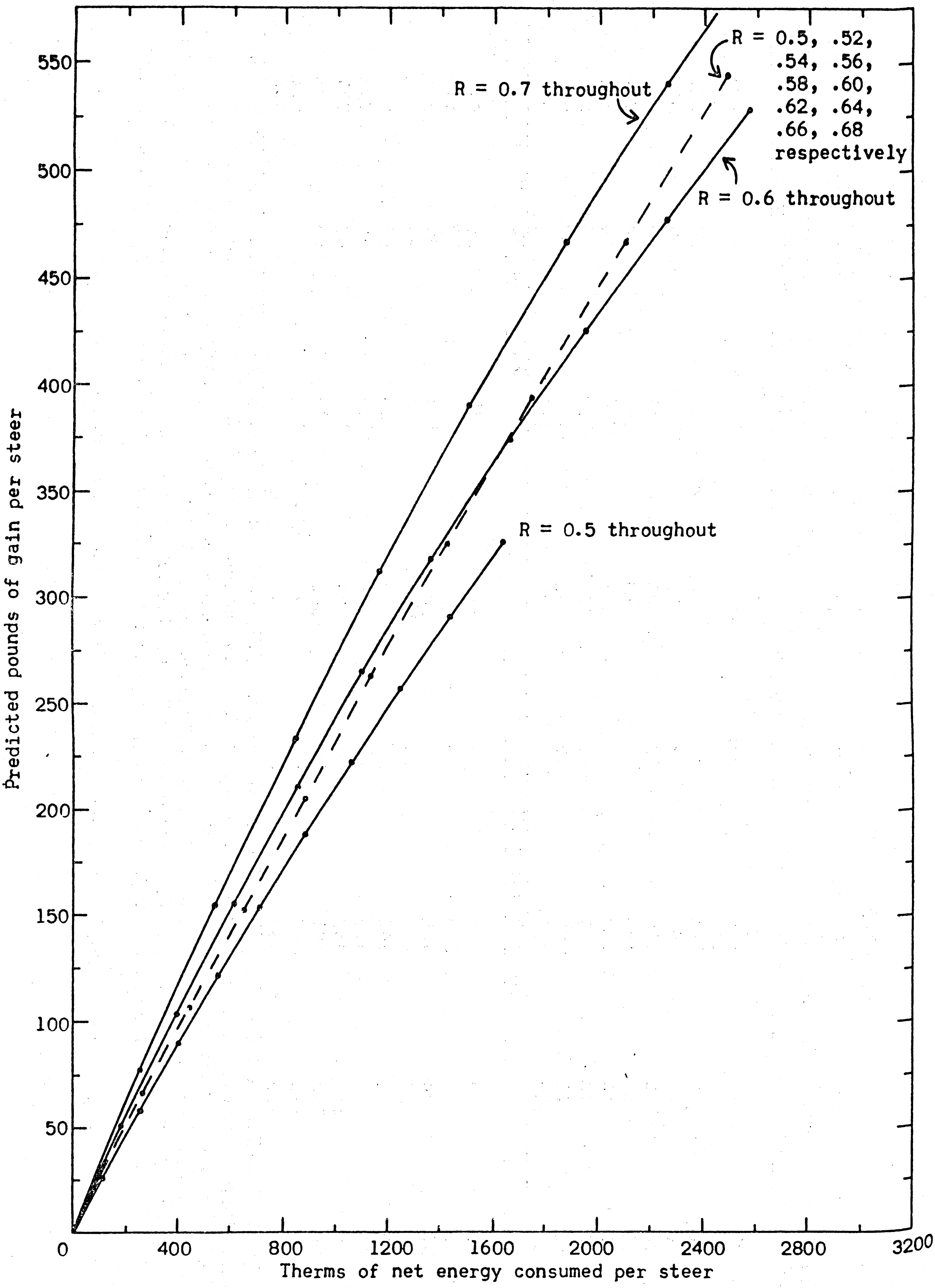


Figure 2. Predicted monthly energy consumption and pounds of gain for steers on four rations where R refers to the ratio of therms of net energy to dry matter per pound of ration. Each dot on the curves signifies the end of a monthly feeding period.

TABLE 2. Margins of predicted values of beef gains over feed cost from four different rations with initial steer weights of 450 pounds. Peavine silage is assumed to cost $5.00

TABLE 2. Margins of predicted values of beef gains over feed cost from four different rations with initial steer weights of 450 pounds. Peavine silage is assumed to cost $5.00 per ton and concentrate $50.00 per ton

Length of Feeding Period	Total Days on Feed	Ration Number I /a		Ration Number II /b	
		Price of Beef Gain per cwt. $15	$20	Price of Beef Gain per cwt. $15	$20
30	30	$1.20	$2.65	$1.83	$4.38
30	60	1.14	2.64	1.55	4.15
30	90	1.09	2.64	1.24	3.89
30	120	1.02	2.62	0.96	3.66
30	150	0.94	2.59	0.51	3.21
30	180	0.71	2.36	0.02	2.72
30	210	0.63	2.33	-0.44	2.26
30	240	0.38	2.08	-1.05	1.60
30	270	0.31	2.06	-1.62	0.98
30	300	0.05	1.80	-2.23	0.32
		Ration Number III /c		Ration Number IV /d	
30	30	$2.60	$6.40	$1.20	$2.65
30	660	2.14	6.04	1.28	3.03
30	90	1.57	5.52	1.35	3.40
30	120	0.82	4.77	1.33	3.68
30	150	-.08	3.82	1.20	3.85
30	180	-1.10	2.70	0.86	3.76
30	210	-2.16	1.54	0.42	3.57
30	240	-3.29	0.26	-0.08	3.32
30	270	-4.43	-1.03	-0.69	2.96
30	300	-5.68	-2.48	-1.63	2.17

/a A net energy-dry matter ratio of 0.5 is assumed for Ratio #1. This ration would correspond to 17.926 lbs. peavine silage to one lb. of concentrate. (Peavine silage was assumed to have a net energy value of 0.116 per pound with 25.9% dry matter. The concentrate had a tabulated net energy value of 0.688 with 89.2% dry matter.)

/b Net energy-dry matter ratio of 0.6 which would correspond to 3.8782 lbs. pea silage per pound of concentrate.

/c Net energy-dry matter ratio of 0.7 corresponding to 0.9740 lbs. silage per pound of concentrate.

/d For Ration #4 it is assumed that the net energy-dry matter ratio starts at 0.5, then increases by 0.02 for each period.

A simplified economic analysis of the physical predictions of Table 1 is presented in Table 2. Returns over the cost of feed reflect the importance of beef prices in choosing the optimum energy level as well as the optimum length of feeding period.

Quality effects can and should be considered in a bona fide analysis since we have found highly significant relationships between final slaughter grade and the energy level of the ration. However, these considerations are omitted at this time because of space limitations.

Conclusion

There is considerable opportunity in production economic research to devise procedures to make experimental results more appropriate and applicable to the actual decision-making environment. One way to accomplish this objective in the area of plant nutrition would be to incorporate soil test variables into a generalized yield predicting equation. For animal nutrition, time, quality, and past performance of the animals are factors which need to be considered. With improved data processing facilities and increased research, the development of improved methods for production economic research is likely to be accelerated.

DISCUSSION: SUGGESTED METHODS OF THE ANALYSIS OF EXPERIMENTAL DATA RELATING TO PRODUCTION ECONOMICS

By

Ronald D. Krenz

University of Wyoming

My comments on Dr. Brown's paper will be of two types, both brief. I find little to argue with in Dr. Brown's paper, hence I will first try to summarize his presentation with emphasis on certain contributions Dr. Brown has here presented. Secondly, I will supplement the material in this paper with a few additional suggestions on alternative methods of analysis and presentation of production economics data.

Dr. Brown deals with two situations in which improvements in our economic analysis must and can be made before producers can readily utilize experimental data. In the fertilization of crops, the typical production experiment too often deals with only one of the multitude of resource situations which exist. The typical experiment may well define a particular soil type, but two variables often omitted or forgotten are those of weather and plant nutrients in the soil. Both of these variables are highly variable and no doubt are of major importance in determining crop yields.

Dr. Brown suggests that we include an index or measure of plant nutrients in the soil into our yield estimation equation. Hence, we would come up with a multitude of yield estimates, each estimate based on plant nutrients added and plant nutrients in the soil. The producer then must pick the set of yield estimates based on the characteristics of the particular soil involved. Essentially, the production economist has made it possible for the producer to add to the input data. At this stage it must be the producers responsibility to obtain the input information.

Typical livestock feed studies suggest at least four things. One, that there is only one length of feeding period permissible; two, that livestock should be fed one and only one ration the duration of the feeding period; three, this ration is made up of only a limited number of feed inputs; and four, the producer can make all decisions relative to feeding at the start of the feeding operation.

The typical study may give us isoquants and isoclines over a wide variety of body weights and feed quantities but for only a very limited number of feed types. Hence, its application is quite limited.

Dr. Brown suggests that we divide the complete feeding period into subperiods and provide methods whereby the livestock feeder can determine, for a particular lot of cattle, whether to sell or feed longer and if so, what to feed. The producers decision process at completion of each subperiod would consist of these steps:

1. Formulate expectations of price of cattle and feed for the next period.
2. With the prediction model provided by the production economist, estimate the least cost feeds and quantities needed to carry an animal through the next period.
3. Compare returns and make a decision, either to sell now or feed for another period.

Realistically the producer would consider the outcome with the cattle then on feed with the opportunity of selling out and replacing with lighter weight animals which normally give higher rates of gain.

The essence of this method of analysis is that instead of trying to predict weight gains given quantities of specific feed, we generalize and try to predict gains with such variables as net energy intake and past performance of the livestock. Then employ linear programming or other techniques to determine the least cost way of providing the required nutrients and net energy.

What this model suggests is that we forego making general recommendations to producers, such as, if the price of hay is such and such and the price of corn is so much, feed this ration etc. Instead we take into consideration shorter feeding periods, information on past performance for specific cattle and also allow consideration of any feed inputs. This means that the burden of analysis and decision making falls on the producer; where it should be. This suggests that this method is more likely to be adopted by the large scale feeder. However, this is the direction in which the livestock industry is headed.

Both of Dr. Brown's suggestions would allow greater application of experimental data to the particular situation by the producer.

Now for some suggestions.

In regard to fertilizer studies, how can weather variables also be included in our yield estimation equations ? In most cases with non-irrigated crops, available soil moisture would be the most important weather variable. A soil moisture test can be made as easily as a soil nutrient test. Hence, soil moisture at time of fertilizer application is another variable which can be added to our estimation equation in the same manner that Dr. Brown has included soil nutrients. What is more important, some fertilizer applications are made at times when the crop is well advanced, such as side dressing corn with nitrogen.

In many cases a soil moisture variable will probably not be statistically significant, regardless, it may be significant in some cases and where such data is available the additional cost of computation may be well rewarded.

Dr. Brown has suggested in his paper that the average production response is the "best" single estimate for maximization of profits over time. This may be true for an individual with a long planning horizon but may not be true for a producer with limited planning period.

Walker and Mcarthy at Iowa have demonstrated methods which utilize game theory in decision making when the distribution response surfaces and they're probabilities of accurance are known.

In some of my work at Iowa I applied decision theory to machinery and farm size problems. Results indicated that the average number of days available for field operations was a poor estimate of average net returns over time. When timeliness of operations is considered there is not a linear relationship between time available for crop operations and net farm returns. Application of decision theory indicated quite different optimal strategies for slightly different expectation patterns.

I conclude by stating that this paper, in my opinion, deserves close examination by individuals doing research in the area of production functions. Depending upon your situation the variables to be included will differ and the methods will differ. The essential point of this paper is that methods must be developed which make experimental data more useful. We are not suggesting that the production function or surface is an invalid theory. Rather we are admitting that this type of analysis is hard to deal with when many variables must be considered and are going ahead with other methods more amenable to realistic decision making. Our theory stays the same; only the techniques are different.