AN ECONOMIC EVALUATION OF THREE SOIL NITROGEN TESTS

Thesis for the Degree of M. S.

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Gordon R. Anderson

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AN ECONOMIC EVALUATION OF THREE SOIL NITROGEN TESTS

by

Gordon R. Anderson

An Abstract

Submitted to the College of Agriculture of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

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1958

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ABSTRACT

This study evaluates three soil nitrogen tests from the standpoint of usefulness to farm managers.

The evaluation is based on data taken from the Campbell wheat plots which are a part of a joint agro-economic research venture sponsored by the Agricultural Economics Department and the Soils Department of Michigan State University. The data included 1956 wheat yields from 130 plots of 1/62 acre size in a homogeneous field, N application rates for 1955 and 1956, and soil samples from each plot tested by three different methods; i.e., Iowa N test, Truog N test, and the Organic Matter test.

In order to establish the usefulness of N tests, it was necessary to explicate some relevant concepts of management. A problem occurs whenever there is a conflict between beliefs, between values, or between a belief and a value. A belief is defined as a concept of reality (what is), and a value is defined as a notion of the ideal (what ought to be).

A farmer's main problem is that of securing satisfaction. A sub-problem is that of growing a particular crop for maximum profit. Within this sub-problem lie questions concerning the nitrogen level of the soil (belief-belief problem) and the nature of the production function from which optimum profit points can be determined (belief-value problem).

An examination of nitrogen fertilization information from technological researchers disclosed the fact that some doubt exists as to the true value of results obtained from any one of the three nitrogen soil tests; i.e., their value in resolving a belief-belief conflict. It was not clear just how these results are or may be used objectively to determine fertilizer requirements of crops; i.e., their value in resolving a belief-value conflict.

An attempt was then made to develop a chain of objective relationships between test results and the determination of optimum fertilizer application rates.

The first step was a calculation of correlations between pairs of test results to determine an answer to the question, "Do these tests tell the same story?" The correlation coefficients were quite low, so low in fact as to measure degrees of association of no practical importance.

Next, correlations were calculated between each test and previous known N applications, which ranged from zero#/acre to 240#/acre, and which were consummated within the previous 6 months. Once again the correlation coefficients were very low.

So far, it was determined that the tests did not tell the same story, and that no one was superior to any other, based on the assumption that a test should distinguish a recently applied range of N. These results would tend to complicate the belief-belief conflict rather than resolve it.

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value of each test by fitting its result into a well established form of prediction equation. A basic prediction equation of the form $Y = a + b_1N_a + b_2N_a^2$ was fitted to the yield and N application data and it was found that the coefficient of determination was .3844 and the standard error of estimate was 3.83 bu. Optimum profit points were calculated and found to be consistent with reason and experience. For example, with wheat at $2.00/bu. and anhydrous ammonia at $.10/lb., 83# of NH_3 was determined to be the optimum application rate.

It was then assumed that there is a constant marginal rate of substitution (λ) between applied nitrogen (N_a) and residual nitrogen (N_r) as determined by test. λ was estimated for the Iowa and Truog tests, but no sensible estimate of λ could be made for the O.M. test.

The Iowa and Truog tests were then introduced into the same type of prediction equation, i.e. $Y = a + b_1(N_a + \lambda N_r) + b_2(N_a + \lambda N_r)^2$, to see if an improved prediction would result. The coefficients of determination were not materially improved, and the calculated optimum application rates were such that a further check on the efficacy of the two tests was indicated.

A graphic comparison of iso-product curves and iso-product curves constructed from actual equal production points revealed no apparent similarities. Further, when curves were constructed from production points with the O.M. test results plotted against application rates, they too proved to be erratic, and showed no reasonable relationships between N_a and N_r. An inspection of the graphs showed that no linear relationship between N_a and N_r would fit the data very well. A variable rate of substitution arrived at by other computational procedures would not improve the fit without resulting in iso-product lines which cross each other in ways inconsistent with the law of diminishing returns.

At this point no other ways of incorporating a nitrogen test result into a prediction equation were apparent. Techniques assuming non-continuous functions would offer little chance of making N soil tests more useful, because solving the problem of determining the marginal rate of substitution between N_r and N_a is a necessary preliminary to fitting either continuous or discontinuous functions which include N_r and N_a as the independent variables.

In conclusion, it was found that the evaluation of the three soil N tests, with respect to their usefulness to farm managers, produced evidence to support the contention that the problem concerning the nature of the N fertility of a specific soil sample is complicated rather than resolved by present tests. The problem concerning optimum N fertilizer application rates was also not resolved by test results, as no objective method of introducing the test results into a prediction equation giving sensible results could be discovered.

Approved Glenn L. Johnson
Major Professor

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CHAPTER I

THE PROBLEM IN PERSPECTIVE

Farmers' replies to the question, "Why do you farm?" encompass a gamut of reasons from enjoyment of fresh air, through love of relative independence, to the necessity for earning a living. Pointed questioning, however, usually elicits admissions that profit is a necessary adjunct to all such pertinent belief-value sub-structures.

Publicly employed professional agriculturists engaged in technological research frequently justify such expenditures of public money on the general principle that research results will contribute either directly or indirectly, sooner or later, to the assurance of an efficiently produced and adequate national food and fiber supply.

The farmers' interest in profit, the researchers' interest in technological discoveries, and the public's interest in an adequate and efficiently produced food and fiber supply, when considered simultaneously within the framework of the "democratic process," form the component parts of an enormously complex dynamic model of social and/or individual choice and action.

Agricultural production economists have accepted the responsibility of analyzing this model and the multitudinous

sub-models within it for the purpose of educing or extracting information which can promote the interests of the apposite groups and/or individuals. A high value has come to be placed upon objectivity in such analyses.

The following chapters describe an attempt to fit objectively a fragment of technological research results into a simple economic model, such that the farmers' interest in profit, and the public's interest in an adequate and reasonably priced food supply may be directly or indirectly forwarded.[1]

The research results of this thesis concern soil, the importance of which, as a factor in farm production, is obvious. Soils and agronomy scientists have, to date, learned much about its nature. Many studies have provided us with information concerning the relationships between soil elements and plant growth. One outcome of these studies has been the development of specific tests for the quantitative determination of various soil elements important to plant nutrition. Three such tests are the Iowa, Truog, and O.M. tests for soil nitrogen.

This thesis is specifically concerned with an evaluation of these three soil nitrogen tests from the standpoint of farm management. Such an evaluation may be in the form of an exposition of a simple model of sequential relationships,

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[1]The more complex problem of measuring change in general welfare is not under consideration herein.

between the soil nitrogen test results and the farmers' profit interest.

If, for instance, a farmer wants to make a decision concerning the most profitable amount of N fertilizer to apply on a wheat field, and intends to use a soil N test result as a factor in that decision, then he should expect a relationship between the test result and the high profit application rate.

The succeeding chapters will consider in order: (1) the farmers' use of production information for profit maximization within the managerial process; (2) the soil researchers' potential contribution of production information to farm managers with particular respect to soil nitrogen, its tests and fortification; (3) an evaluation of the usefulness of the information discussed in 2. to farm managers, and (4) a summary and conclusions of the evaluation.

CHAPTER II

PRODUCTION INFORMATION AND THE MANAGERIAL PROCESS[1]

The farm operator who is engaged in the constant and continuous duty of decision making is said to be managing the farm. Decision making is the core of the managerial process and distinguishes it from all other human procedures in the conduct of the farm business. Obviously decisions, and hence management, are necessary only when problems exist.

A brief excursus into the nature of problems in relation to farm management is in order at this point. If we accept farmers' reasons for farming as being included essentially within the general concept of "satisfaction seeking," we can then say that farmers are seeking full appeasement of desires, longings, needs and requirements.[2] The manager's main problem can then be defined as any perplexing question,

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[1]The management theory concepts presented in this chapter are drawn from the following sources:

G. L. Johnson and C. B. Haver, Decision-Making Principles in Farm Management, Kentucky Bulletin 593 (Lexington: Kentucky Agricultural Experiment Station, 1953).

G. L. Johnson, Managerial Concepts for Agriculturists, Kentucky Bulletin 619 (Lexington: Kentucky Agricultural Experiment Station, 1954).

[2]Webster's Dictionary of Synonyms, (Springfield, Mass.: G. and C. Merriam Co., 1951).

situation, or the like, which demands a solution in order that satisfaction be obtained. Some farm management research workers, realizing that such definitions are too general to be useful, delved deeper into problem-decision concepts, and synthesized somewhat more specific management models.[3] These, however, are still too general, but from them we can extract the following salient points:

A belief is defined as a concept of reality (what is).

A value is defined as a notion of the ideal (what ought to be).

A problem then occurs whenever there is a conflict between beliefs, between values, or between a belief and a value. Such conflicts are ever present because change is normal, and partial ignorance is universal. Change and imperfect knowledge then explain the need for management, and learning and deciding are, therefore, fundamental tasks of management.

The five functions that a manager, operating in the presence of continuous change, and only partly informed, must perform if he is to chart successfully the course of his business over a period of time, are as follows:

a. observation

b. analysis

c. decision making

d. action taking

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[3] Johnson and Haver, _op. cit._

e. acceptance of responsibility for action taken

Five broad subject-matter areas which managers must study as a basis for adjustment, can be distinguished:

a. price structures and changes.

b. production methods and responses.

c. prospective technological developments.

d. the behavior and capacities of people associated with farm businesses including changes therein.

e. the economic, political and social situations in which a farm business operates including changes therein.

Five different knowledge situations in which managers may find themselves are tentatively conceived:

a. Perfect knowledge - knowledge is nearly enough perfect to permit action without the protection of formal or informal insurance.

b. Risk action - present knowledge is good enough for action, because the risks involved are assessable and insurable, and additional knowledge is not worth the cost of acquisition, so action is taken.

c. Learning - the value of what can be learned is worth more than the cost of learning it, so action is postponed.

d. Inaction - present knowledge concerning the problem is insufficient for positive action, and the cost of learning exceeds the value of what would be learned, so no action is taken.

e. Forced action - the existing state of knowledge is inadequate, and if time were available more knowledge could be acquired. However, some outside influence forces action, so time is not available.

The classification of degrees of knowledge was introduced as being "tentatively conceived." Recent information presented by G. L. Johnson[4] indicates that these five degrees of knowledge, while clearly relevant, are still inadequate. Originally the classification provided the basis for six questions to be used in the Interstate Managerial Survey, and designed to determine whether farmers do, in fact, encounter, and are able to comprehend and know when they encounter, these situations. A high proportion of the questioned farmers were able to understand and give verified examples of situations in which they had encountered these varying degrees of knowledge. However, close examination of the answers indicates that the classification is valuable mainly at the time of decision. Ex poste, it appears difficult for farmers to distinguish among the various negative decisions. For instance, it is difficult for a farmer to tell, after a decision, whether he decided not to act because circumstances forced him not to act or because he decided on

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[4]Glenn L. Johnson, "Methodology for Studying Decision Making," Address to The American Farm Economic Association, Junaluska, North Carolina, August 1957.

a risk action basis that he was willing to refuse to act and take the consequences of being wrong. It was also difficult to distinguish, ex poste, between negative forced actions and plain inactions. While it appears that the classification is inadequate, it is also apparent that Wald's[5] contribution prevents researchers from returning to Knight's[6] risk, uncertainty and certainty classification.

The five knowledge situations are used in the ex-ante sense in this thesis.

We are now able to see how soil nitrogen tests fit into the managerial process. The act of sending a sample of soil to a testing laboratory for the nitrogen analysis evidences on the one hand the awareness of a belief-value conflict - ("I think I ought to be getting more wheat per acre"); and on the other hand an entreaty to solve a belief-belief conflict - ("Just what is the nature of the fertility of said soil?"). The act also tells us that the farmer is performing the first task of management (observation) and is in the "learning" situation. Marginality concepts applied to the foregoing situation might appear graphically as in Fig. 1.

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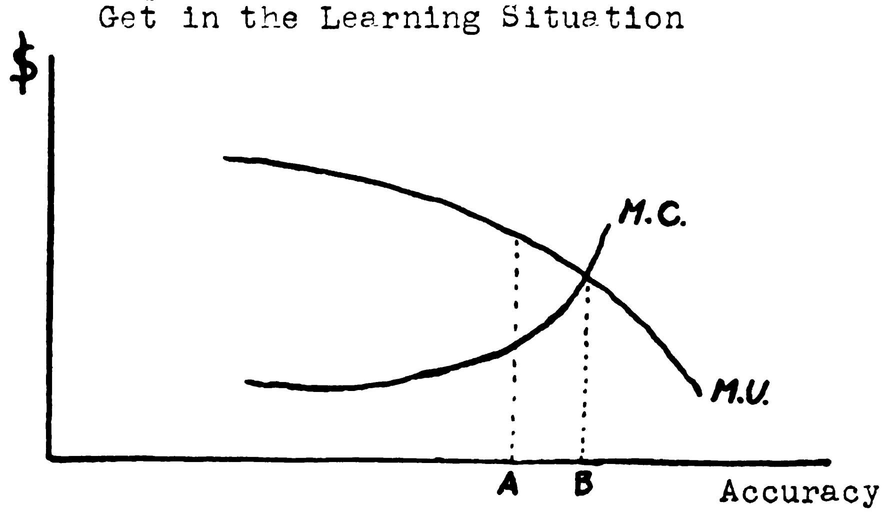
[5]Abraham Wald, Sequential Analysis, (New York: John Wiley and Sons, Inc., 1947). Sequential analysis provided the basis for dividing imperfect knowledge situations into subjective risk situations, on one hand, and into three subjective uncertainty situations, on the other hand. The distinction depends on the subjective standards of accuracy elected by the analyst.

[6]Frank Knight, Risk, Uncertainty and Profit, (New York: Houghton-Mifflin Co., 1921).

The observing farmer in the learning situation is at A, where MU >MC. He feels that the cost of more information will not exceed its value, so wants to move to the right; hence he sends in his soil sample to be tested.

If analyses of the test results make him feel that he has arrived at point B, where MU = MC, he will then act with no further consideration (the decision is made), having subjectively moved from the "learning" to a "risk" or "perfect knowledge" situation; and having satisfactorily completed the observation, analysis, and decision tasks of management.

Fig. 1. - Amount of Information to Get in the Learning Situation



The MU of soil test data is a function of the manager's ability to analyze these data. The question then arises, "Is it possible for anyone to analyze said data?" Very likely, if the professional agriculturist cannot, then the farmer does not stand a chance. The question asked in this paragraph is actually another way of presenting the purpose of the study.

Summary

The farmer's main problem is that of securing satisfaction. A sub-problem is that of growing a particular crop for maximum profit. Within this sub-problem lie questions concerning the nitrogen level of the soil, and the nature of the production function from which optimum profit points can be determined. Three nitrogen soil tests giving three different measurements of fertility would seem to complicate rather than to clarify part of the problem. The complication occurs in the sense that incompatible test data add a belief-belief conflict to the belief-value conflict which defined the problem. If both the main and sub-problem are not subject to resolution, the usefulness of soil test data would be zero, and their marginal utility could not be equated with the marginal cost. If, on the other hand, they could be resolved, the soil test data would be useful to farm managers.

CHAPTER III

NITROGEN FERTILIZATION INFORMATION FROM TECHNOLOGICAL RESEARCH

C. E. Millar[1] said in 1955, "With the recognition of the fact that plants obtain their mineral nutrients from the soil came the demand for methods to determine the quantities of available nutrients in soils. It is interesting to note that, although the search for such methods has been under way for over a century, it still continues. Much progress has been made, but a method which works satisfactorily under all conditions has not yet been devised. When, to the inquiry concerning the quantities of available nutrients present in a given soil, is added the query, 'how much of each nutrient should be added to give a large yield of a given crop,' the problem becomes more complicated. Because of the dynamic nature of the soil system and the fact that one is dealing with a living organism, the plant, which is sensitive to all environmental conditions, a method of obtaining a definite answer to the above questions may never be developed. Nevertheless, information has been obtained which is helpful in giving approximate answers to these questions."

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[1]C. E. Millar, Soil Fertility, (New York: John Wiley & Sons, Inc., 1955), Chap. 13.

Because of the apparent orderliness of natural relationships which have so far been brought to light by research, the author tends toward a more optimistic faith in the eventual resolution of all pragmatic questions concerning commercial fertilization on farms. So long as the variables in a soil system, in a plant system, and in natural environment are not definitely proven to be infinite in number or reaction, their eventual appraisal and evaluation seem theoretically possible.

In the case of nitrogen, one of three different soil tests is being used at the present time by one or more of the upper midwest land-grant college soils research departments in attempting to answer the above stated queries. The tests considered here included the O.M. test, the Truog test, and the Iowa test.

The O.M. Test[2]

In the O.M., or organic matter test, an attempt is made to measure the total carbon in the sample. The result is converted to total organic matter by the use of an arbitrary conversion factor. Then another conversion factor, the mineralization factor, is used to estimate the nitrogen

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[2] "Soil Organic Matter Determination," (Soils Testing Laboratory, Michigan State University, East Lansing), (mimeograph).

C. M. Woodruff, "Estimating the N Delivery of Soil from the OM Determination as Reflected by Sanborn Field," Soil Science Society of America Proceedings, Vol. 14 (1949), 208-212.

in the sample which, by projection to the field on an acreage basis, will be released during the growing season in a form available to a specific crop.

Difficulty in achieving consistent results is due to several causes. There are several methods of determining carbon, ranging from the dry combustion method, to the highly subjective method based on the feel of the wet soil between the fingers of the lab technician. The conversion factor is based on the average rate of disappearance of soil nitrogen in long term field experiments, or on mathematical proportionality constants calculated from soil tests and crop yields, using variations of Mitscherlich's equations for growth where one nutrient is limiting.

The Truog Test[3]

The Truog test for available nitrogen is based on the solubility of various forms of nitrogen in a permanganate solution. It measures NH_3 nitrogen, and the more labile forms of organic nitrogen.

Difficulty in achieving accurately useful results from this test lies in the facts that the less labile forms of organic nitrogen are not measured, and that microbial suppression of N availability in presence of carbonaceous residues is not taken into account.

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[3] Directions No. 697-18 for the Hellige-Truog Combination Soil Tester, Technical Information Bulletin, Hellige, Inc., 877 Stewart Avenue, Garden City, New York.

The Iowa Test[4]

During the past decade much hope for accurately determining a useful measure of the available nitrogen in soils has been pinned on incubation techniques, of which the Iowa test is representative. Soil scientists are in agreement on the fact that the rate of mineralization of soil nitrogen is more important to crop growth than the amount of mineralized nitrogen in the soil at any given moment. Therefore, the technique of measuring said rate by artificial incubation has become popular. The soil sample with its indigenous organisms is incubated artificially for a specified time, usually two weeks, and the mineral nitrogen is measured. A conversion factor is applied, and an estimate is made of the mineralization rate of nitrogen under field conditions.

The difficulties with the incubation test can best be summed up in the words of soil scientists Harmson and Van Schreven[5] who say, "It should not be forgotten that the incubated soil samples are kept under entirely artificial conditions. The results of such experiments are in no way comparable with the mineralization process under field conditions. So it must be considered worthless to try to imitate natural

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[4]George Stanford and John Hanway, "Predicting Nitrogen Fertilizer Needs of Iowa Soils: II. A Simplified Technique for Determining Relative Nitrate Production in Soils," <u>Soil Science Society of America Proceedings</u>, Vol. 19, No. 1, (January 1955), 74-77.

[5]G. W. Harmson and D. A. VanSchreven, "Mineralization of Organic Nitrogen in Soil," <u>Advances in Agronomy</u>, ed. A. G. Norman, Vol. VII.

conditions in incubation experiments, and we will have to accept mineralization experiments in the laboratory as providing us with an artificial magnitude which has great value but which must be interpreted with care. --- Reliable results can be expected only when the incubation technique is restricted to one soil type, one climatic zone, and one farming system, and when all samples are collected within one season, preferably during early spring. --- Experimental evidence showing correlation between incubation results and crop production has varied from the one percent level of reliability to wholly negative results."

<u>Use of Test Results in Accelerating the Management Process</u>

The soil researcher's incorporation of test results into fertilizer recommendations to the farmer is an example of the socialization of the analysis task of management. The analysis, as performed by the professional, is based primarily upon the results from field experiments.[6] Soil test results, and agronomic knowledge, experience and judgment, are used in applying and interpreting the experimental results.

In Michigan there are 300 recognized types of soil. The shape of the land surface and the height of the water table cause additional soil differences. Experiments have been conducted on many soils, but not on all the recognized

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[6]For example, see <u>Fertilizer Recommendations for Michigan Crops</u>, Extension Bulletin 159, (East Lansing, Michigan State College), pp. 7.

types. In addition there are areas not characteristic of any recognized type. Thus it is sometimes necessary to resort to experience and judgment in performing the analysis task. Other pertinent variables such as cultural practices, past and present rotations and soil tilth increase the difficulty of analysis because their values are often unknown.

The place of soil test results in making analyses is seen in the following quotes from Michigan Extension Bulletin 159:[7] "The use of soil testing results makes less essential a knowledge of how the soil has previously been managed. This does not hold true so much with respect to nitrogen as it does for phosphoric acid and potash." "The immediate nitrogen needs of a crop growing on a mineral soil depends more on the system of management than on the soil type or test at the time of planting." "In fact, the crops which immediately follow alfalfa or clover may obtain sufficient nitrogen from the decomposing plant residues." Michigan recommendations for N fertilizer on wheat[8] do not take into account soil nitrogen test results.

The completed analysis is presented to the farmer in the form of recommendations for specific quantities of N fertilizer to use, allowing him to move from the observation task directly to the decision task.

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[7] Ibid. p. 8.

[8] Ibid. p. 13.

Summary

It is clear that some doubt exists as to the true value of results obtained from any one of the three nitrogen soil tests. It is not clear just how these results are or may be used objectively to determine fertilizer requirements of crops. Considering the high value placed upon objectivity in modern research, analyses performed mainly by use of experience and judgment are not recognized as being highly desirable.

CHAPTER IV

AN EVALUATION OF THE TESTS

In Chapters I and II an argument is developed for the presentation to the farmer of production information in a form which both accommodates his profit interest, and facilitates his managerial tasks. Chapter III includes the background of and the form in which information is presented to him by soil research personnel.

This chapter describes an attempt to develop a chain of objective relationships between soil N test results and the determination of optimum N fertilizer application rates. The failure of the attempt provides some evidence to support the conclusion that soil nitrogen tests are of little operational value to farm managers, at least in the situation under consideration.

Experimental Data

The evaluation will be based on the results of manipulating data taken from the Campbell wheat plots which are part of a joint agro-economic research venture sponsored by the Agricultural Economics Department and the Soils Department of Michigan State University. Pertinent information concerning these plots is listed as follows:

1. Soil type is Kalamazoo silt loam.
2. Number of wheat plots of 1/62.5 acre size = 130.
3. The field on which plots are located is level, and was evenly fertile according to soil tests in 1954.
4. 1955 N application ranged from 0 to 240 lbs/acre on oats.
5. 1956 N application ranged from 0 to 240 lbs/acre on wheat.
6. A soil sample (to plow depth) was taken from each plot in the fall of 1955, and tested for N content by each of the three methods.
7. 1956 wheat yields were calculated on a per-acre basis.

Plan of Procedure

The first step will be a calculation of correlations between results of the N tests to determine the answer to the first obvious question, "Do these tests tell the same story?" In the light of managerial theory, the question could be phrased, "Do these tests collectively support an identical concept of the nature of reality, or do they introduce a conflict between beliefs?"

If the correlations are high and positive, any convenient one may be used in the search for objective relationships. If, however, the correlations are low and/or negative, it will be necessary to tarry over the problem of efficaciousness long enough to procure evidence from correlations between individual tests and previously applied nitrogen or yields. Should this evidence indicate the superiority of one test, the others can be discarded and work concentrated on the superior test; but should the evidence be inconclusive, the three must be considered further.

At this point the assumptions would have to be made that soil tests measure residual soil nitrogen (N_r); that field test production functions are based on, and farmers are interested in, applied nitrogen (N_a), and that the two substitute for each other in some definite but as yet unknown proportion, e.g. $N_t = N_a + \lambda N_r$. Therefore, the next step would be to estimate the marginal rate of substitution[1] of N_r for N_a (λ). This estimate would be necessary in order to introduce test results into well established production functions based on N_a as the independent variable.

If such introductions improve the existing yield prediction equations, and if resulting economic derivatives are compatible with reason and experience, then a farm manager would have a basis for using one or more of the soil N tests, at least within the limits of the experimental data. By similar reasoning, should none of the test introductions improve presently workable production functions based on N_a, then there would be evidence to support a similarly limited conclusion that soil N tests have little value to farm managers, at least within the limits of the situation under investigation.

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[1]For the sake of simplicity, and because of a lack of reasons for anything more complex, it will be assumed that there is a linear rate of substitution between N_a and N_r. However, by the same reasoning, there is a lack of reasons for anything less complex than a curvilinear rate of substitution. Further analysis will determine the necessity for resolving the problem.

The Findings

The simple correlation coefficients among the three tests were quite low (see Table 1). Even though the correlations are significantly different from zero (statistically), they measure a degree of association between the tests which is not of practical importance.

TABLE 1

CORRELATION BETWEEN TESTS

	r	Sr	Level of Significance
O.M. and Truog	.1350	.087	.03
O.M. and Iowa	.4296	.080	.01
Truog and Iowa	.1389	.087	.03

As these tests do not tell the same story, an attempt should be made to determine relative superiorities. This can be done by correlating each one with previous N applications. This appears to be a rational move in that 1955 N applications ranged from zero to 240 lbs/acre, and were consummated within the previous 6 months. 1955 oat yields did not vary enough to even out the N_a range. Oat yields varied 20 bushels between plots. To even out the range, 12 lbs/acre N_a would be required for each bushel increase. Sundquist's[2] analysis indicated that the N_a requirement per bushel was more nearly

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[2]W. Burt Sundquist, "An Economic Analysis of Some Controlled Fertilizer Input-Output Experiments in Michigan" (unpublished Ph.D. thesis, Michigan State University, 1957).

one pound. There appears to be no other documentary evidence available to refute that estimate. If it is argued that leaching would level out such an application rate differential in such a short period of time, it can also be argued that annual N soil tests for practical purposes are futile.[3] Soil samples are taken as sections of the soil profile to plow depth. Most of the nitrogen used by the plant is gathered from this stratum. If leaching moves so much nitrogen to a deeper level that soil sample tests cannot distinguish a 240 lb. range of N applications made within the previous six months, then the farm decision maker must be justified in deciding to eliminate the costs of sampling and testing when the results would contribute nothing which was not already known.

Results of said correlations produce r values which are very low, and significance levels which are very low for two of the three correlations (see Table 2 on following page). The Iowa test, although statistically significantly correlated with previous N_a, has a low correlation value.

In attempting to determine the predictive value of the three N tests, one may first set up a production function of the type $Y = f(N_a)$, and then attempt to improve the prediction of Y by incorporating N_r in the function as

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[3]Note: A. R. Wolcott of the Michigan State University Soils Department, points out that since there were no significant effects of previous fertilizer treatment on the soil test results, sufficient time has not elapsed in this experiment for the experimental fertilizer treatments to impose an adequate range of variability in the soil.

TABLE 2

CORRELATIONS BETWEEN TESTS AND
PRIOR N APPLICATIONS

	r	Sr	Level of Significance
O.M. Test	.0638	.088	.25
Truog Test	.0133	.088	.25
Iowa Test	.1484	.087	.05

$Y = f(N_a, N_r)$. The N_r, of course, will be that residual N which is determined by test. The problem here is to incorporate N_r in a meaningful[4] way. As it is assumed that plant use of N is divided between N_a and N_r, some marginal rate of substitution must be estimated. The estimate (λ) will be based on the following system. First it is assumed that the underlying relationship between yield and total nitrogen (N_t) can be satisfactorily approximated by a quadratic function such as:

(1) $Y = \alpha_0 + \alpha_1 N_t + \alpha_2 N_t^2 + u$ or

(2) $Y = \alpha_0 + \alpha_1 N_a + \alpha_1 \lambda N_r + \alpha_2 N_a^2 + \alpha_2 \lambda^2 N_r^2 + 2\alpha_2 \lambda N_a N_r$

which may be written:

(3) $Y = \beta_0 + \beta_1 N_a + \beta_2 N_r + \beta_3 N_a^2 + \beta_4 N_r^2 + \beta_5 N_a N_r$

Comparing equations (3) and (2), it is seen that the coefficients in (3) are subject to the three restrictions:

$$\frac{\beta_2}{\beta_1} = \sqrt{\frac{\beta_4}{\beta_3}} = \frac{\beta_5}{2\beta_3} = \lambda$$

[4]Meaningful is to be understood as testable.

Equation (3) can then be fitted by ordinary least-squares using 18 observations of plot yields with N_a ranging from zero lbs/acre to 240 lbs/acre and with P_2O_5 constant at zero lbs/acre.[5] K_2O was not considered as Sundquist's N, P_2O_5, K_2O equations based on the same data produced coefficients for K_2O which were not significant. Actual N_a rates and yields are listed in Table 3.

TABLE 3

DATA USED FOR ESTIMATES OF LAMBDA (λ)

Yield	N_a Rate	N_r(Tests)		
		Iowa lbs/acre	Truog lbs/acre	O.M. %
32.3	0	70	125	2.12
28.5	0	61	200	1.75
25.2	0	48	100	1.23
26.3	0	43	100	1.23
28.2	0	47	75	1.23
26.8	0	48	125	1.52
22.5	0	46	75	1.23
30.5	0	58	300	1.52
28.1	0	68	225	1.61
28.6	0	51	75	1.34
31.8	0	67	225	1.52
30.4	80	49	75	1.34
32.0	0	56	75	1.42
32.2	20	46	75	.98
28.5	80	54	75	1.23
39.1	80	50	100	1.06
34.1	240	54	100	1.42
36.2	240	71	300	1.15

Obvious data limitations appear in Table 3. There are not enough observations, and too great a concentration

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[5]The coefficient for P_2O_5 was significant, so P_2O_5 was held constant at zero lbs/acre. Only 18 of the 130 observations fitted that restriction. (Sundquist, op. cit.)

of observations at the zero level of the N_a rate to expect highly significant estimates of the β coefficients to ensue. Actually, most of the β coefficients fell between the .25 and the .10 levels of significance. The lack of significance of these estimates is not encouraging with respect to answering the question, "Which of the tests has the best predictive value?" However, one is justified in continuing the analysis, because an answer, either negative or positive, to the related question, "Do any of these tests contribute objectively to managerial decisions?" is highly desirable. It is worth knowing whether further analysis provides more definite conclusions.

The alternative of designing and conducting an experiment to test these relationships would take too much time and expense, and is beyond the intent of this evaluation.

Table 4 shows the calculations of λ for each of the three tests.

TABLE 4

ESTIMATES OF λ IN $Y = f(N_a, N_r)$

Restriction	Iowa Test	Truog Test	O.M. Test
$\frac{\beta_2}{\beta_1}$	$\lambda = 4.05$	$\lambda = .52$	$\lambda = -133.27$
$\sqrt{\frac{\beta_4}{\beta_3}}$	$= 2.78$	$= .57$	$= \sqrt{-51{,}211.75}$
$\frac{\beta_5}{2\beta_3}$	$= .58$	$= -.035$	$= 227.38$
	$\bar{\lambda} = 2.47$	$\bar{\lambda} = .352$	$\bar{\lambda} =$?

At this point the O.M. test can be ruled out of further consideration for the following reasons:

1. It is not significantly correlated (.25 level of significance) with previous N applications (ranging from 0 to 240 lbs/acre).
2. N_r as determined by the O.M. test cannot be incorporated into a prediction equation when λ is estimated as above, because λ cannot be determined.

Lambda = 2.47 will be used in incorporating the Iowa test in a prediction equation. Lambda = .352 will be used in incorporating the Truog test in a prediction equation.

The basic production function will be $Y = f(N_a)$ where $N_a = N_t$ for the following reasons: (1) such functions from several upper-midwest soils research departments have proven useful over a period of years, and (2) this function based on field trials is basic to most nitrogen fertilizer recommendations. A polynomial will be used to express the function for the following reasons: (1) it should be compatible with the law of diminishing returns within the limits of the data, (2) it is fairly simple to work with, especially in computing derivatives, (3) Sundquist's[6] results on the same data with polynomials and exponentials indicate the possibility of acceptable results, and (4) data plotted on Graph I suggest its feasibility.

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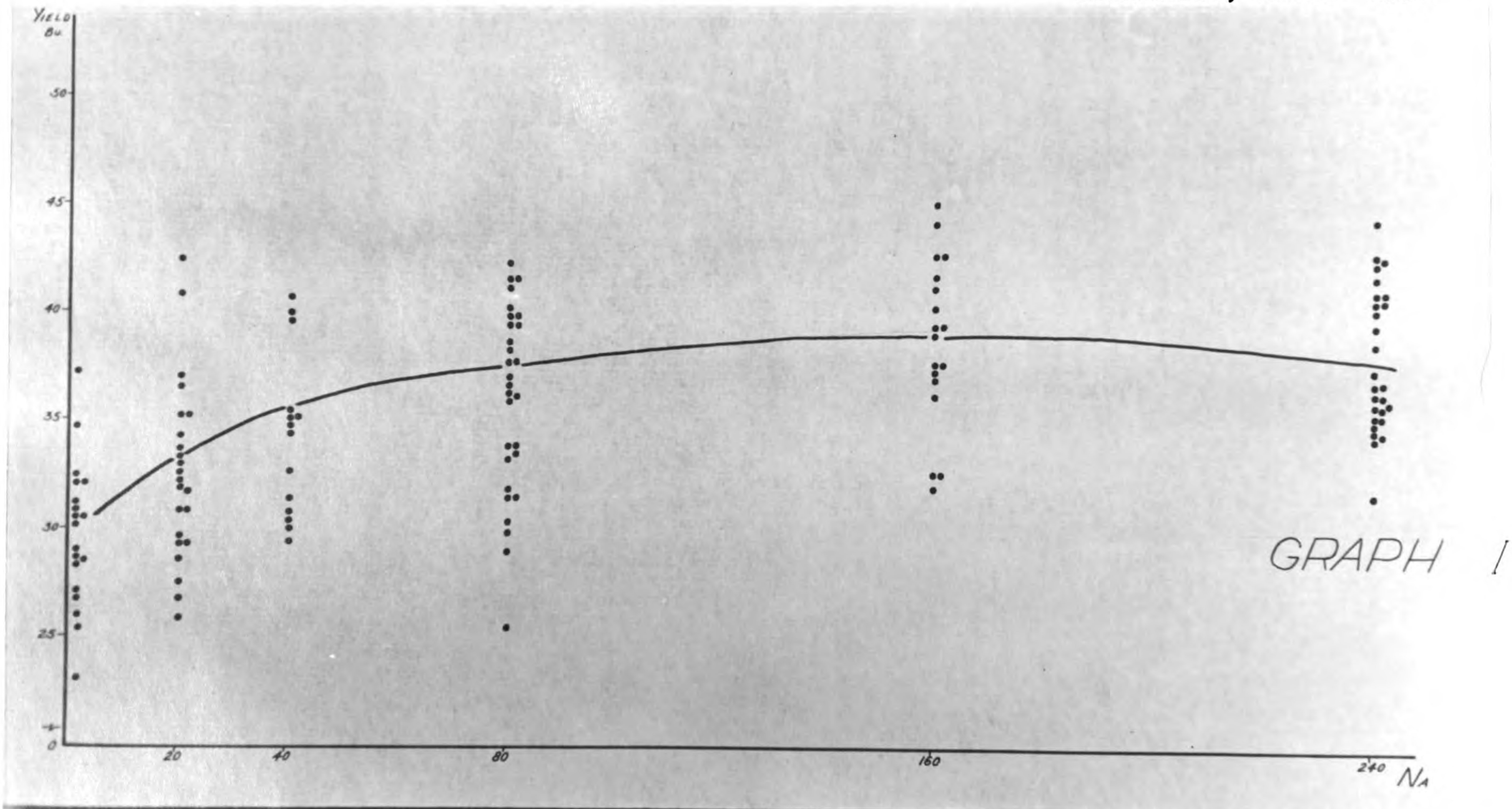
[6] Ibid.

RELATIONSHIP BETWEEN WHEAT YIELDS AND NITROGEN APPLICATION RATES.

$$Y = a + b_1 N_a + b_2 N_a^2$$

Campbell Wheat Plots
Kalamazoo, Mich. 1956



Results of fitting a polynomial of the form $Y = a + b_1 N_a + b_2 N_a^2 + u$ to the experimental data are as follows:

$$Y = 30.09 + .0999\ N_a - .0003\ N_a^2$$

$$\bar{R}^2 = ..3844$$

$$\bar{S} = 3.83$$

Sundquist obtained the following coefficients in an NPK polynomial[7] of the form $Y = a + bN_a + cN_a^2$ fitted to more data from the same experiment:

$$.0359\ N_a$$

$$-.0002\ N_a^2$$

Optimum rates of N fertilizer application were calculated from the above equation as follows:

$$Y = a + b_1 N_a + b_2 N_a^2$$

$$MPP_{n_a}(Y) = b_1 + 2b_2 N_a$$

$$\text{Optimum point} = b_1 + 2b_2 N_a = \frac{Pn}{Py}$$

Plugging in the values for b_1, b_2, the price of N, and the price of Y, results as tabulated in Table 5 are obtained.

These results are quite compatible with recommendations based on soils research and actual farm use.

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[7]First and second degree terms for individual nutrients, first degree cross-product terms, all nutrients taken two at a time.

TABLE 5

OPTIMUM APPLICATION RATES OF N FERTILIZERS
(IN LBS/ACRE) BASED ON $Y = f(N_a)$

Wheat Price	NH_3 @.10/lb.	NH_4NO_3 @.10/lb.	$(NH_4)_2SO_4$ @.13/lb.
1.90	79	70	52
2.00	83	75	58
2.10	87	79	63

When the Iowa test is incorporated into the same type of equation, the results for fitting

$$Y = a + b_1N_t + b_2N_t^2 + u$$

where $N_t = N_a + \lambda N_r$

and $\lambda = 2.47$

are $Y = 16.64 + .1331 \ N_t - .0002 \ N_t^2$

$\bar{R}^2 = .3920$

$\bar{S} = 3.81$

Optimum application rates of N fertilizer (NH_3) derived from the above equation are tabulated in Table 6.

TABLE 6

OPTIMUM APPLICATION RATES OF N FERTILIZER
BASED ON $Y = f(N_aN_r)$ INCORPORATING IOWA TEST

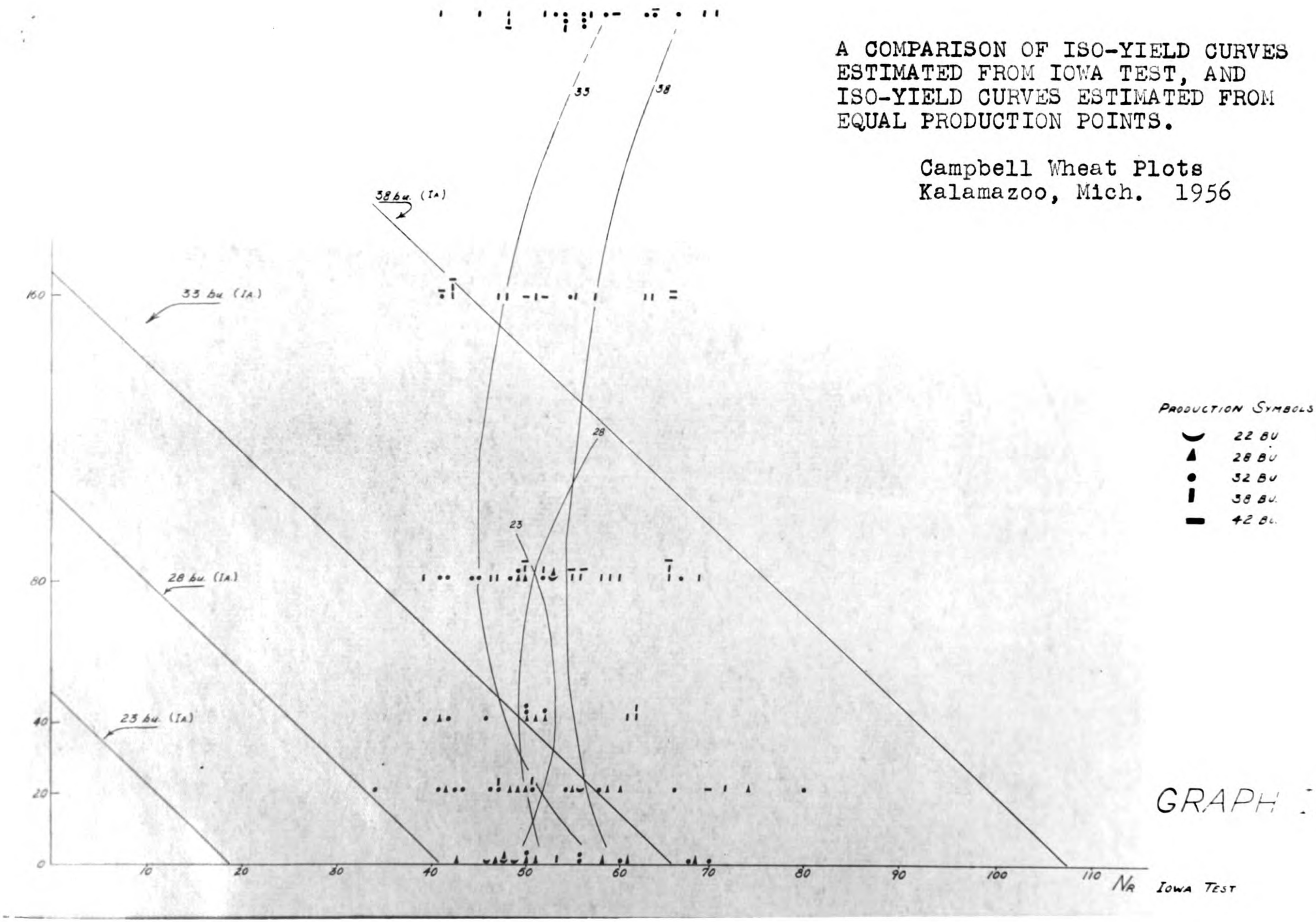
Test Result		Optimum N application Rate Wheat 2.00/bu. NH_3 .10/lb.
Low	35#	121
Medium	60#	60
High	80#	10

The incorporation of the Iowa test into the prediction equation produces a range of optimum N application rates adjusted for N_r (by test) which, at first glance, has intuitive appeal. However, when it is remembered that the correlation between the Iowa test results and previous N applications is very low, and the coefficient of determination and the standard error of estimate of the original equation are not materially improved by incorporation of the test, a further check on the efficacy of the prediction equation including the Iowa test is appropriate. The form of the function is not suspect if the assumption of substitutability of N_r for N_a is valid, but the measure of that substitutability based on soil N test results is suspect.

One check of the validity of the marginal rate of substitution of N_r for N_a can be accomplished by setting up a graph of actual yield levels plotted against expected yield levels based on iso-product curves drawn between N_r and N_a (see Graph II). An examination of this graph reveals that there are no apparent similarities between estimated iso-product curves and iso-product points. The range of optimum application rates of N fertilizer, based on the test result differential, predicts an optimum yield of 35.6 bushels. The 35.6 bu. iso-yield curve does not correspond in any way to a similar iso-yield curve constructed from actual production points. Further, it would appear that almost any other estimate of λ would be no "better" or "worse" than the one used.

A COMPARISON OF ISO-YIELD CURVES ESTIMATED FROM IOWA TEST, AND ISO-YIELD CURVES ESTIMATED FROM EQUAL PRODUCTION POINTS.

Campbell Wheat Plots
Kalamazoo, Mich. 1956



GRAPH

Conclusions regarding Iowa test:

1. It is significantly (statistically) correlated with previous N applications, but the correlation is so low ($r = .14$) as to be of little practical importance.
2. When incorporated into a prediction equation, the $\bar{R}^2$ and $\bar{S}$ are not significantly improved over those obtained in the basic equation where $Y = f(N_a)$.

Although optimum application rates of N fertilizer calculated from the original prediction equation are consistent with reason and experience, when N_r is incorporated into the equation, the optimum application rates fall on an iso-yield curve which in no way corresponds to curves constructed from the original data.

Truog Test

When the Truog test is incorporated into the equation, the results for fitting

$$Y = a + b_1N_t + b_2N_t^2$$

where $N_t = N_a + \lambda N_r$

and $\lambda = .352$

are

$$Y = 27.25 \pm .0999\ N_t \ -.0002\ N_t^2$$

$$\bar{R}^2 = .3521$$

$$\bar{S} = 4.48$$

Optimum application rates of N fertilizer (NH_3) derived from the above equation are tabulated in Table 7 on the following page.

A chart of actual yield levels plotted against expected yield levels based on iso-product lines between N_a

TABLE 7

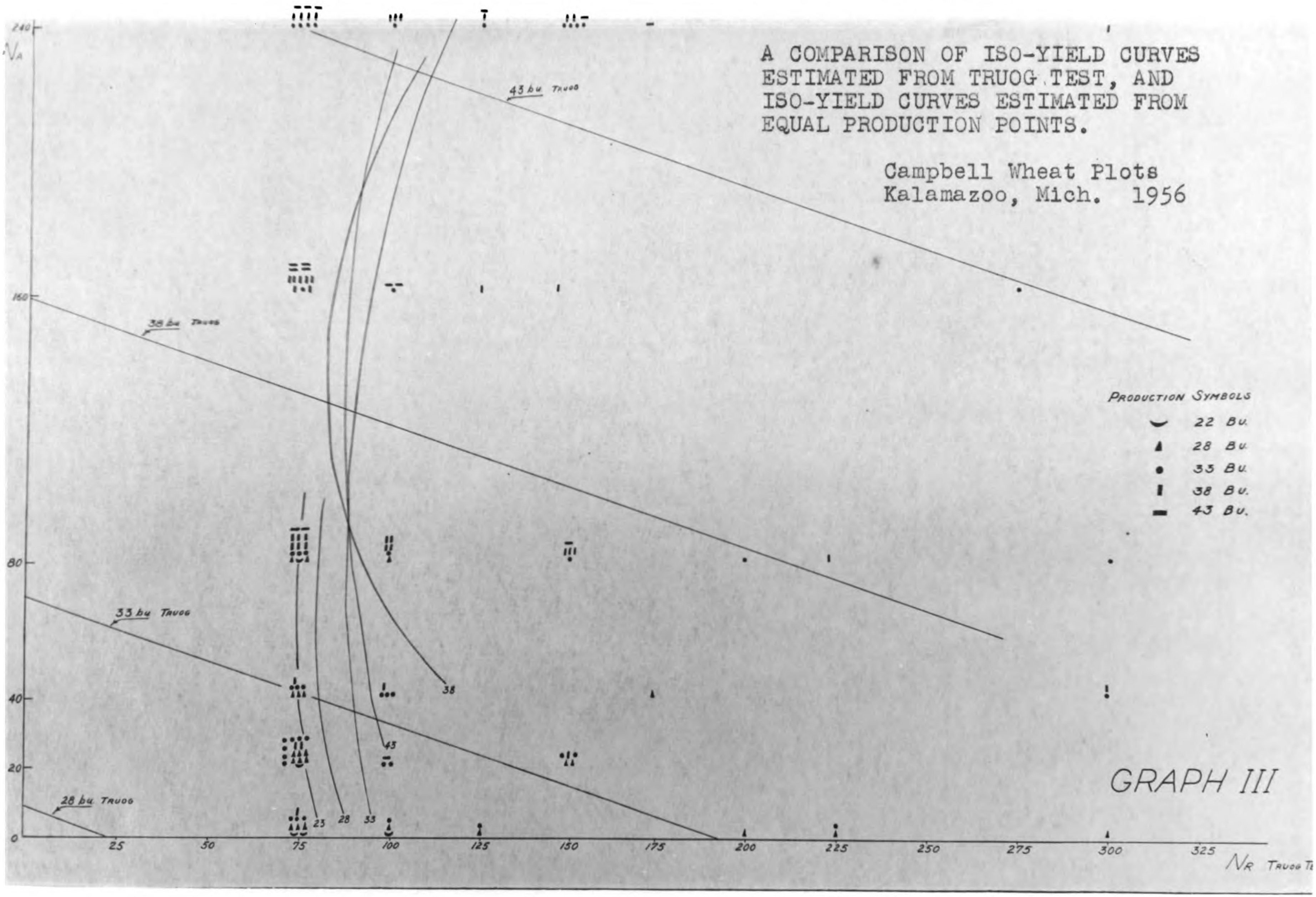
OPTIMUM APPLICATION RATES OF N FERTILIZER BASED ON $Y = f(N_a N_r)$ INCORPORATING TRUOG TEST

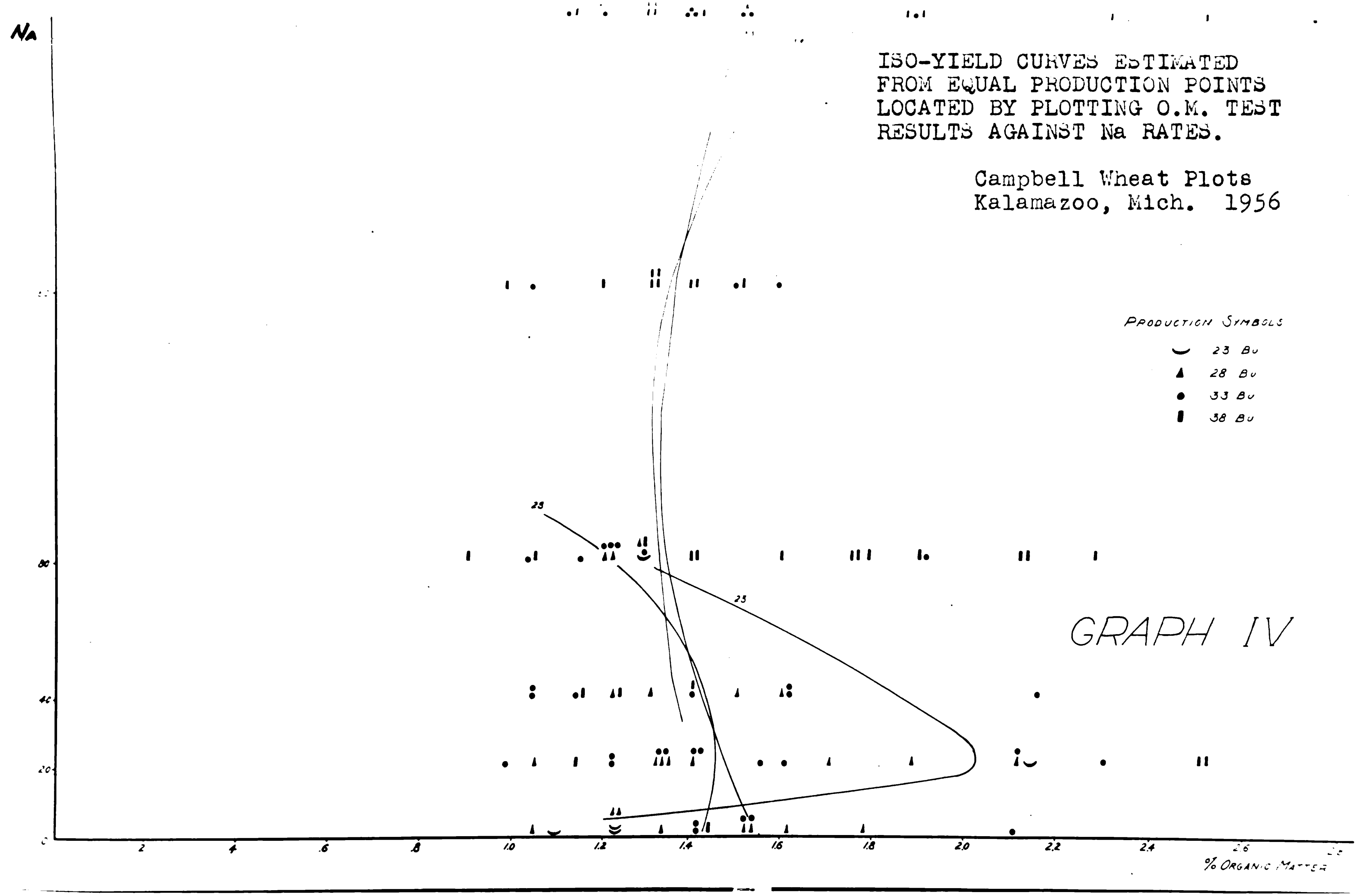
Test Result		Optimum N Application Rate Wheat 2.00/bu. NH_3 .10/lb.
Low	75#	181
Medium	150#	155
High	300#	102

and N_r (Truog) again indicates no apparent significant similarities (see Graph III). The conclusions are the same as for the Iowa test.

O.M. Test

There is no estimate for λ in the case of the O.M. test, but test results can be plotted against application rates with respect to yield levels (see Graph IV). The iso-product lines in this case are erratic, so the conclusion for this test also is that there are no apparent objective relationships between N_a and N_r.


A COMPARISON OF ISO-YIELD CURVES ESTIMATED FROM TRUOG TEST, AND ISO-YIELD CURVES ESTIMATED FROM EQUAL PRODUCTION POINTS.
Campbell Wheat Plots
Kalamazoo, Mich. 1956
PRODUCTION SYMBOLS
22 BU.
28 BU.
33 BU.
38 BU.
43 BU.
43 bu TRUOG
38 bu TRUOG
33 bu TRUOG
28 bu TRUOG
23
28
33
38
43
N_A
240
160
80
40
20
0
25
50
75
100
125
150
175
200
225
250
275
300
325
N_R TRUOG TE
GRAPH III


ISO-YIELD CURVES ESTIMATED FROM EQUAL PRODUCTION POINTS LOCATED BY PLOTTING O.M. TEST RESULTS AGAINST Na RATES.
Campbell Wheat Plots
Kalamazoo, Mich. 1956
PRODUCTION SYMBOLS
23 BU
28 BU
33 BU
38 BU
GRAPH IV
Na
80
40
20
23
23
2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
% ORGANIC MATTER

CHAPTER V

SUMMARY AND CONCLUSIONS

An attempt has been made to evaluate three soil nitrogen tests from the standpoint of farm management. As decision making is the core of the managerial process, and profit is a necessary intermediate end, the evaluation has sought to determine which of the three test results (if any) contributes objectively to decisions leading to optimum N fertilizer application rates and hence maximum profit in the situation under investigation.

Correlations between test results were very low, thereby complicating rather than simplifying decision making. However, within these results lay hope that one test might very well be "better" than the other two.

Correlations between test results and known previous N application rates were also low, thereby introducing some doubt as to the efficacy of all three tests.

A simple yield prediction equation including relationships between test results, applied N, and optimum N application rates was then developed, and the test results were individually plugged in. Optimum N application rates calculated from these equations proved suspect.

Finally, when the results of the attempts to fit the

soil nitrogen test data into yield prediction equations were plotted on diagrams, it became apparent that (1) the actual iso-product curves were not straight, if existent, (2) the actual iso-product curves did not make sense in terms of the law of diminishing returns, and (3) the actual iso-product curves were erratic.

Therefore, computations based on a value of λ estimated as we have estimated it, and on incorporation of residual nitrogen (by test) do not make conceptual sense. Graphs II and III show that no linear relationship between N_r and N_a would fit the data very well. A variable rate of substitution arrived at by other computational procedures would not improve the fit very much without resulting in iso-product lines which cross each other in ways inconsistent with the law of diminishing returns.

Incorporation of residual nitrogen (by test) in the basic prediction equation did not improve the coefficient of determination, and was not useful in making predictions.

We are now at a loss as to how to incorporate a nitrogen test into a prediction equation to make sense.

Until a successful method is found, it can be concluded that none of the three soil nitrogen tests were usable in an objective determination of nitrogen fertilizer application rates in the case of the data considered herein.

The conclusion that any techniques assuming noncontinuous functions offer little change of making N soil tests more useful is also supported to some extent in this

thesis. It is difficult to see how point estimates on a production surface could be calculated reasonably with the use of λ, when the same λ used in attempting to estimate a continuous function gave nonsensical results. A solution to the problem of determining the marginal rate of substitution between N_r and N_a is a necessary preliminary to any technique of fitting functions in which N_r and N_a are independent variables.

Finally, it should be mentioned that the negative conclusion of this thesis could conceivably hold only for the data on which it is based.

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