THE CONTROLLED-SURVEY PROCEDURE: A SUGGESTED METHOD FOR OBTAINING REPRESENTATIVE AGRONOMIC-ECONOMIC DATA

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

Bernard R. Hoffnar

1963

This is to certify that the

thesis entitled

THE CONTROLLED-SURVEY PROCEDURE:
A SUGGESTED METHOD FOR OBTAINING
REPRESENTATIVE AGRONOMIC-ECONOMIC DATA

presented by

Bernard R. Hoffnar

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Ag. Econ.

Major professor

Date February 22, 1963

O-169

ABSTRACT

THE CONTROLLED-SURVEY PROCEDURE: A SUGGESTED METHOD
FOR OBTAINING REPRESENTATIVE AGRONOMIC-ECONOMIC DATA

Experiments conducted in Michigan between 1954 and 1961 produced data characterized by high levels of unexplained variance and by a general lack of representativeness. This indicated a need for a new approach. It was believed that the controlled-survey experiments conducted in 1961 and 1962 would produce data that were both more representative of a broad universe of farms and which contained low levels of unexplained variance.

The purpose of this study was to appraise the controlled-survey procedure of locating acre size plots within randomly chosen farm fields which met certain specified soil and management conditions. Another purpose was to determine economically optimum applications of nitrogen and phosphate for wheat.

Within the controlled-survey experiments, subplots were harvested from within the acre size plots to study which size plot produced the best data.

A check plot was located on each of the farm fields in the controlled-survey. This was done so that between-farm differences could be taken into account.

A survey was conducted in 1961 and 1962 to obtain wheat yield and fertilizer use information about randomly selected farm fields that met the same general requirements as the fields used in the controlled-survey. The survey data were used as a measure of representativeness for the controlled-survey data.

A "typical" experiment, with the same treatments as the controlled-survey but using 1/100 acre plots, was conducted in 1962. This experiment was located within one farm field. The results of this experiment were

compared with those from both the survey and controlled-survey. The benefits of conducting an experiment using small plots all located within a single field were compared with the benefits of locating large acre size plots on randomly chosen fields.

Data from the 1961 and 1962 controlled-survey experiments were analyzed to obtain economically optimal amounts of N and P to apply. The survey data were also used to obtain information about the most economical amounts of N and P for farmers to use. The 1962 "typical" experiment provided no information concerning the economics of fertilizer use for farmers.

The costs and benefits of conducting the controlled-survey were estimated. Costs and benefits were also estimated for experiments located within a single field. The costs and benefits of varying the size of plot with the number of replications held constant were estimated. The costs and benefits of substituting large plots for replications were compared.

In general, this cost and benefit analysis indicated that the larger plots, while costing more, produced data with the most benefits. For the plot size and number of replication comparisons, the benefits increased up to a certain plot size as larger plots were substituted for replications, and the costs decreased as larger plots were substituted for replications.

The study provided some basis for researcher judgments about the best size of plot to include in an experiment. Further, some advantages of joint research and extension efforts appear to be associated controlled-survey experiments using large plots located on randomly chosen farm fields.

THE CONTROLLED-SURVEY PROCEDURE: A SUGGESTED METHOD FOR OBTAINING REPRESENTATIVE AGRONOMIC-ECONOMIC DATA

by

Bernard R. Hoffnar

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics

1963

ACKNOWLEDGMENTS

The author wishes to express his appreciation:

to The Tennessee Valley Authority and Michigan State University for the funds that financed this project.

to a number of Agricultural Economics graduate students, too numerous to mention, who helped plant and harvest wheat for the two year duration of the project.

to the Soil Science Department for providing materials and labor.

to Helen Rishoi who typed and helped edit the manuscript.

to Professor Hubert Brown of the Farm Crops Department who took considerable time to discuss the numerous problems that arose.

to Dr. Robert Gustafson of the Agricultural Economics Department who read and criticized the early drafts of the thesis and to Dr. Lynn Robertson, Jr. of the Soil Science Department who contributed much to the author's understanding of the nature of soils and who read and criticized an early draft of the thesis.

to Dr. Glenn L. Johnson who served as the patient, understanding major professor and who made graduate work stimulating and interesting.

TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

Table		Page

Table		Page

LIST OF DIAGRAMS

CHAPTER I

INTRODUCTION

A considerable national cooperative agronomic-economic research effort has been directed toward obtaining better information about the nature of crop yield response to various levels and combinations of fertilizer nutrients.[1] The Tennessee Valley Authority, prompted by activities of the NCFRC (North Central Fertilizer Research Committee), cooperated with various universities, notably the State University of Iowa and Michigan State University, to encourage this cooperative agronomic-economic research.

Most of the agronomic-economic studies initiated in the past ten years have stated the following as their primary objectives: (1) the determination of optimal combinations of fertilizer nutrients for varying price levels and (2) the determination of the substitutability of one nutrient for another in the production of a particular crop. Considerable evidence has been collected which demonstrates that optimal levels of nutrients do vary as prices of factors and product vary, which in turn implies that a type of substitution does take place among nutrients in the production of a crop. While the above objectives were and are important and should be considered, related, relevant problems have, in the main, been ignored or assumed nonexistent.

This thesis concentrates on two of these related problems. One of these is that of obtaining data which are representative of an important universe to which extension workers and others with practical interests

---

[1]Earl O. Heady and John L. Dillon, Agricultural Production Functions (Ames: Iowa State University Press, 1961), pp. 475-553.

wish to make inferences. Thus, this thesis will concentrate on the effectiveness of various experimental procedures in obtaining more representative data than have been obtained in the past. The second related sub-problem to be investigated in this thesis will be that of reducing within-treatment variance and/or standard errors of estimates for functions designed to predict yields. These two sub-problems of the general problem of estimating response to fertilizer nutrients are also related to the broader question of whether agronomic-economic research is a worthwhile enterprise. Considerable funds have been expended in the area of agronomic-economic research, with information forthcoming which has had value in demonstrating the law of diminishing returns[1] and has been of some practical value to extension workers and farmers. Whether this research pays its way is not clear.

With respect to the problems of representativeness and uncontrolled variance, it should be noted that agronomic-economic researchers in Michigan and elsewhere, in general, accepted experimental procedures developed earlier by agronomists. The lack of representative data and large unexplained variances which characterized data produced by such procedures may result from an over concern with disciplinary problems with too little attention to the practical problems of large, important groups of farmers and others; as a result, questions exist about the appropriateness of experimental procedures that minimize within-treatment variance by confining experimental work to unique situations not representative of practical farm situations. Some agronomists have also been concerned with this problem. For instance, in 1933 The Journal of the American Society of Agronomy reported

---

[1]The Tennessee Valley Authority has been the leader in sponsoring research in this area.

the work of a group of agronomists concerned with standards for conducting field experiments. This report states, "Field experiments should be so located with respect to soil and climate that the results may be applicable where recommendations are to be made."[1]

Fisher and Love have both pointed out the necessity of obtaining data which were representative of a broad population as well as relatively free of unexplained variance. Fisher stated, "I have assumed, as the experimenter always does assume, that it is possible to draw valid inferences from the results of experimentation; that it is possible to argue from consequences to causes, from observations to hypotheses; as a statistician would say, from a sample to the population from which the sample was drawn..."[2] The above statement implies that it would be important to obtain a representative sample (experimental site) from which to obtain a randomly distributed sub-sample (experimental plot) so that valid inferences could be drawn about the broader population of which the site is a sample. Love indicated that, "In choosing a [experimental] field, one should not be guided entirely by uniformity, since, while a fairly uniform field may be available, it may not be representative of the general type of soil on which agriculture is practiced in the region where the experiment is to be conducted."[3]

Considerable importance must be attached to the ability of a researcher to choose a site that is indeed "representative of the general type of soil

---

[1]T. A. Kiesselbach, et. al., "Standards for the Conduct of Field Experiments," The Journal of the American Society of Agronomy, 25, 1933, pp. 803-804.

[2]Ronald A. Fisher, The Design of Experiments (13th ed.; London: Oliver and Boyd, 1958), p. 3.

[3]Harry H. Love, Experimental Methods in Agricultural Research (Rio Piedras: The Agricultural Experiment Station, The University of Puerto Rico, 1943), p. 159.

on which agriculture is practiced in the region where the experiment is to be conducted." A criterion is needed which would allow the representativeness of data to be tested. This is true for both basic and practical research.[1]

If the problem that is being researched is one of determining whether or not a relationship exists between certain variables under highly controlled but not practical conditions, the experimenter probably will use the level of within-treatment variance as the main criterion in evaluating experimental techniques. He will do this, confident that the "highly controlled conditions" will prevent changes from occurring in the population which he intends to sample.

The situation is basically similar if the problem is to estimate relationships in a more practical universe. However, many practical situations involve substantial variations which are "averaged out" in commercial operations. Attempts to control sources of variation in these instances may narrow the universe of investigation to a unique situation not at all representative of the practical universe of interest. The problem in these instances is one of simultaneously reducing variance and of maintaining representativeness. When it is desired to sample a universe involving a given agronomic situation encountered by a large group of farmers, representativeness of an experiment can be checked by a random survey of the same situation for the group of farmers in the defined population.

---

[1]If analysis of variance techniques are used, more emphasis is placed on replication than on dispersing treatments within a given range of observation. If regression analysis is used, the opposite is true. The analysis of variance and regression techniques incorporate no assumption about plot size and/or about the usefulness of data. Both techniques merely provide information about the experiment as it was set up and conducted.

Glenn L. Johnson was the first of the agronomic-economic researchers to point out the possibilities of designing experiments to provide more representative data as well as less heterogeneous data.[1]

> Some researchers may point out that consolidating nine adjacent plots into one plot loses the advantages secured from scattering these nine plots randomly over the entire experimental area. This is a valid point if the causes of variance are not uniformly distributed over the field. If this situation exists, as it probably does, it suggests that both between-plot variance and the general representativeness of the experiment might be increased when increasing plot size if field size is also increased, i.e., if larger plots are sampled over a wider geographic area. Further reflection indicates that it might even be desirable to sample not a field but the entire geographic area to which the experimental results are going to be applied.

General Plan of the Thesis

Chapter II will deal with the history of agronomic-economic research in Michigan and that conducted and/or analyzed by personnel associated with Michigan State University. It will describe the general nature of the experiments, what was learned, the modifications made, the new procedures incorporated to overcome some of the problems previously encountered, and the remaining difficulties which prompted the work presented in this thesis.

Chapter III will be concerned with the conceptual problems of lowering unexplained variance and defining the population the data represent. The criterion that has typically been used to evaluate experimental techniques will be discussed. An alternative criterion is suggested. This chapter also describes the field work, experimental procedures, and related surveys which produced the data analyzed in Chapters IV and V.

---

[1]Glenn L. Johnson, "Planning Agronomic-Economic Research in View of Results to Date," Fertilizer Innovations and Resource Use (ed.), E. L. Baum, et. al. (Ames: Iowa State University Press, 1957), pp. 223-224.

Chapter IV will deal with statistical analysis of the data obtained from the experiments and surveys. Economic analysis of the various data is conducted as is an analysis of the experiments to determine their ability to produce representative data. Some practical conclusions are contained in this chapter.

Chapter V presents an estimate of costs and benefits associated with variations in plot size, shape, replication and location. These costs are related to reductions in variances and increases in representativeness. Conclusions will be reached about "economical designs of experiments" as a result of comparing costs and benefits.

Finally, Chapter VI contains the summary and conclusions (1) with respect to the criterion of representativeness of data for the various experimental methodologies and techniques included in the two year experiment and (2) with respect to practical problems farmers face when deciding to fertilize their wheat crop. The implications of the above summary and conclusions for future research in this general area are presented.

CHAPTER II

A BRIEF SUMMARY OF AGRONOMIC-ECONOMIC RESEARCH CONDUCTED BY MSU PERSONNEL FOR 1954-61

Agronomic-economic experimentation was initiated in Michigan in 1954. The program at Michigan State University has been a broad one. Specialty crops as well as general rotations have been included in the fertility experiments. Intensive row crop rotations were also included so that fertility requirements could be specified. Furthermore, research has been conducted in Canada and Colombia, S.A., under the auspices of personnel either currently or at one time associated with Michigan State University. Since 1954, a number of objectives have been explored; some were attained, while others were not. The objectives of the first six years of experimentation were as follows:[1]

1. To determine the changes in crop yields that result from changes in the amounts and combinations of the three major fertilizer elements.
2. To determine basic interrelationships existing between applications of the different fertilizer elements and crop yields.
3. To determine, at various price levels, the optimum combination of fertilizer nutrients for crops grown in several sequences.
4. To investigate the fertility and management implications of selected intensive row crop rotations.

---

[1]Quoted from the initial TVA-MSU project, Cooperative Agreement No. MICH.-863.2.

5. To test the effectiveness of the experimental designs in producing data from which economic fertilization recommendations can be based.
6. To determine the reliability of soil tests and how they can best be incorporated into recommendations for fertilizer use.
7. To study regional effects of various fertilizer treatments.
8. To investigate the reliability of fertilizer response experiments carried out under greenhouse conditions.

Experiments designed to explore the aforementioned objectives were conducted. A general farming rotation that included oats, wheat, alfalfa and corn was initiated so that the effects of various combinations and levels of the major soil nutrients on yields could be specified for such a rotation grown on a droughty, sandy soil. A cash crop rotation of navy beans, wheat and corn was conducted, using various combinations and levels of N, P and K on a heavy clay-loam soil. This rotation was designed to determine the economics of various high fertilizer levels and combinations for the cash crop rotation on this productive clay-loam soil. In addition, a greenhouse experiment that incorporated the same treatment levels and combinations as those in the cash crop rotation was conducted concurrently with that experiment. An experiment on muck was initiated with the objectives (1) to determine its potato production capabilities, (2) to evaluate various alternative experimental designs, and (3) to determine economical rates at which potatoes should be fertilized. A continuous corn experiment was initiated on a clay-loam soil (1) to determine the feasibility of such a rotation and (2) to determine the optimal fertilizer rates and combinations for the continuous corn rotation. Another fertility experiment with corn as the crop was commenced on a clay-loam soil to investigate the relationship between residual and applied fertilizer on corn over a three year period. Other experiments were designed to obtain similar information using alfalfa as the crop. The experiments mentioned above were conducted in Michigan through the joint efforts of the Soil Science and Agricultural Economics Departments.

Furthermore, researchers from MSU were associated with experiments in Ontario, Canada, and Colombia, S.A. A major objective of the research in Ontario was to encourage interdisciplinary research. Another objective was to obtain information about the relationship of fertilizer nutrients and potato yields.[1] Trant,[2] Bertolotto,[3] and Delgado[4] analyzed results produced by Trant, Kyle and Lawton in the Colombia, S.A., project. The purposes of the experimentation in Colombia were (1) to quantify the relationship between yield and plant nutrients and (2) to consider irrigation and seeding rate along with plant nutrients as independent variables in the equations used to predict yield.

The experiments conducted in Michigan and elsewhere were initiated to obtain practical information which would be useful to a large group of

---

[1]Philip A Wright, "An Economic Analysis of Potato Yields on Certain Ontario Mineral Soils in Controlled Fertilizer Experiments, 1954-1956" (Unpublished Ph.D. dissertation, Dept. of Agricultural Economics, Michigan State University, 1962), p. 51.

[2]G. I. Trant, "Implications of Calculated Economic Optima in the Cauca Valley, Colombia, South America," Journal of Farm Economics, XL (February, 1958), pp. 123-133.

[3]Hernan Bertolotto, "Economic Analysis of Fertilizer Input-Output Data from the Cauca Valley, Colombia" (Unpublished M.S. thesis, Dept. of Agricultural Economics, Michigan State University, 1959).

[4]Enrique Delgado C., "Economic Optima from an Experimental Corn-Fertilizer Production Function, Cauca Valley, Colombia, S.A., 1958" (Unpublished M.S. thesis, Dept. of Agricultural Economics, Michigan State University, 1962).

farmers.[1,2] It was assumed throughout that a single field could produce data that would represent large, practical universes. The following is a brief summary of the experimentation in Michigan.

The research conducted in Michigan was characterized mainly by $\bar{R}^2$ values less than .50. Only eight out of 31 functions fitted explained as much as 50 percent of the variation in the dependent variable, and one of these used greenhouse data. An hypothesis was put forth that high fertility levels, due either to soil fertility build-up or to high current treatments, caused a scattering effect on yields leading, therefore, to low $\bar{R}^2$ values. Experiments were modified to alleviate this problem, but $\bar{R}^2$ values of less than .50 continued to be common. N was the only variable whose coefficient consistently differed significantly from zero. Similar experiences were encountered when plot size and number of treatment levels were reduced. Even though experimental sites were reduced to about one-half acre in the search for a homogeneous experimental site, the $\bar{R}^2$ values remained, in most instances, below .50. Incorporating soil test results as independent variables did not increase the amount of variance explained. The problem of producing data that were representative of some practical universe of farms was recognized as experiments were conducted over time.

Considerable unexplained variance existed within each set of Michigan experimental data. None of the experiments produced data applicable to a

---

[1] W. B. Sundquist and L. S. Robertson, Jr., An Economic Analysis of Some Controlled Fertilizer Input-Output Experiments in Michigan, Technical Bulletin 269, East Lansing: Michigan State University, Agricultural Experiment Station, 1959.

[2] Bernard Hoffnar and Glenn L. Johnson, "Agronomic-Economic Experimentation at Michigan State University--A Summary Emphasizing the Cooperative Research With TVA," Dept. of Agricultural Economics mimeographed Report 888, Michigan State University, 1962.

broad, specified universe. In general, the data obtained were characterized by relatively high levels of unexplained variance and by lack of representativeness for practical, defined universes of farms.

The survey conducted in Gratiot County brought some interesting possibilities into focus. Here was a set of rather crude data from fields approximately 15 acres in size. High intercorrelations existed among N, P and K because the farmers used premixed commercial fertilizer in which the nutrients were fixed in some specific ratio; hence, no coefficient of an independent variable differed significantly from zero at the five percent level. However, 44 percent of the variation in the yield data was explained when a square root polynomial was fitted to the data. The standard error of estimate equaled 7.27 bushels compared to 5.41 bushels computed from the 1957 wheat crop grown in the cash crop rotation experiment. The reasons that the equation explained this amount of yield variance may be speculated upon. It may have been a happen-stance.[1] It is also true that the relatively large fields (15 acres) could have averaged out a considerable amount of the error. If the fields were considered as fifteen hundred 1/100 acre plots lying side by side, the mean of the 1,500 replications would, in all probability, have a lower standard error than would that of six 1/100 acre replications randomly located on a similar site. The second of the two speculations appears to be the more reasonable, given the existing level of knowledge relevant to such a problem.

There is little question that the survey results would be applicable, at least to farms similar to those included in the survey, there being quite a number of these. The strongest statement that can be made for the

---

[1]The R value differed significantly from zero at the one percent level.

controlled experimental results was that they were applicable to the experimental site. The level of unexplained variance was maintained at levels comparable to those in controlled experimental data; further, the data obtained from the survey were certainly applicable to a broader universe than the data from the experiments.

The totality of these experiences indicates the need

(1) to reduce the level of unexplained variance or

(2) to decrease the standard error of the coefficients and

(3) to obtain data that are representative of broad, practical, meaningful and definable universes.

The above needs may be attained by

(1) instituting tighter experimental controls

(2) utilizing better experimental designs or

(3) sampling at random a defined, meaningful universe.

The following chapter will deal with an experimental procedure which attempts to satisfy the above stated needs. Some attention will be given to the various criteria that can be used to evaluate experimental procedure.

The following notation will be used in Chapter IV. For the mathematical model

$$Y_i' = \beta_o + \beta_1 N_i + \beta_2 N_i^2 + \beta_3 P_i + \beta_4 P_i^2 + \beta_5 N_i P_i + \beta_6 K_i + \varepsilon_i$$

where Y_i' represents the i^{th} yield, the β_i's represent the universe parameters, the ε_i's are independent and are normally distributed with mean 0 and variance, σ^2. The equation $Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$ was estimated where Y is the predicted Y' and the "a" and bi's are the estimated β_i's.

CHAPTER III

THE CONTROLLED-SURVEYS, THE SURVEYS, AND A "TYPICAL" EXPERIMENT

Empirical evidence in the previous chapter indicated that past experiments in Michigan have produced data generally characterized by high levels of unexplained variance which were applicable to very limited universes. These results indicated a need to

(1) reduce the level of unexplained variance

(2) increase the significance of b values and

(3) increase the applicability of data to broad, more practically meaningful universes capable of easy description.

A group of agronomists and agricultural economists[1] met in 1960 to discuss the results of the past experiments in Michigan and to indicate the direction future research should take. Consideration was given to the results of the survey conducted in Gratiot County[2] which indicated that a practical population could be specified by including all farmers growing wheat on fields (1) on which beans had been grown the previous year, with corn grown the year before beans; (2) which had sufficient uniform tile drainage; (3) which had primarily clay-loam soils that could satisfy soil management group 2c specifications; (4) which had had no barnyard manure applied in the past three years; (5) which had a medium to low Bray P_1 soil test; and (6) which were located in a specified geographic region.

---

[1]The TVA and Michigan State University agronomists and agricultural economists who met included Wesley Smith, Orvis Engelstad, Clifford Hildreth, Lynn Robertson, Fred Davis, Glenn Johnson and Bernard Hoffnar.

[2]See Chapter II, p. 11.

It was known that a number of farmers in the Thumb area of Michigan had fields which would meet these specifications and could thus be part of a broad, practical population of farms. A decision was made to sample this universe of farms randomly to obtain data that would be applicable to it.

How the plot work should be handled for a particular farm was not apparent at first. A number of possible approaches were considered. The first alternative consisted of having each farmer selected plant his own wheat with his own drill but apply previously specified amounts and combinations of fertilizer. Someone from the research staff would have had to have been on hand to help with the setting of the drill. This alternative was rejected because considerable differences in the depth of planting and in the placement of fertilizer would have occurred, and these differences, in time, would have produced heterogeneous data. Another alternative considered consisted of having two plots with different fertility treatments located on each selected farm but planted by researchers. This procedure was rejected because if large between farm differences did occur, the data obtained would be meaningless. In an attempt to handle this problem, it was suggested that one of the two plots located on each farm be a check plot so that if between farm differences did occur, it could be taken into account. This was rejected because the design would be inefficient since half of the plots would be check plots. After further discussion, a compromise alternative was accepted. Each farm in the controlled-survey experiment would contain three treatment plots and one check plot.[1]

---

[1]The check plots received zero levels of the nutrients that were under study.

The question of plot size stimulated considerable comment. One suggestion was that whole wheat fields be used as the experimental plots. This was rejected as being too costly, if University personnel were to plant the wheat. An acre size plot was finally decided upon as being large enough to average out effects on yields that would occur due to soil heterogeneity and other factors[1] but small enough to keep costs within reason.

A survey initiated concurrently with the controlled-survey experiment attempted to sample the same population of farms as the controlled-survey, in order to obtain data that could be used as a measure of the representativeness of controlled-survey data.

A Description of the Experiments and the Surveys Conducted in the 1960-61 Crop Year

The controlled-survey experiment and a survey were conducted in the 1960-61 wheat crop year (hereafter referred to as the 1961 crop year). The controlled-survey was modified and continued the next crop year, 1962. The survey was also continued. An experiment conducted in a manner comparable to those referred to in Chapter II was added in 1962. This section will present a detailed description of these experiments and surveys.

The Controlled-Survey, 1961

A general soil map of Michigan was used to select three areas, each approximately 20 x 20 miles wide and containing the clay-loam soil grouped in soil management group 2c. This particular area size was chosen to allow machinery for planting and harvesting to be readily accessible to the farm

---

[1]These factors include (1) plot damage due to weather, pheasants, sparrows, etc., and (2) yield differences that occur due to not employing careful experimental techniques.

plots within each area. Six sections from within each of the three areas were randomly chosen. The farmer nearest the northwest corner of each section was contacted to determine whether or not his farm would be included in the population specifications. If this farmer had land that could meet the requirements, he was in the sample; if not, the next farmer, moving in a clockwise direction around the section, was interviewed. If a section did not contain anyone meeting the specifications, another section was randomly chosen to replace it. Each selected field was checked by a soils specialist to insure that the specified soil group predominated. Soil samples were taken from each field and analyzed. Residual phosphate, as measured by the Bray P_1 method, was held at medium to low levels.

A four acre area was selected from each of the 18 randomly chosen fields, and four 1 acre plots were located within the area. Each field contained one plot that received zero levels of nitrogen and phosphate; the other three plots received treatments chosen from the composite design in Table 1. This design was chosen because it contained but nine treatments and was deemed optimal for a second degree polynomial equation fitted by the method of least squares to most closely represent the true function.[1] Each plot, including the check plot, received 40 pounds of K per acre. The treatments for a particular field were chosen in such a manner as to maximize the differences among the three.

Each of the three areas chosen included six farms and each farm had three treatment plots; there were thus 18 treatment plots within each area. This allowed the design to be replicated twice within each of the three areas. The total experiment was thus replicated six times.

---

[1] G. E. P. Box and Norman R. Draper, "A Basis for the Selection of a Response Surface Design," Journal of the American Statistical Association, Vol. 54, No. 287 (September, 1959), pp. 622-654.

Table 1. The treatment levels and combinations used in the controlled-survey experiment.[1]

Pounds of N per acre	Pounds of P per acre: 0	20	40	60	80
0			x		
15		x		x	
30	x		x		x
45		x		x	
60			x		

[1]Each x represents a level and combination of N and P.

The fertilizer applied to each plot was mixed in the field. The drill was calibrated, the fertilizer weighed prior to sowing, and the plots seeded with the fertilizer planted in contact with the seed. The fertilizer that remained in the drill after seeding was weighed; thus, the amount of fertilizer that was applied to each plot was measured and not estimated. Since the size of the plot was known, an accurate estimate of the amount of fertilizer applied per acre was obtained. The above procedure was repeated for every plot planted.

The plots were observed and notes made at various times during the fall and spring. Some trouble was encountered when one of the drills used in an area continually plugged up. This was overcome by measuring the skips in the spring and making appropriate adjustments in the data.

At first, the harvesting procedure consisted of locating a farmer within each area who owned a self-propelled combine and who had few harvest obligations, but the weather at the time of harvest was very wet, delaying the harvest as much as three weeks. The farmers who were supposed to combine the plots in two of the three areas could do little of this combining. In one area, each farmer participating in the controlled-survey project cut the plots on his farm. In another area, one of the farmers who had plots on his farm was able to combine three plot areas, including his own, while the other three plot areas were combined by the farmers on whose farms the plots were located. In the last area, the weather was such that the custom operator was able to combine all six plot areas.[1]

In an attempt to obtain information about the variability of yields from various sized plots receiving the same treatment, each acre plot was sub-sampled by harvesting three different sized plots in addition to harvesting the remainder of the whole plot. Two adjacent 1/100 acre plots were harvested from the end of each plot. A 1/5 acre area was also harvested from the end of each whole plot. The two 1/100 acre and the 1/5 acre plots were weighed in the field. The whole plot was augered from the combine into a truck or wagon which had been weighed empty. The truck or wagon was weighed at the nearest scale. Many times the next whole plot yield was augered into the same truck, which was weighed again. Smaller plots were harvested from each whole plot, two 1/100 acre areas, and a 1/5 acre area. The harvesting procedure followed[2] required the measuring of two areas, each 43.5 feet long, from one end of the field and another area measuring 871.2 feet long.[3]

One plot on one farm was harvested in 1/100 acre areas. A combine that had an eight foot cutting head was used to harvest this plot; thus,

---

[1]Even with the wet harvesting conditions, no significant differences were found to exist in moisture found in wheat samples taken from the plots located on different farms.

[2]Assuming that a combine with a ten foot wide header was used.

[3]The 871.2 feet included the two areas that were 43 1/2 feet long.

each 1/100 acre plot was 54.5 feet long. There were six of these 1/100 acre plots side by side and 13 of them end to end within the whole plot area.

The Survey, 1961

This survey was conducted concurrently with the controlled-survey experiment. The inclusion of a farm in the survey depended upon its meeting the specifications placed on the controlled-survey farms. The farms included in the survey were randomly selected from within each 20 x 20 mile area previously specified. Six sections were randomly chosen from within each area. The northwest corner was the starting point, with the first six farms in an east, west, north or south direction interviewed. The direction in which the interviewer proceeded from the section corner was determined in a random manner. While the restrictions which each of these farms had to meet were similar to those included in the experiment, the restrictions were not as carefully checked. Although each field was not checked, the farmer was asked to describe the soil in his field, using terms such as sandy, loamy, clay or combinations of these terms. If the farmer described his field as containing predominantly a clay-loam soil, he was then included in the sample.[1] This field, of course, had to meet the rotational, drainage and livestock specifications imposed on the controlled-survey farms. No soil tests were taken from fields owned by farmers included in the survey.[1] A total of 116 observations were obtained in 1961.

Data about the rate and combination of fertilizer nutrients applied at planting time were obtained in the winter of 1960-61. Most of the

---

[1]See p. 43 for possible consequences of failure to maintain uniformity in these respects.

farmers top-dressed their wheat while they were seeding it with a legume. Information about the level and combination of nutrients applied at that time was obtained.[1] Yield estimates were obtained shortly after harvest. Since most farmers in this area sold their wheat shortly after harvest, the yield estimates were probably quite accurate, especially if one considers the precise measurements that are made so that wheat acreage does not exceed that allotted.

The Controlled-Survey, 1962

The controlled-survey experiment was conducted in 1961-62 in the same basic manner as that conducted the previous year. A few modifications were necessary to reduce the amount of time needed to complete the project, since the decision to continue the project was not made until late August. Fewer farms were included in the project; three of the six farmers who cooperated in 1961 in each area were selected at random. Each farm had three additional treatment plots located within its plot area. Each of the nine farms in the project thus had seven plots, with a total of 63 plots located on all the farms. Planting and harvesting procedures remained the same except 1/10 acre area samples were harvested instead of 1/5 acre areas. This change was made because various researchers indicated that ten percent of an area was of sufficient size to adequately estimate the yield from the whole plot.

---

[1] Farmers whose fields were low in soil nutrients in all probability applied more fertilizer than those whose fields had high levels of nutrients in the soil. The yields obtained might have been the same with considerable differences in the amounts of fertilizer applied to each field.

No harvest problems similar to those of the previous year were encountered. There was, however, considerable winterkill[1] of wheat within the general area of the plots. Some of the plots suffered considerable damage. If a plot included an area of winterkill that was large enough for a drill to be used to seed the area to oats, the seeded area was measured and deleted from the harvestable area of the wheat plot. Smaller areas of winterkill were not measured but were considered to be part of the plot area and were thus included as part of the harvestable area. Weather conditions at harvest time were ideal. One combine was used in each area for harvesting. Other procedures were conducted similarly to those of the previous year.

The Survey, 1962

The 1962 survey was conducted in a manner similar to that of the previous year except that each farmer was asked to estimate the percent winterkill that had occurred to his wheat. A group of farmers who cooperated in the 1961 survey also cooperated in 1962. A number of farmers were excluded in 1962 because they planted wheat on fields that did not meet the rotational, drainage and livestock specifications. A total of 70 observations on wheat fields were obtained.

The "Typical" Experiment, 1962[2]

A small plot experiment (the harvested area equaled 1/100 acre) was initiated within a field which met specifications identical to those

---

[1]Smothering of the wheat by sheets of ice.

[2]This experiment was conducted in a manner similar to that of the experiments summarized in Chapter II. A portion of one field containing 1/100 acre plots was utilized.

imposed on the fields included in the controlled-survey experiment. The farm was not selected at random. The farmer had previously had fertility research conducted on his farm but not on the field selected for this experiment. Qualified plot technicians laid out the plot area, seeded the plots, and applied the fertilizer treatments. The fertilizer was applied at planting time in contact with the seed, using a Van Brunt drill. Records were kept so that an estimate could be made of the amount of fertilizer that was actually applied to the plots. The plot area had a reduction in yield due to winterkill damage. This damage was uniform over the plot area; thus, no adjustments were made in any of the individual plot yields. The design of this experiment was similar to that of the controlled-survey (see Table 1), except that there were only six replications of the check plot, whereas there were nine in the 1962 controlled-survey experiment. The results of this "typical" experiment will be analyzed and compared with the results of the controlled-survey experiment and the survey. The levels of unexplained variance and representativeness of the controlled-survey and "typical" experiments will be compared.

The following chapter presents the analysis of the experiments and surveys described above. First, each will be analyzed individually; then a comparative analysis will be made of the experiments and surveys.

CHAPTER IV

THE AGRONOMIC-ECONOMIC ANALYSIS OF THE INPUT-OUTPUT DATA

This chapter will present an examination of the experiments and surveys conducted in 1961 and 1962. The 1961 controlled-survey experiment[1] analysis includes

(1) a production function analysis of actual yields and applied N and P

(2) a production function analysis of check plot yield differences and applied N and P

(3) an analysis comparing actual and theoretical applied amounts of N, P and K

(4) an analysis of yields from subplots within the whole plots, and

(5) an economic analysis with some practical conclusions.

The 1961 survey data were analyzed and comparisons made between the survey and controlled-survey results. The 1962 controlled-survey experiment analysis includes

(1) a production function analysis of actual yields and applied N and P

(2) a production function analysis of check plot yield differences and applied N and P

(3) an analysis of yields from subplots within the whole plots, and

---

[1]The following chapter will contain the analysis of the one-acre plot which was harvested in 1/100 acre areas.

(4) an economic analysis with some practical conclusions.

The "typical" experiment, as described on pages 21 and 22, and the survey were analyzed individually.

An analysis comparing the "typical" experiment, the controlled-survey experiment, and the survey follows the above, with separate comparisons for

(1) the "typical" experiment and the controlled-survey experiment

(2) the survey and the controlled-survey experiment

(3) the controlled-survey experiment, the "typical" experiment and the survey.

Finally, a summary is presented that emphasizes the practical results of the experiences obtained in 1961 and 1962.

1961 Experiments and Survey

The analysis of the 1961 controlled-survey data will include as dependent variables yields from the following plot areas: the whole plot, the 1/5 acre sample, each of the two adjacent 1/100 acre samples, and the 1/50 acre sample made up of the sum of the two 1/100 acre samples. The data are presented in Appendix I. The 1961 controlled-survey is fully described on pages 15 to 19. In addition, one whole plot from the controlled-survey was harvested in 1/100 acre segments; these data will be analyzed in the following chapter (see Appendix II for these data).

Each farm in the controlled-survey had one check plot which received zero amounts of nitrogen and phosphate and 40 pounds of potash. This procedure was followed so that between-farm differences could be accounted for by subtracting the check plot yield from that of the other plots on the farm. This procedure allows a rough estimate of between-farm differences to be made using the 18 similar check plot observations, one on each farm.[1]

---

[1]No relationship was found to exist between the check plot yields and the varying levels of K applied.

Potash was included as a variable in the analysis of these data because, in practice, it was impossible to hold its application completely constant for each plot. Potash was included only as a linear term in the equations, as the applications of potash were generally within ten pounds of the 40 pound application that was supposed to be applied.

A survey was also conducted in 1961. See pages 19 to 20 for a description of the procedures used to obtain the survey data. The analysis of the survey data included attempts to estimate the functional relationship between yields and fertilizer applications. In addition, the survey was used to examine the representativeness of the controlled-survey data.

The 1961 Controlled-Survey Experiment

The examination of the 1961 controlled-survey experiment will include an analysis of actual yields, an analysis of check plot yield differences, a comparative analysis of actual and intended applications of N, P and K, an analysis of yields from the subplots harvested from the acre plots, and an economic analysis with some practical conclusions.

Analysis of actual yields.--Examination of all the data without adjustments for between-farm differences indicated that considerable amounts of between-farm variance existed within the data and that this was fairly independent of plot sample size. The analysis used yields as the dependent variable from each of the following:

(1) the whole plot

(2) the 1/5 acre sample

(3) the first 1/100 acre sample

(4) the second 1/100 acre sample, and

(5) the 1/50 acre sample.

The independent variables included N, N^2, P, P^2, NP and K. Some of the signs of the coefficients of these independent variables for each equation were inconsistent with the law of diminishing returns (see Table 2). The coefficient of the K variable differed significantly from zero at the five percent level in each equation. The coefficients of multiple determination ($\bar{R}^2$) tended to decrease as the size of the subplot diminished. The inverse occurred for the standard errors of estimate (S). Table 2 presents the estimates on which the above statements are based.

When the 18 check plot observations were excluded, the estimates were similar to those just discussed. The $\bar{R}^2$'s decreased as sample area decreased except for the analysis based on the 1/50 acre data. S values tended to increase as sample area decreased. Only one potash variable in one equation differed significantly from zero at the five percent level. Table 3 contains a summary of the estimates based on data, excluding the check plot observations.

<u>Analysis of check plot yield differences</u>.--Inspection of the check plot data revealed that considerable between-farm variation existed within these data. Thus, the check plot yield on each farm was subtracted from the yields obtained from other plots located on that farm. This procedure was followed for yields obtained from the various sizes of subplots harvested as well as for the whole plot. The check plot yields were also determined for the corresponding subplots.

These yield differences, including the check plot yield differences equal to zero, were then considered as dependent variables in equations that included N, N^2, P, P^2, NP and K as independent variables. The resulting coefficients were generally consistent with the law of diminishing returns. No coefficient for the K variable in any equation differed significantly from zero at the ten percent level. The N coefficient did, however, differ significantly from zero at the ten percent level in four

Table 2. Equations based on actual yields, 1961 controlled-survey experiment, including check plots.[1] (n = 72)

Yield	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$							$\bar{R}^2$	S
	a	b_1	b_2	b_3	b_4	b_5	b_6		
Y_1 from whole plot	+59.77787 4.56552	+.10019 .12789	+.00066 .00249	+.01896 .07944	+.00048 .00128	+.00112 .00247	-.17811 .08148	.407	6.66
Y_2 from 1/5 acre sample	+58.85810 4.36169	+.08703 1.2218	+.00154 .00238	+.01521 .07589	+.00054 .00122	+.00039 .00236	-.16727 .07784	.412	6.37
Y_3 from 1/100 acre sample 2nd	+62.73052 5.84427	-.10041 .16371	+.00722 .00319	-.02080 .10169	+.00267 .00164	-.00454 .00317	-.25662 .10430	.268	8.53
Y_4 from 1/100 acre sample 1st	+61.20958 7.11856	-.09934 .19941	+.00674 .00389	-.00009 .12386	+.00331 .00200	-.00487 .00386	-.26800 .12704	.226	10.39
Y_5 from 1/50 acre sample	+61.10656 6.08087	-.062215 .17034	+.00585 .00332	+.00386 .10581	+.00250 .00171	-.00397 .00329	-.23963 .10852	.251	8.88

[1] The number under each b value is its standard error.

Table 3. **Equations based on actual yields, 1961 controlled-survey, excluding check plots.**[1] (n = 54)

Yield	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$							$\bar{R}^2$	S
	a	b_1	b_2	b_3	b_4	b_5	b_6		
Y_1 from whole plot	+73.18925 9.73332	-.15743 .20366	+.00261 .00285	-.12647 .12007	+.00099 .00145	+.00358 .00299	-.32224 .15125	.246	6.87
Y_2 from 1/5 acre sample	+64.99327 9.39568	-.01548 .19659	+.00243 .00275	-.04657 .11591	+.00087 .00140	+.00128 .00289	-.24732 .14601	.261	6.63
Y_3 from 1/100 acre sample 2nd	+64.47756 12.51779	-.11755 .26192	+.00748 .00367	-.03466 .15442	+.00284 .00186	-.00448 .00385	-.29051 .19452	.143	8.83
Y_4 for 1/100 acre sample 1st	+63.28857 14.81242	-.11340 .30993	+.00705 .00434	-.02142 .18273	+.00354 .00220	-.00489 .00455	-.31416 .23018	.118	10.45
Y_5 for 1/50 acre sample	+62.42110 12.84625	-.10471 .26879	+.00604 .00376	-.01573 .15847	+.00244 .00191	-.00346 .00395	-.23789 .19963	.094	9.06

[1] The number under each b value is its standard error.

of the five equations. Table 4 provides a summary of this analysis. It should be noted that $\bar{R}^2$ values increased and S values decreased as the subplots grew larger.

Variances of the marginal physical products (MPP) were calculated using the procedure developed by Doll[1] and Wright.[2] No derivative was found to be significantly different from zero at the ten percent level. However, it is not meaningful to test whether the MPP of a low cost factor producing a high value crop differs significantly from zero, since the MPP may approach zero at the high profit point. Hence, another procedure to test the reliability of the MPP estimates was developed which did not use the null hypothesis.[3] The procedure developed involved placing confidence limits on the marginal physical product curves and observing the points at which

---

[1]John P. Doll, Emil H. Jebe, and Robert D. Munson, "Computation of Variance Estimates for Marginal Physical Products and Marginal Rates of Substitution," Journal of Farm Economics, XLII (August, 1960), pp. 596-607.

[2]Wright, op. cit., pp. 18-20.

[3]The following procedure was developed by Dr. Robert Gustafson after a discussion with Dr. Glenn L. Johnson and the author concerning the relevancy of placing confidence limits on MPP curves. A procedure by which the confidence limits may be specified for the high profit level of nutrients is as follows.

Assume the functional form to be

(1) $Y = b_o + b_1X_1 + b_2X_1^2 + b_3X_2 + b_4X_2^2 + b_5X_1X_2$

(2) $MPPX_1(Y) = b_1 + 2b_2X_1 + b_5X_2$

(3) $Var\ (MPPX_1(Y)) = \sigma_\mu^2\ (C_{11} + 4C_{22}X_1^2 + C_{55}X_2^2 + 4C_{12}X_1 + 2C_{15}X_2 + 4C_{25}X_1X_2)$

where the C_{ij} are elements of the inverse of the sums of squares and cross product matrix, and σ_μ^2 is the variance of the disturbance term in the regression.

Given X_1 and X_2, confidence limits for $MPPX_1(Y)$ are $b_1 + 2b_2X_1 + b_5X_2$

the price ratio line crossed the confidence limits.[1] This procedure was used for the MPP of nitrogen derived from equation 1 in Table 4. The results appear in Diagram 1. Diagram 2 contains the 90 percent confidence limits for the MPP of P derived from equation 1 in Table 4.

$\pm$ t S where t is the suitable value from a table of the t distribution and

$$(4)\quad S = \sqrt{\text{Estimated Var } (MPPX_1(Y))}$$

Setting the <u>lower</u> confidence limit equal to $\frac{P_{X_1}}{P_Y}$, we have

$$(5)\quad t\,S\,\sqrt{C_{11} + 4C_{22}X_1^2 + c_{55}X_2^2 + 4C_{12}X_1 - 2C_{15}X_2 + 4C_{25}X_1X_2} + \frac{P_{X_1}}{P_Y} - b_1 - 2b_2X_1 - b_5X_2 = 0$$

Simplifying:

$$(6)\quad \text{let } L = a + bX_1 + c\sqrt{e_o + e_1X_1 + e_2X_1^2}$$

where $a = \frac{P_{X_1}}{P_Y} - b_1 - b_5X_2$

$b = -2b_2$

$c = t\,S$

$e_o = C_{11} + C_{55}X_2^2 + 2C_{15}X_2$

$e_1 = 4C_{12} + 4C_{22}X_2$

$e_2 = 4C_{22}$

Setting X_2 equal to its high profit level, we want to find X_1 such that $L = 0$.

This will give us the lower confidence limit for the high profit X_1, given that X_2 is being used at its (point estimate) high profit level. The nature of the function L is such that Newton's method of approximation* (combined perhaps with some graphing) generally seems to work satisfactorily. We have:

*See, e.g., Glenn James and Robert C. James, <u>Mathematical Dictionary</u>, Van Nostrand, 1959, p. 266.

[1] It is imperative that individual observations be used and not means of replications as the estimated variance (S^2) of the prediction equation would be meaningless. The S^2 is an important component in the derivation of the confidence limits.

Table 4. Equations based on check plot yield differences for the 1961 controlled-survey experiment, <u>including</u> check plots.[1] (n = 72)

Equation Number	Yield	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$							$\bar{R}^2$	S
		a	b_1	b_2	b_3	b_4	b_5	b_6		
1	Y_1 from whole plot	+.02056 2.80055	+.26118 .07845	-.00156 .00153	+.09433 .04873	-.00074 .00079	+.00076 .00152	+.01078 .04998	.617	4.09
1'	Y_1 from whole plot	+.59260 .89377	+.25522 .07290	-.00147 .00147	+.08969 .04340	-.00069 .00074	+.00078 .00150	2/	.622	4.06
2	Y_2 from 1/5 acre sample	+1.35255 .85719	+.27254 .10805	-.00211 .00211	+.05213 .06712	-.00032 .00108	+.00123 .00209	-.01742 .06884	.450	5.63
3	Y_3 from 1/100 acre sample 2nd	+1.85316 5.08134	+.23332 .14234	-.00031 .00277	-.00829 .08842	+.00120 .00143	-.00113 .00275	-.03635 .09069	.273	7.42
4	Y_4 from 1/100 acre sample 1st	+.08017 4.86071	+.28735 .13616	-.00132 .00265	+.00873 .08458	+.00162 .00136	-.00207 .00263	+.00757 .08675	.302	7.10
5	Y_5 from 1/50 acre sample	-.20862 4.60655	+.30217 .12904	-.00197 .00252	+.02177 .08015	+.00088 .00129	-.00092 .00250	+.01241 .08221	.312	6.72

[1] The number under each b value is its standard error.

[2] The K variable was excluded in this equation.

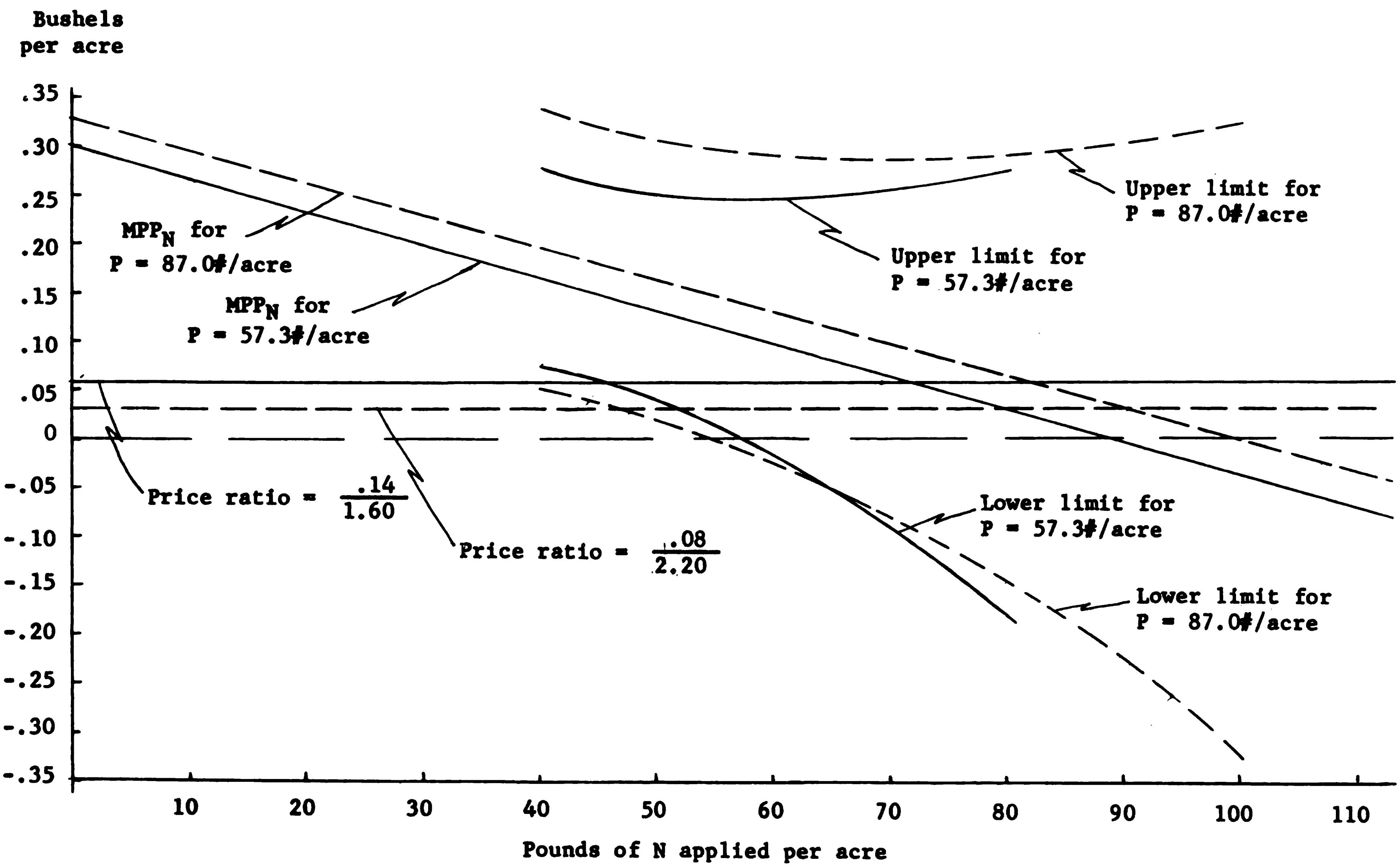

Diagram 1. 90 percent confidence limits for the marginal physical products of nitrogen (N) in the production of wheat.

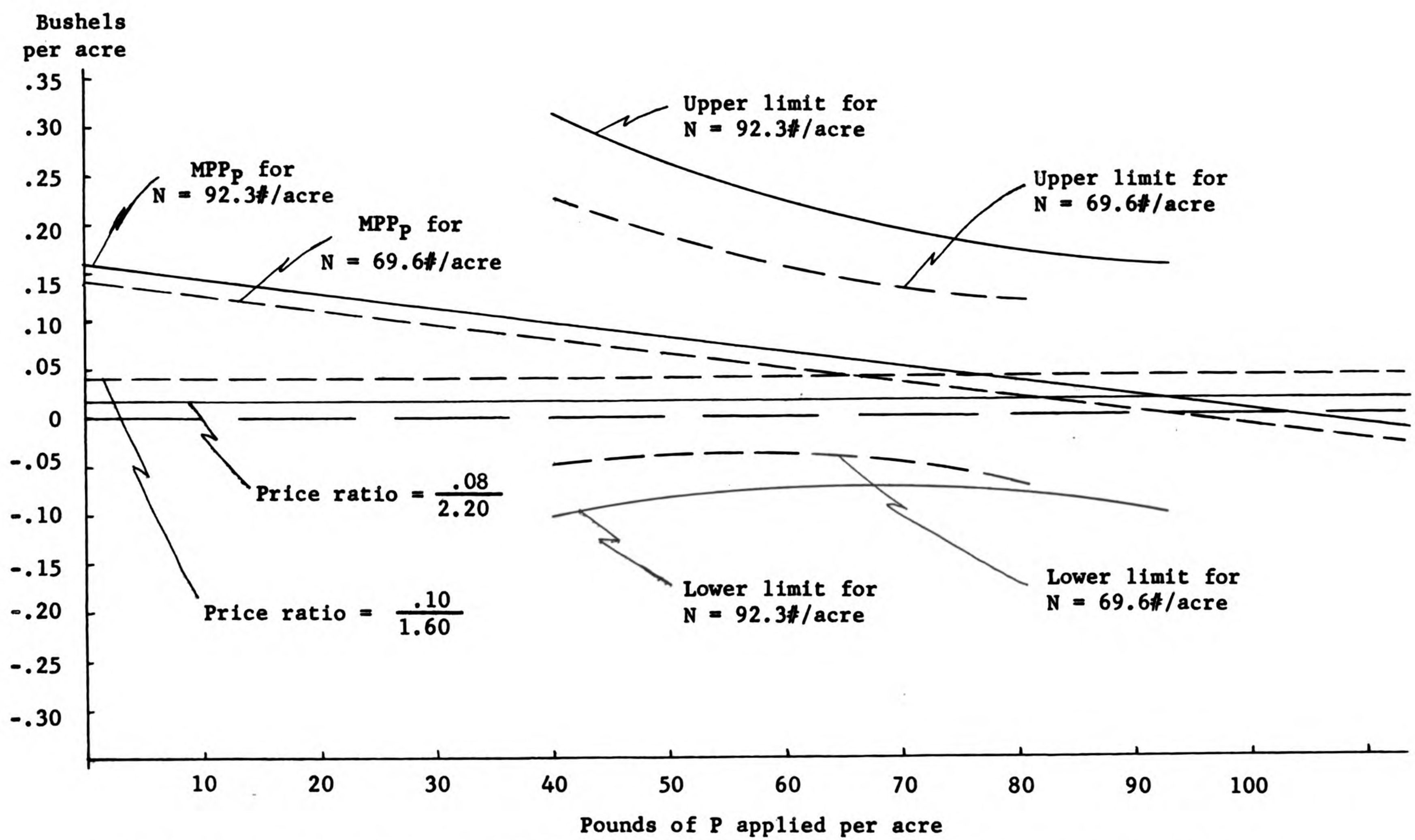

Diagram 2. 90 percent confidence limits for the Marginal physical products of phosphate (P) in the production of wheat.

Two conclusions based on the analyses of the check plot yield difference data include: (1) for an important range of price ratios, the 90 percent confidence limits indicated that it was profitable to use greater

---

(7) $$\frac{dL}{dX_1} = b + \frac{c(e_1 + 2e_2X_1)}{2\sqrt{e_o + e_1X_1 + e_2X_1^2}}$$

Choose a value of $X_1 = D_o$ such that $\frac{dL}{dX_1} > 0$;

compute L. Compute

(8) $$D_1 = D_o - \frac{L}{\frac{dL}{dX_1}}$$

for the next approximation of X_1, where L and $\frac{dL}{dX_1}$ are evaluated at $X_1 = D_o$.

Having obtained D_1, the values of L and $\frac{dL}{dX_1}$, for $X_1 = D_1$ are computed.

The procedure is repeated until $L = 0$, to whatever degree of accuracy is desired.

It is possible that $L > 0$ for all $X_1 > 0$. To check this

compute L and $\frac{dL}{dX_1}$, for $X_1 = 0$.

If $L > 0$ and $\frac{dL}{dX_1} > 0$, then

$L > 0$ for all $X_1 > 0$ and no positive X_1 satisfies the condition in equation (5).

If $L > 0$ but $\frac{dL}{dX_1} < 0$, it is possible that $L < 0$ for some $X_1 > 0$. To check this, a graphical procedure seems most convenient.

The upper confidence limit for the high profit X_1, given X_2, could be found, if desired, by similar procedures.

than 40 pounds of N per acre and (2) for P, the 90 percent confidence limits indicated that the difference between the point estimate optimal level of P and zero could be due to chance. The economic analysis of these data on pages 44 to 51 will consider this in more detail.

Another procedure that avoids testing whether the MPP differs significantly from zero was tried.[1] It is to test the null hypothesis $\beta_1 = \beta_2 = \beta_5 = 0$ and/or $\beta_3 = \beta_4 = \beta_5 = 0$ for the equation $Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$. R^2 values were computed for the equations $Y = a + b_1N + b_2N^2 + b_6K$ and $Y = a + b_3P + b_4P^2 + b_6K$; these R^2 values are included in Table 5, as are the R^2 values calculated for the equations in Table 4. (See footnote 1 of Table 5 for an explanation of the test.) The null hypothesis, $\beta_1 = \beta_2 = \beta_5 = 0$, was rejected for every equation at the 25 percent level of significance. The larger the plot area harvested the larger the $F_{65,3}$ value and thus the higher the level of significance. For the whole plot data, the hypothesis $\beta_1 = \beta_2 = \beta_5 = 0$ was rejected between the five and one percent level of significance. The $\beta_3 = \beta_4 = \beta_5 = 0$ hypothesis was not rejected at the 25 percent level in three instances. It was rejected at this level when equations based on whole plot and on 1/100 acre data were considered.

The above analysis indicated that the total effect of N was important in influencing wheat yield. The significance of the effect of N was near the one percent level for the data from the whole plot. The total effect of P was not as significant as was that for N; however, its level of significance was between 50 and 25 percent.

Data, excluding the check plot yield differences that equaled zero, were analyzed. The results were comparable to those presented in Table 4

---

[1]This procedure was suggested by Dr. Robert Gustafson. The β_i's refer to the universe coefficients not to the estimates of the universe coefficients which are labeled b_i.

Table 5. R^2 and F values for various equations fitted to the check plot yield difference data, 1961. (n = 72)

Yield	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$		
	R_o^2 assuming no $\beta = 0$	R_{s1}^2 assuming $\beta_1 = \beta_2 = \beta_5 = 0$	R_{s2}^2 assuming $\beta_3 = \beta_4 = \beta_5 = 0$
	R^2 values		
Y_1 from whole plot	.667	.330 (21.87) [1/,2/]	.602 (4.22)
Y_2 from 1/5 acre sample	.497	.263 (10.08)	.453 (1.90)
Y_3 from 1/100 acre sample-2nd	.335	.188 (4.79)	.292 (1.40)
Y_4 from 1/100 acre sample-1st	.361	.253 (3.66)	.274 (2.95)
Y_5 from 1/50 acre	.370	.231 (4.78)	.314 (1.930)

[1/] Numbers in parentheses are $F_{N-7,3} = \frac{N-7}{3} \frac{R_o^2 - R_{si}^2}{1 - R_o^2}$

[2/] The distribution for $F_{60,3}$ is

50%	25%	10%	5%	1%
1.25	2.47	5.15	8.57	26.3

from W. J. Dixson and F. J. Massey, Jr., Introduction to Statistical Analysis (2nd ed.; New York: McGraw-Hill Book Co., Inc., 1957), p. 391.

in that $\bar{R}^2$ values increased and S values decreased as sample area increased in size. The signs of the coefficients were not generally consistent with the law of diminishing returns. None of the coefficients differed significantly from zero at the ten percent level. Table 6 presents the results of the analysis of these data. The variances of the MPP's were not derived for the equations in Table 6, as signs of the coefficients were not generally consistent with the law of diminishing returns and the coefficients were, in general, quite small relative to their standard error.

Table 6. Equations based on check plot yield differences for the 1961 controlled-survey experiment, excluding check plots.[1] (n = 54)

Yield	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$							$\bar{R}^2$	S
	a	b_1	b_2	b_3	b_4	b_5	b_6		
Y_1 from whole plot	+4.30447 6.65964	+.13389 .13934	-.00094 .00195	+.03395 .08215	-.00085 .00099	+.00225 .00205	+.00616 .10349	.335	4.70
Y_1 from whole plot	+4.66137 2.87136	+.12956 .11763	-.00089 .00173	+.03087 .06305	-.00082 .00086	+.00227 .00198	2/	.349	4.65
Y_2 from 1/5 acre sample	+7.85278 9.30350	+.13694 .19466	-.00117 .00273	-.02168 .11477	-.00014 .00138	+.00258 .00286	-.07739 .14457	.204	6.56
Y_3 from 1/100 acre sample-2nd	+6.02805 12.33280	+.18909 .25805	+.00030 .00361	-.04242 .15214	+.00158 .00184	-.00093 .00379	-.11434 .19165	.102	8.70
Y_4 for 1/100 acre sample-1st	+3.72660 11.76968	+.18173 .24627	-.00080 .00345	-.04182 .14519	+.00155 .00175	-.00085 .00362	+.00113 .18290	.073	8.30
Y_5 from 1/50 acre sample	+2.47149 11.15602	+.21290 .23343	-.00159 .00327	-.01899 .13762	+.00075 .00166	+.00016 .00343	+.01839 .17336	.073	7.87

1/ The number under each b value is its standard error.

2/ The K variable was excluded in this equation.

It should be noted that the $\bar{R}^2$ values are lower for every equation in Table 6 than in Table 4. This is due primarily to the absence of the 18 additional observations that equaled zero. By definition, these observations are measured without variation, since the yield from the check plot subtracted from itself equals zero.

Comparative analysis using actual versus intended applied amounts of fertilizer nutrients.--Since the amount and combination of the fertilizer nutrients applied to each plot was carefully weighed, actual values could be used. This would alleviate the error resulting from using intended applications. To find out the importance of this error, two equations, one using the intended, the other the actual input data, were fitted to the yield data from all 72 of the whole plots.[1] The $\bar{R}^2$ and S values equaled .407 and 6.66, respectively, when the actual applications were used. These values were .423 and 6.32 when the intended applications were used as data. The difference between the $\bar{R}^2$ values was small and contrary to expectations. The same was true of the S values.

Analysis of yields from the different subplots within the acre plots.--The yield data from each of the four subplots were compared with the yield data from the whole plot. Table 7 includes the results of fitting the four equations, using yield data from the subplots as independent variables and the yield data from the whole plot as the dependent variable. As the subplots increase in size, larger $\bar{R}^2$ values and smaller S values were found. The "a" values (Y = a + biYi) tended to increase and the "b" values decrease as the size of the sample area decreased. At the lower yield levels, the yields from the subplots overestimated the whole plot yields,

---

[1]The check plot yield difference data were not used in this comparison as the check plot on each farm did not receive the intended application of K.

and at the higher yield levels, the subplot yields underestimated the whole plot yields. This occurred because of the high levels of variation that existed within the subplot yield data. The variation in the independent variable caused the "a" values to increase and the "b" values to decrease. This information will be used in discussions later in this chapter.

Table 7. Equations estimating whole plot yields with yields from the subplots as independent variables, 1961 controlled-survey. (n=72)

Nature of Yi's	(Whole plot yield = Y = a + biYi)			$\bar{R}^2$	S
	a		bi		
1/5 acre yields	8.38	+	.86	.686	4.88
1/100 acre yields, 2nd	23.34	+	.61	.498	6.18
1/100 acre yields, 1st	29.28	+	.52	.496	6.18
1/50 acre yields	23.62	+	.61	.523	6.02

The 1961 Survey Analysis

The survey yield data were obtained shortly after wheat harvest in July. Farmers in the survey applied fertilizer twice during the year, at planting time and again early in the spring when they seeded their wheat to a legume. All but four of the farmers following this procedure. The remaining 112 applied fertilizer twice during the year. The fertilizers applied at planting time and in the spring were used as separate variables in the initial analysis. Six independent variables were included in the Cobb-Douglas equation that was fitted to the data. These variables included N, P and K applied at planting time and N, P and K applied in the spring. None of the coefficients differed significantly from zero at the five percent level. Less than one percent of the variation was explained by the equation fitted to the data. High correlations existed among the independent variables, i.e., the simple correlation between P and K applied in the spring equaled .98. The total amounts of each of the three nutrients were used as independent variables in a Cobb-Douglas type equation and in a polynomial equation to predict yield. Both analyses produced R^2 values less than .01. A standard error of estimate of about ten bushels resulted from fitting the polynomial equation to the data.

Survey and Controlled-Survey Comparison

The survey data were subdivided into four groups. These groups were formed by stratifying the data by the reported amount of nitrogen and phosphate used. A group of 31 low N-low P users, of 27 low N-high P, of 26 high N-low P, and one of 32 high N-high P users were delineated (see Table 11). The five equations that were fitted to the check plot yield difference data from the whole and subplots were used to predict the survey yields. The average levels of N and P for each survey group were substituted into each of the five equations to obtain a predicted yield. The average check plot yield for the appropriate whole plot or subplots were then added to these predicted yields.

The results of these substitutions and additions are presented in Table 8. Each of the equations derived from the controlled-survey accurately estimated the survey yields for the four different fertilizer levels. The level of potash included in the prediction equation was determined by calculating the average level for each of the categories delineated; it varied for each of the four groupings.

S_S^2 was calculated for each equation as a measure of the differences that existed between the predicted and survey yields.[1]

---

[1]The method of calculating the predicted yield based on the survey data caused a possible difference to exist between the predicted and survey yield. This, of course, is only one possible source of the differences between the predicted and average yields for the farms in the survey. Dr.

For future easy reference, this value will be labeled S_S^2. See footnote 2 of Table 8 for the definition of this value. The S_S^2 value was lowest for the 1/50 acre subplot analysis. The analysis of the two 1/100 acre subplots

---

Robert Gustafson developed the following as an explanation for this possible difference:

Suppose for n farms and 2 nutrients

$$(1)\quad Y_i = b_o + b_1N_i + b_2N_i^2 + b_3P_i + b_4P_i^2 + b_5N_iP_i \quad \text{for } i = 1,\ldots,n$$

where Y_i is yield on farm i, and N_i, P_i represent per acre amounts of nutrients on farm i.

If the data are aggregated we obtain

$$(2)\quad \bar{Y} = b_o + \frac{b_1}{n}\Sigma N_i + \frac{b_2}{n}\Sigma N_i^2 + \frac{b_3}{n}\Sigma P_i + \frac{b_4}{n}\Sigma P_i^2 + \frac{b_5}{n}\Sigma N_iP_i$$

where $\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$

When the aggregated inputs are used to predict average yield, the result is

$$(3)\quad Y_P = b_o + \frac{b_1}{n}\Sigma N_i + \frac{b_2}{n^2}(\Sigma N_i)^2 + \frac{b_3}{n}\Sigma P_i + \frac{b_4}{n^2}(\Sigma P_i)^2 + \frac{b_5}{n^2}(\Sigma N_i)(\Sigma P_i)$$

Subtracting Y_P from $\bar{Y}$ we obtain

$$(4)\quad \bar{Y}-Y_P = \frac{b_2}{n}\left[\Sigma N_i^2 - \frac{1}{n}(\Sigma N_i)^2\right] + \frac{b_4}{n}\left[\Sigma P_i^2 - \frac{1}{n}(\Sigma P_i)^2\right] + \frac{b_5}{n}\left[\Sigma N_iP_i - \frac{1}{n}(\Sigma N_i)(\Sigma P_i)\right]$$

or rewriting

$$(5)\quad \bar{Y}-Y_P = \frac{b_2}{n}\sum_{i=1}^{n}(N_i-\bar{N})^2 + \frac{b_4}{n}\sum_{i=1}^{n}(P_i-\bar{P})^2 + \frac{b_5}{n}\sum_{i=1}^{n}(N_i-\bar{N})(P_i-\bar{P})$$

where $\bar{Y}-Y_P$ represents the difference between the actual average yield from the aggregated data and the predicted average yield based on the average amounts of N and P from the aggregated data.

The first two terms in equation (5), $\frac{b_2}{n}\sum_{i=1}^{n}(N_i-\bar{N})^2$ and $\frac{b_4}{n}\sum_{i=1}^{n}(P_i-\bar{P})^2$, are always negative (assuming $b_2 < 0$ and $b_4 < 0$ as they should be). The third term may, in general, be either positive or negative.

This problem would have been avoided if in equation (3) the means of the squared terms had been used instead of the squared means.

Table 8. Analysis of survey data with yields predicted by equations derived from the controlled-survey experiment, 1961.

Equations from Table 4	Av. check plot yield	Low: av. N=27.1 pounds/acre Low: av. P=51.5 pounds/acre[2]		Low: av. N=29.1 pounds/acre High: av. P=82.6 pounds/acre[3]		High: av. N=53.4 pounds/acre Low: av. P=44.8 pounds/acre[4]		High: av. N=49.3 pounds/acre High: av. P=87.9 pounds/acre[5]		s_S^2 [1]
		Av. Y from survey	Y from C-S	Av. Y from survey	Y from C-S	Av. Y from survey	Y from C-S	Av. Y from survey	Y from C-S	
1. whole plot	49.7	59.89	60.10	60.56	61.34	57.59	64.24	64.49	65.48	11.46
2. 1/5 acre sample	49.9	59.89	61.44	60.56	63.71	57.59	65.17	64.49	68.31	21.09
3. 1/100 acre sample-2nd	49.3	59.89	56.76	60.56	59.88	57.59	60.50	64.49	62.82	5.39
4. 1/100 acre sample-1st	47.3	59.89	56.40	60.56	61.96	57.59	57.98	64.49	63.22	3.98
5. 1/50 acre sample	48.4	59.89	57.68	60.56	61.79	57.59	59.78	64.49	63.96	2.88

[1] $s_S^2 = \Sigma \frac{(\text{yield from the survey - predicted yield})^2}{n}$; $n = 4$

[2] Average level of K = 46.0 pounds per acre.

[3] Average level of K = 71.1 pounds per acre.

[4] Average level of K = 43.0 pounds per acre.

[5] Average level of K = 75.0 pounds per acre.

produced the next lowest S_S^2 values, with the 1/5 acre area analysis producing the highest S_S^2. It should be noted that the smaller the plot area, the more inaccurate the measurements of N, P and K and yields.[1] This may have been one cause of the relatively high levels of unexplained variance that existed within the data from the subplots presented in Tables 2 through 7. The data obtained from the survey were also somewhat inaccurate, as farmers' estimates of inputs and outputs were used. In addition, farmers whose fields were low in soil nutrients in all likelihood applied more fertilizer than did those whose fields had high levels of nutrients in the soil. Thus, yields would vary little, while the amount of fertilizer applied would vary more. The response to fertilizer would be smaller and thus agree more with the data from the subplots in the controlled-survey.

The predicted yields from the controlled-survey subplots responded less to different applications of fertilizer than did the predicted yields based on the whole plot data (see Table 8). The between-treatment yield variation was less in the subplot data than in the whole plot data. Similarly, predicted yields from the small subplots were probably overestimated for low applications and underestimated for large applications of N; this tendency probably arose from biases introduced in the least squares estimates by increasing random errors associated with measurements of the independent variables as plot size was reduced. The equations derived from the subplot data exhibited less response to N because of the relatively high levels of yield variation not associated with treatment and because of the errors in observing the amounts of nutrients applied. The equations fitted to the data of this nature would tend to have high "a"

---

[1]The applications of N, P and K on the subplots were assumed to be identical to those on the whole plot area; however, it is possible that the fertilizer was applied at a slower or faster rate than the average for the whole plot.

values and low "b" values. The controlled-survey subplot data had characteristics that were similar to those of the survey data. The characteristics of the whole plot data and the survey data were less similar.

An Economic Analysis of the 1961 Data

An economic analysis of the 1961 controlled-survey data was carried out to determine the optimum levels of N and P for two sets of prices. This analysis was based on the equations shown in Table 4. Two price alternatives were considered. One included the prices of N and P, each equal to $.08 per pound and the price of wheat equal to $2.20 per bushel. The other price alternative included these prices at $.14 per pound, $.10 per pound, and $1.60 per bushel. In addition, the marginal physical product estimates were tested to determine if they differed significantly from zero at the ten percent or five percent levels[1] for the high profit applications of nutrients found in Table 9 for the two price ratios considered.

The high profit combinations for N and P were calculated. These are reported in Table 9, along with the profits above fertilizer cost. The second order conditions for a maximum did not hold for the derivative of the function with respect to P in equations 3, 4 and 5. Thus, high profit levels of N were calculated for the two sets of prices for these equations, holding P constant at the mean application rate of 40 pounds per acre.

The profit above fertilizer costs was highest for the optimum levels of N and P derived from equation 2 in Table 9. Since the levels of N and P were both considerably beyond the range of the actual applications, the profits derived from them were not realistic.

---

[1] Doll, loc. cit., and Wright, loc. cit.

Table 9. Per acre high profit levels and returns above fertilizer costs at indicated prices, controlled-survey experiment, 1961.

Equation No. from Table 4	Price of N = \$0.08, Price of P = \$0.08, Price of Wheat = \$2.20: High profit amounts of N	P	Returns above fert. cost*	Price of N = \$0.14, Price of P = \$0.10, Price of Wheat = \$1.60: High profit amounts of N	P	Returns above fert. cost*
	----Pounds----		Dollars	----Pounds----		Dollars
1	92.3	87.0	136.56	69.6	57.3	88.93
1'	99.6	94.9	137.80	73.3	61.1	89.23
2	143.5	300.4	151.33	88.9	154.8	90.37
3	243.2	1/	145.92	162.3	1/	84.00
4	58.9	1/	117.35	41.8	1/	78.72
5	58.4	1/	121.16	43.7	1/	81.51

*Price of K assumed equal to \$0.06 per pound.

1/ P applied at 40 pound level.

The optimum amounts of N and P were obtained using equation 1 in Table 4; they were 92.3 pounds of N and 87.0 pounds of P. These would be the amounts of N and P a farmer would apply if he paid the low price for N and P and received the high price for wheat. His return above fertilizer costs would have been \$136.56 per acre.

Taking the case in which the farmer pays the high price of N and P and receives the low wheat price, the optimum amounts of N and P derived from equation 1 are as follows: 69.6 pounds of N per acre and 57.3 pounds of P per acre. The return above fertilizer costs would have been \$88.93 per acre.

Then, if the farmer had paid the low price for N and P while receiving the high price for wheat, and if he had applied 69.6 and 57.3 pounds of N and P per acre, respectively, he would have received \$135.71 as his per acre return above fertilizer cost. This is $0.85 less than his return above fertilizer cost when he used 92.3 pounds of N and 87.0 pounds of P.

In order to determine the sensitivity of returns above fertilizer costs to changing levels of N and P, Table 10 was constructed. Returns were calculated using two sets of prices for ten pound increments of both N and P. Equation 1' from Table 4 was used to calculate the returns above fertilizer costs. This equation was based on the check plot yield difference data for the whole plots and explained a higher proportion of the yield variation than the other equations. The signs of the coefficients in this equation agreed with the law of diminishing returns. Returns above fertilizer costs increased at a diminishing rate and then decreased as the application of P varied between 0 and 80 pounds per acre. The returns above fertilizer costs associated with larger applications of N increased at a diminishing rate but did not decrease for applications of N that varied between 0 and 60 pounds per acre. Returns were responsive to changes in N; if P was held at the 80 pound level, returns ranged from $116.18 per acre for a 10 pound application of N to $135.80 per acre for a 60 pound application. In general, the profits which were calculated for the varying increments of N and P exhibited a low response to P and a somewhat higher response to N. An application of 40 pounds per acre of N and 40 pounds per acre of P returned $129.74 per acre above fertilizer costs. This is $6.14 less per acre than the application of 60 pounds of N and 70 pounds of P. On the basis of this 1961 information, it would have paid a farmer to have applied these higher levels of N and P.

An analysis of the survey data proved unrewarding when a second degree polynomial and a Cobb-Douglas type equation were fitted to the data. No economic analysis was attempted using these equations. As an alternative, the data were grouped into four categories representing farmers who applied

Table 10. Estimated returns above the cost of N and P, 1961 controlled-survey.[1]

Pounds per acre P \ N	Yield, in bushels per acre 0	10	20	30	40	50	60
10	49.70	-	-	-	-	-	-
10	-	53.60	55.79	57.69	59.29	60.60	61.61
20	-	54.37	56.64	58.61	60.29	61.68	62.77
30	-	55.00	57.35	59.40	61.16	62.62	63.79
40	-	55.49	57.92	60.05	61.88	63.42	64.67
50	-	55.85	58.35	60.56	62.47	64.09	65.41
60	-	56.06	58.64	60.93	62.92	64.62	66.02
70	-	56.14	58.80	61.16	63.23	65.01	66.49
80	-	56.08	58.82	61.26	63.40	65.26	66.82

Pounds per acre P \ N	Returns above the cost of N and P Price of N = $.08/pound Price of P = $.08/pound Price of Wheat = $2.20/bushel 0	10	20	30	40	50	60
0	109.34	-	-	-	-	-	-
10	-	116.32	120.34	123.72	126.44	128.52	129.94
20	-	117.21	121.41	124.94	127.84	130.10	131.69
30	-	117.80	122.17	125.88	128.95	131.36	133.14
40	-	118.08	122.62	126.51	129.74	132.32	134.27
50	-	118.07	122.77	126.83	130.23	133.00	135.10
60	-	117.73	122.61	126.85	130.42	133.36	135.64
70	-	117.11	122.16	126.55	130.31	133.42	135.88
80	-	116.18	121.40	125.97	129.88	133.17	135.80

Table 10 - continued

Pounds per acre P \ N	Returns above the cost of N and P Price of N = $.14/pound Price of P = $.10/pound Price of Wheat = $1.60/bushel						
	0	10	20	30	40	50	60
0	79.52	-	-	-	-	-	-
10	-	83.36	85.46	87.10	88.26	88.96	89.18
20	-	83.59	85.82	87.58	88.86	89.69	90.03
30	-	83.60	85.96	87.84	89.26	90.19	90.66
40	-	83.36	85.87	87.88	89.40	90.47	91.07
50	-	82.96	85.56	87.70	89.35	90.54	91.26
60	-	82.30	85.02	87.29	89.07	90.39	91.23
70	-	81.42	84.28	86.66	88.57	90.02	90.98
80	-	80.33	83.31	85.82	87.84	89.42	90.51

[1]Equation 1' from Table 4 was used for these computations.

different amounts of N and P. Table 11 contains the average levels of N, P, K and yields for each of these groupings, and net returns above fertilizer costs, assuming the usual sets of price ratio. The farmers in group 4 who used, on the average, high levels of N, P and K, netted less per acre, when the fertilizer price was high relative to the price of wheat, than did those in group 1 who used, on the average, low levels of N, P and K.

A comparison of Tables 10 and 11 revealed that the returns above fertilizer costs derived from the whole plot data of the controlled-survey were higher than the returns calculated for the four groupings of the 1961 survey results. As stated earlier, the survey yield results were less responsive to applications of nutrients and thus had low returns above fertilizer costs. If controls identical to the controlled-survey

Table 11. Net returns above fertilizer costs for the four groupings of the 1961 survey results.

Group No.	Average levels of nutrients applied			Average yield	Returns above fertilizer costs[1]	
	N	P	K		Price of N = \$.08/lb. Price of P = \$.08/lb. Price of Wheat = \$2.20/bu.	Price of N = \$.14/lb. Price of P = \$.10/lb. Price of Wheat = \$1.60/bu.
	Pounds			Bushels	Dollars	
1	27.1	51.5	46.0	59.9	122.73	84.14
2	29.1	82.6	71.1	60.6	120.12	80.36
3	53.4	44.8	43.0	57.6	116.28	77.62
4	49.3	87.9	75.0	64.5	126.42	83.01

[1]Price of K equals \$.06 per pound for both sets of prices.

had been imposed on the farms included in the survey, the returns above fertilizer costs would have been more similar for the survey and controlled-survey analyses.

The comparison of survey and controlled-survey results shown in Table 8 indicates that the analysis of the 1961 controlled-survey data provided a rather consistent predictor of wheat yields using average levels of N, P and K for farms that were, in general, similar to those included in the controlled-survey. The prediction based on the 1/50 acre subplot proved to be closer to the survey yields than the predictions based on other data.

The analysis of the controlled-survey data has indicated that 50 pounds of N per acre and 40 pounds of P per acre would have returned \$132.32 per acre, while these approximate levels of nutrients returned \$116.28 per acre for survey data. An application of about 50 pounds of N and 80 pounds of P returned \$133.17 per acre based on the data from the controlled-survey, as compared to the \$126.42 per acre based on the survey data.

Confidence limits were placed on the MPP of N and P in the production of wheat. The lower 90 percent confidence limit derived from equation 1 in Table 4 equaled the price ratio, N = \$.14 per pound over wheat = \$1.60 per bushel, at 48 pounds of N. The profit per acre when 48 pounds of N and 57 pounds of P were applied was only \$1.12 less than that when the point-estimate optimal levels of N and P were applied. The price ratios of N = \$.08 per pound over wheat = \$2.20 per bushel, equaled the 90 percent confidence limit at 52 pounds of N. For this set of prices and for 52 pounds of N and 87 pounds of P, the profit per acre was \$5.85 less than that for the point-estimate optimal combination of nutrients.

For the 1961 data, the economic analysis indicated that N affected yields to a greater extent than did P. The 90 percent confidence limits placed on the MPP of N when it equaled the price ratio indicated that at least 50 pounds of N should be applied per acre. The difference in returns above fertilizer costs when 50 pounds instead of 92 pounds of N per acre was used equaled $5.85 per acre. The total effect of N on yield was demonstrated when the null hypothesis $b_1 = b_2 = b_5 = 0$ was rejected at between the one and five percent level when the equation based on the whole plot data was used.

The 90 percent confidence limits placed on the high profit level of P indicated there was no significant difference between a zero application of P and the optimal application of 87 pounds of P per acre. The profit levels contained in Table 10 indicate a lack of response of returns to increased applications of P. The total effect of P on yields was not as great as the total effect of N on yields. This was demonstrated when the null hypothesis $b_3 = b_4 = b_5 = 0$ was tested. This hypothesis was rejected at between the 25 and 10 percent level of significance. An application of at least 40 pounds of P would not have adversely affected returns above fertilizer costs, but it would have supplied the wheat with a maintenance amount of P for the growing season.[1] Higher applications of P would have had little effect on returns above fertilizer costs (see Table 10).

1962 Experiments and Survey

A broad outline of the controlled-survey appears in the previous chapter. The survey was also discussed in some detail in that chapter. The 1962 experiment and survey were conducted in practically the same manner. The differences are spelled out in Chapter III. See Appendices IV and V for the 1962 data. The 1962 controlled-survey included nine farms and seven plots per farm. The difference between the 1961 and 1962

---

[1]This maintenance amount would insure that the yield response to N would not be depressed because of lack of P.

controlled-surveysare fully described in Chapter III. This new procedure allowed the plots to be planted at the usual planting time. An additional experiment was initiated in 1962, incorporating the design used in the controlled-survey with the entire experiment being located within one field on a farm (see Appendix VI for the data). The "typical" experiment is fully described on pages 21 and 22 in Chapter III. This experiment was conducted so that information from an analysis of the data obtained therefrom could be compared with the analysis of the controlled-survey experiment and with data obtained from the survey.

The 1962 Controlled-Survey Experiment

In addition to the differences discussed above, there were also a few differences with respect to harvesting between the 1962 controlled-survey experiment and that of the previous year. These differences were: (1) a 1/10 acre subplot was harvested instead of a 1/5 acre area and (2) no single plot was harvested in 1/100 acre areas. The winter weather caused extensive winterkill damage over the entire area in which the experiment was conducted. Some plots had more winterkill damage than others; however, no relationship was observed to exist between the amount of winterkill and fertilizer treatment. As indicated in Chapter III, if wheat had been winterkilled over an area large enough so that a drill could be used to plant oats, then oats were planted. This was done so that weed infestation could be held to a minimum. Care was taken to "square up" the winterkilled areas so that they could be more easily measured; thus, necessary adjustments for the reduction in wheat acreage could be made in the wheat yield data.

Analysis of actual yields.--The analysis of the data obtained from the subplots as well as those from the whole plot is presented in Table 12. The check plots are included as observations. The yields are

Table 12. Equations based on actual yields, 1962 controlled-survey experiment.[1] (n = 63)

Yield	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$							$\bar{R}^2$	S
	a	b_1	b_2	b_3	b_4	b_5	b_6		
Y_1 from whole plot	+37.29716 8.76488	+.05563 .14482	+.00184 .00242	+.07307 .08671	+.00032 .00116	-.00152 .00261	+.14077 .17495	.134	8.15
Y_2 from 1/10 acre area	+38.36676 10.47871	+.16601 .18174	-.00039 .00298	+.08282 .09576	-.00175 .00139	+.00368 .00308	+.04568 .21978	.006	8.08
Y_3 from 1st 1/100 acre area	+47.67962 10.82176	-.14757 .17881	+.00266 .00299	+.05097 .10789	-.00084 .00144	-.00114 .00324	+.04266 .21588	[2]	10.06
Y_4 from 2nd 1/100 acre area	42.40370 11.35410	-.03681 .23138	+.00057 .00392	+.31816 .12985	-.00331 .00173	+.00033 .00390	+.02252 .25974	.030	12.10
Y_5 from 1/5 acre area	+44.96712 9.48948	-.06459 .16858	+.00110 .00286	+.18417 .09461	-.00207 .00126	+.00070 .00284	+.03238 .18924	.001	8.82

[1] The number under each b value is its standard error.

[2] Less than zero when adjusted for degrees of freedom.

unadjusted for check plots and thus represent the total yield, converted to bushels per acre, for each particular subplot area. The data are quite heterogeneous. The equation based on yields from 1/10 acre was the only one having coefficients with signs consistent with the law of diminishing returns. None of the coefficients in this equation differed significantly from zero at the 20 percent level. In general, as the size of the subplot increased, $\bar{R}^2$ values increased and S values decreased. The $\bar{R}^2$ values were quite low, ranging from 0 to .134. No economic analysis was attempted using these data, and attention was concentrated on the check plot yield difference data.

Analysis of check plot yield differences.--The check plot yields were subtracted from the treatment yield for each farm. Yield differences were then considered as a function of treatment levels. The resultant estimates are presented in Table 13. The $\bar{R}^2$ values ranged from 0 to .262, with the higher values associated with the analysis of data from the larger plot areas. The high S values were associated with the small subplots. The equation based on data for the 1/50 acre plot area was the only one that had coefficients with signs that agreed generally with the law of diminishing returns. However, only the coefficient of the P^2 variable differed significantly from zero at the ten percent level of significance. The coefficient of the N variable for equation 1 and that of the K variable in equation 2 were the only other coefficients that differed significantly from zero at the ten percent level.

Marginal physical products were calculated using equations 1, 2 and 5 in Table 13. None of the calculated MPP's differed significantly from zero at the 20 percent level for optimum nutrient levels calculated for two sets of price ratios. Ninety percent confidence limits were derived for the MPP of N, assuming P equal to 40 pounds for equation 1 from Table

Table 13. Equations based on check plot yield differences for the 1962 controlled-survey experiment.[1] (n=63)

Equation No.	Yield	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$							$\bar{R}^2$	S
		a	b_1	b_2	b_3	b_4	b_5	b_6		
1	Y_1 from whole plot	-4.47837 6.18200	+.20367 .10214	-.00104 .00171	-.00572 .06116	+.00016 .00082	+.00039 .00184	+.08190 .12339	.262	5.75
2	Y_2 from 1/10 acre area	+18.49886 10.10444	-.12195 .15717	-.00045 .00247	+.15233 .09966	-.00216 .00144	+.00440 .00257	-.40590 .21689	.195	5.86
3	Y_3 from 1st 1/100 acre area[2]	+12.07577 11.58466	-.04064 .19141	+.00022 .00320	+.00567 .11550	-.00090 .00154	+.00195 .00347	-.22713 .23110	-.049	10.77
5	Y_5 from 1/5 acre area	+7.49814 6.81617	+.15124 .12109	-.00316 .00205	+.11153 .06795	-.00177 .00091	+.00188 .00204	-.16310 .13593	.098	6.33

[1] The number under each b value is its standard error.

[2] The yield differences using the 2nd 1/100 acre area were not calculated. The first 1/100 acre was chosen because of its lower S value (see Table 10); the R^2 values were substantially the same.

13. Neither the lower nor upper limit crossed the zero price ratio line at positive levels of N.

The null hypothesis $\beta_1 = \beta_2 = \beta_5 = 0$ (the total effect of N equal zero) was rejected at the ten percent level of significance, in the case when equation 1 from Table 12 was used in the analysis. Table 14 contains the results of testing this hypothesis. For equation 2, this null hypothesis was rejected between the 50 and 25 percent level of significance. The larger the harvested area, the larger the $F_{N-7,3}$ and the higher the level of significance. The null hypothesis $\beta_3 = \beta_4 = \beta_5 = 0$ (the total effect of P equal zero) was rejected between the 50 and 25 percent level of significance when equation 5 was used and between 25 and 10 percent when equation 2 was used. It was not rejected for equation 1.

Table 14. R^2 and F values for various equations fitted to the check plot yield difference data, 1962.

Yield	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$		
	R_o^2 assuming no $\beta = 0$	R_{s1}^2 assuming $\beta_1 = \beta_2 = \beta_5 = 0$	R_{s2}^2 assuming $\beta_3 = \beta_4 = \beta_5 = 0$
	R^2 values		
1. Y_1 from whole plot (n=63)	.334	.091 (6.81)[1/,2/]	.332 (.34)
2. Y_2 from 1/10 acre area (n=45)	.305	.231 (1.35)	.165 (2.55)
5. Y_5 from 1/5 acre area (n=60)	.190	.148 (.82)	.125 (1.26)

[1/] Numbers in parentheses are $F_{N-7,3} = \frac{N-7}{3} \frac{R_o^2 - R_{si}^2}{1 - R_o^2}$

Table continued on following page.

Table 14 - continued

[2]Distribution for		50%	25%	10%	5%	1%
	$F_{60,3}$	1.25	2.47	5.15	8.57	26.3
	$F_{50,3}$	1.25	2.47	5.15	8.58	26.4
	$F_{40,3}$	1.25	2.47	5.16	8.59	26.4

from Dixson and Massey, loc. cit.

Analysis of yields harvested from different sized areas within the acre plots.--An analysis of yields from the various sample areas was conducted to determine the relationship between yield from the whole plot and that from the subplots. Table 15 includes a summary of this analysis. The $\bar{R}^2$ values were quite low, with the S values relatively high. The "a" value in each equation was quite high when, theoretically, it should have been near zero. The "b" values were low. The damage caused by winterkill was a factor in causing the subplot yields to be poor predictors of the whole plot yields.

Table 15. Equations estimating whole plot yields with yields from the sample areas as independent variables, 1962 controlled-survey.

Nature of Yi's	(Whole plot yield = Y = a + biYi)		$\bar{R}^2$	S
	a	bi		
1/10 acre yield n=45	31.67	.43	.157	7.61
1/100 acre yield n=60	31.28	.36	.164	7.84
1/50 acre yield n=60	24.80	.51	.257	7.40

These 1962 results are similar to those obtained in 1961. The low yields from the whole plot were overestimated and the high yields underestimated by the subplot yields. The random errors associated with the yield data from the subplots, as compared with that from the whole plot yield, was a possible cause for the high "a" value and the low "b" values that resulted. This problem is discussed in more detail on pages 40 and 41.

The 1962 "Typical" Experiment Analysis

This phase of the 1962 project was designed so that results from a controlled-survey could be compared with a "typical" experiment. The theoretical levels of N, P and K applied were the same as for the controlled-survey experiment. The approximate actual amount applied for the "typical" experiment was measured by weighing each fertilizer treatment in and out of the drill after six replications had been planted.[1] (Table 16 contains the list of intended and approximate actual applications of N, P and K.) When the wheat was fertilized for this experiment, much care was taken to calibrate the drill accurately. A 1/100 acre area was laid out and the drill pulled the length of the area, with the discharged fertilizer caught and weighed. This procedure was repeated until two successive weights were obtained which agreed with the theoretical amount. Observation of data presented in Table 16 indicates that this careful procedure did not eliminate errors in applying nutrients.

Table 16. The intended and approximate actual applications of fertilizer nutrients in the "typical" experiment conducted in 1962.

Intended per acre applications			Approx. actual per acre applications		
N	P	K	N	P	K
Pounds					
0	0	40	0	0	72.8
0	40	40	0	61.2	61.2
15	20	40	19.7	26.2	52.4
15	60	40	17.0	67.8	45.2
30	0	40	31.2	0	41.6
30	40	40	36.0	48.0	48.0
30	80	40	38.4	102.4	51.2
45	20	40	58.1	25.8	51.6
45	60	40	53.6	71.4	47.6
60	40	40	73.8	49.2	49.2

[1]This approximate actual amount applied was adjusted for the estimated amount of fertilizer that was used on the ends of the plots.

Two equations were fitted to the data from this "typical" experiment; one equation included the approximate actual amount of fertilizer applied, the other the intended amount of fertilizer applied as independent variables. The $\bar{R}^2$ values for both equations were less than zero. Winterkill damage had caused the individual plot yields to be low, with no response to N or P. The S values were each above seven bushels per acre. The coefficients were small and, when considered individually, did not differ significantly from zero at the 20 percent level. The signs of the coefficients in the equations did not agree with the law of diminishing returns. Table 17 contains the equations as well as the S values. See pages 66 and 67 for some comparison with the controlled-survey.

The 1962 Survey Analysis

The survey data in 1962 were obtained using the same farmers who cooperated the previous year (Appendix V contains the data). See Chapter III for a more detailed discussion of the survey procedure. The number of actual observations was decreased to 70 because the fields some farmers planted to wheat in 1962 did not meet the previously described requirements. Information about the percent of winterkill of wheat was obtained. Each farmer was asked for the total yield he obtained from the area he planted; if the winterkill exceeded 20 percent of the wheat field, the average yield on the farm was adjusted upward in line with the adjustments made in the controlled-survey. No adjustments were made if the estimated winterkill damage was less than 20 percent of the field. The following three functions resulted when the data were analyzed.

$$\text{Log } \hat{Y} = 1.33247 - \underset{(.06187)}{.09309} \log N + \underset{(.08769)}{.13956} \log P + \underset{(.07760)}{.11499} \log K$$

$$\bar{R}^2 = .15$$

$$S = .07978$$

Table 17. The equations fitted to the 1962 "typical" experiment data.[1/] (n = 60)

Equation No.	Data used	$Y = a + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$							$\bar{R}^2$	S
		a	b_1	b_2	b_3	b_4	b_5	b_6		
1.	Using intended N, P and K applications	32.07162 12.98341	-.00522 .17129	-.00073 .00336	+.13456 .12847	-.00063 .00189	-.00144 .00345	2/	3/	7.23
2.	Using approximate actual applications of N, P and K	34.78829 17.21107	-.02984 .28471	-.00025 .00291	+.08886 .10771	-.00023 .00119	-.00078 .00251	-.04297 .24124	3/	7.29

1/ The number under each b value is its standard error.

2/ This was omitted since, theoretically, K was held constant.

3/ The $\bar{R}^2$ values were less than zero when adjusted for degrees of freedom.

$$\hat{Y} = 32.425 - \underset{(.34833)}{.27385}\,N + \underset{(.00184)}{.00106}\,N^2 + \underset{(.27246)}{.34320}\,P - \underset{(.00147)}{.00217}\,P^2 + \underset{(.00274)}{.00117}\,NP +$$

$$\underset{(.04984)}{.09382}\,K \qquad \bar{R}^2 = .130 \qquad S = 7.895$$

$$\hat{Y} = 34.729 - \underset{(.42908)}{.34591}\,N + \underset{(.00203)}{.00134}\,N^2 + \underset{(.32963)}{.46531}\,P - \underset{(.00305)}{.00465}\,P^2 - \underset{(.35778)}{.07301}\,K +$$

$$\underset{(.00106)}{.00019}\,K^2 + \underset{(.00413)}{.00334}\,NP + \underset{(.00280)}{.00255}\,PK - \underset{(.00524)}{.00145}\,NK \qquad \bar{R}^2 = .100 \qquad S = 8.029$$

The log function explained the highest proportion of the variance in the data. None of the functions had an individual coefficient that differed significantly from zero at the 10 percent level. This is not surprising, since the levels of intercorrelation among the independent variables were high, i.e., for one equation $r_{PK} = .54$. There were, however, certain coefficients that were surprisingly large relative to their standard error.

Comparative Analysis of the "Typical" Experiment, the Controlled-Survey Experiment and the Survey for 1962

This section will contain comparisons among the various experiments and the survey. First, the "typical" and controlled-survey experiments are compared. Next, comparisons between the survey and controlled-survey are made. Last, a three-way comparison of the "typical" experiment, the controlled-survey and survey are made.

A comparison of the "typical" and controlled-survey experimental results.--The "typical" experiment and the controlled-survey data are compared in Table 18. The mean yields for every treatment level are higher for the controlled-survey experiment than for the "typical" experiment. The standard deviation calculated from the yield data for each treatment level was, in general, smaller for the actual data from the controlled-survey than for the data from the "typical" experiment. This

Table 18. Comparisons of the "typical" experiment and the controlled-survey experiment, 1962.

Intended per acre application N and P	"Typical" Experiment		Controlled-survey experiment		
				Standard deviations	
	Mean Yield	Standard deviation	Mean yield	Actual yield	Check plot yield differences
Pounds	Bushels				
0- 0	30.8	4.58	45.5	6.96	-
0-40	37.2	9.30	47.0	5.95	5.03
15-20	35.8	6.47	42.9	3.77	3.56
15-60	35.0	8.86	53.0	8.46	4.63
30- 0	32.0	8.94	49.9	12.31	10.25
30-40	33.0	5.86	52.5	11.25	7.44
30-80	35.1	7.32	54.5	10.12	6.16
45-20	30.3	5.54	49.0	4.81	6.20
45-60	32.2	7.01	50.8	6.94	6.13
60-40	30.6	8.32	57.4	9.44	6.36

was true even though the controlled-survey data were obtained from nine different farms, while the "typical" experiment data came from a small portion of a single field. Both the controlled-survey and the "typical" experiment data were affected by winterkill damage in 1962. The coefficients in the equations fitted to the "typical" experiment data were low. The $\bar{R}^2$ values for the equations fitted using the data from the "typical" experiment were less than zero; the $\bar{R}^2$ values using the actual yields from the controlled-survey experiment ranged from less than zero when yields from the 1/100 acre areas were used as the dependent variable to .134 when yields from the whole plot were used (see Table 12).

Standard deviations were calculated using the check plot yield differences for each treatment. In all but one case, the standard deviations for the yield differences were lower than that of the actual controlled-survey yields. The check plot on each farm was effective in removing some of the within-treatment yield variation.

Survey and controlled-survey comparisons.--The survey data were subdivided into four groups formed by classifying the data in a two x two table which included high and low levels of both N and P (see Table 22). Average yields obtained and average pounds of N, P and K applied were calculated. The levels of fertilizer nutrients were incorporated in prediction equations (see Table 13) derived from the controlled-survey data. The average check plot yield was added to the estimated Y to obtain the predicted Y. The predicted yields and average survey yields are shown in Table 19. The predicted yields using equation 1 were higher in every case than the average yields from the survey. This is consistent with the

Table 19. Analysis of survey data with yields predicted by equations derived from the controlled-survey experiment, 1962.

Equations from Table 13	Av. check plot yield	Low: av. N=29.2 pounds/acre Low: av. P=57.2 pounds/acre[2]		Low: av. N=32.3 pounds/acre High: av. P=86.8 pounds/acre[3]		High: av. N=57.4 pounds/acre Low: av. P=53.2 pounds/acre[4]		High: av. N=51.9 pounds/acre High: av. P=93.4 pounds/acre[5]		S_S^2 [1]
		Av. Y from survey	Y from C-S	Av. Y from survey	Y from C-S	Av. Y from survey	Y from C-S	Av. Y from survey	Y from C-S	
1	45.5	46.92	51.10	52.18	54.59	42.15	55.14	47.34	56.96	71.14
2	41.2	46.92	44.22	52.18	33.78	42.15	44.39	47.34	42.35	93.94
3	48.9	46.92	49.05	52.18	41.67	42.15	50.56	47.34	46.55	46.59
5	46.7	46.92	51.35	52.18	44.91	42.15	50.15	47.34	46.83	34.18

1/ $S_S^2 = \Sigma \frac{(\text{yield from the survey - predicted yield})^2}{n}$; n = 4

2/ Average level of K = 50.9.

3/ Average level of K = 76.6.

4/ Average level of K = 55.1.

5/ Average level of K = 66.2

information presented on pages 40 and 41. Equation 2 predicted yields close to the survey average in all groups except the low N and high P group. The range in predicted yields for a given equation was generally not great.

The analysis based on equation 1, derived from whole plot yields, proved to be the only one in which yields increased as higher amounts of either N or P were applied. The S_S^2 value was calculated for each equation in Table 19. The analysis based on 1/50 acre plots had the lowest S_S^2 value, while the analysis of the 1/10 acre plot had the highest S_S^2 value.

There were nine fields in the controlled-survey experiment. These fields were a small sample of the total number of fields in the universe of inquiry. This would reduce the representativeness of the data obtained in the controlled-survey experiment and could be a cause for the inability of the controlled-survey results to predict the survey results.

The subplot data from the controlled-survey typically were more heterogeneous than that from the whole plot. The possible inaccurate measurement of the amount of N and P applied to these areas introduced an element of random error that caused the "a" value to be overestimated and the "b" values to be underestimated when production functions were fitted to these data. The survey data was affected by certain farmers applying high levels of N and P to infertile soils and other farmers applying low levels to fertile soils. The survey yields varied little, while the amount of N and P applied varied more. The analysis of the survey data indicated that the yields responded little to applications of fertilizer. These facts about the subplot controlled-survey data and the survey data indicate why they were more comparable than the whole plot controlled-survey data and the survey data.

The analysis of the whole plot data from the controlled-survey indicated more response to N and P than in the equations fitted to the survey data. However, the response to P in the equations fitted to the whole plot controlled-survey data was not great (see Table 14). The results obtained from the equations fitted to the whole plot data are more typical of the way wheat was thought to respond to N and P on the farms than the survey results indicated.

Controlled-survey, "typical" experiment and survey comparisons.--The equation fitted to the approximate actual input data and to the yield data of the "typical" experiment (equation 2 in Table 17) was used as the basis for estimating yields using the four group average amounts of N and P obtained in the 1962 survey. When this equation was solved, assuming the "a" value equal to zero, the estimated yields were negative, the highest negative being -3.21 for the high N-low P survey group. The more N and P applied, the lower the predicted yield. Table 20 contains a summary of this analysis as well as a summary of an analysis in which the average check plot yields from the controlled-survey were substituted for the "a" value in the equation derived from the "typical" experiment. The estimate based wholly on the "typical" experiment data does not, for any group, come close to estimating the survey average yield. The low "a" value and the inability of the function to produce yield responses to varying N, P and K levels were the reasons the S_S^2 value equaled 205.18. In all cases, the higher the "a" value (check plot means), the closer the predicted yields were to the survey averages. Check plot means from the controlled-survey would have predicted survey yields more closely than the predictions based on the "typical" experiment analysis.

The incidence of winterkill in 1962 was a major cause of the heterogeneity in the data from the survey, controlled-survey and the "typical" experiment. For this reason, the data from the "typical" experiment were practically useless. The subplot controlled-survey data were also adversely

Table 20. Comparisons of yields predicted using the "typical" experiment data with controlled-survey check plot yields as "a" values, 1962.

Equation 2 from Table 17 with "a" value equal to	Low N		High P		Low N		High P		s_s^2
	Av. Y from survey	Y from "typical" expt.	Av. Y from survey	Y from "typical" expt.	Av. Y from survey	Y from "typical" expt.	Av. Y from survey	Y from "typical" expt.	
34.79 from equation 2 in Table 17	46.92	34.55	52.18	34.07	42.15	31.58	47.34	32.24	205.18
45.5 (whole plot check plot av.)	46.92	45.26	52.18	44.78	42.15	42.29	47.34	42.95	19.20
41.2 (1/10 acre area check plot average)	46.92	40.96	52.18	40.48	42.15	37.99	47.34	38.65	66.31
48.9 (1st 1/100 acre area check plot average)	46.92	48.66	52.18	48.18	42.15	45.69	47.34	46.35	8.13
44.5 (2nd 1/100 acre area check plot average)	46.92	44.26	52.18	43.78	42.15	41.29	47.34	41.95	26.86
46.7 (1/50 acre area check plot average)	46.92	46.46	52.18	45.98	42.15	43.49	47.34	44.15	12.65

affected by this winterkill damage. Even with the winterkill damage, the analysis of the whole plot data from the controlled-survey produced results which were useful.

An Economic Analysis of the 1962 Data

High profit levels of nutrients were calculated for the 1962 controlled-survey, utilizing equations 1, 2 and 5 from Table 13. The price ratios used were the same as those used in the economic analysis of the 1961 data. Table 21 contains a summary of this economic analysis. Only three of the coefficients in equations 1, 2 and 5 differed significantly from zero at the 10 percent level. None of the marginal physical products differed significantly from zero at the 20 percent level for nutrient levels included in Table 21. As the price ratios changed, the profit above fertilizer cost varied from $32 per acre to as much as $38 per acre, depending on the function on which the estimates were based. Ninety percent confidence limits were derived for the high profit MPP of N assuming P equal to 40 pounds per acre, using equation 5 from Table 13. These limits did not cross either price ratio line at positive levels of N. The null hypothesis $\beta_1 = \beta_2 = \beta_5 = 0$ (the total effect of N is zero) and $\beta_3 = \beta_4 = \beta_5 = 0$ (the total effect of P is zero) were not rejected (at the five percent level of significance) in any case when equations 1, 2 and 5 from Table 13 were used in the analysis. They were, however, generally rejected at between the 50 and 25 percent levels.

Profit levels derived from the equation based on an analysis of yields obtained from the whole plot changed little as nutrient levels varied. The high profit levels of N in this case did vary with prices more absolutely but less percentagewise than did those for the equations fitted to the subplot data. Equation 5, based on 1/50 acre data, produced the greatest percentage changes in the high profit levels of N and P as well as the greatest change in profit above fertilizer cost for the two price ratios considered. No detailed economic analysis was conducted as the data were heterogeneous.

The "typical" experimental data proved to be heterogeneous; thus, no economic analysis was attempted.

The data obtained from the survey of farmers were divided into four groups, with average N, P and K and yields determined for each group (see Table 22). Returns above fertilizer costs were calculated for two sets of price ratios. The returns obtained in the survey, Table 22, and those estimated from equations fitted to the controlled-survey data are quite similar (see Table 21).

Table 21. High profit levels of nitrogen and phosphate computed for two price ratios using equations 1, 2 and 5 from Table 13, 1962.

Equation No. from Table 13	Price of N = \$0.08/lb. Price of P = \$0.08/lb. Price of Wheat = \$2.20/bu.			Price of N = \$0.14/lb. Price of P = \$0.10/lb. Price of Wheat = \$1.60/bu.		
	High profit amounts of		Profit above fert. cost	High profit amounts of		Profit above fert. cost
	N	P		N	P	
	-----Pounds-----		Dollars	-----Pounds------		Dollars
1	87.9	40[1]	109.61	63.4	40[1]	71.20
2	30[1]	57.4	97.53	30[1]	51.3	65.50
5	29.1	36.7	109.64	16.9	22.8	75.94

[1] Assumed equal to mean levels of application.

Practical Conclusions Based on the 1961 and 1962 Experiments and Survey

1. The "typical" experiment produced data that were practically useless.

Table 22. Net returns above fertilizer costs for the four groupings of the 1962 survey data.

Group No.	Average levels of nutrients applied			Average yield	Returns above fertilizer costs[1/]	
	N	P	K		Price of N = $.08/lb. Price of P = $.08/lb. Price of Wheat = $2.20/bu.	Price of N = $.14/lb. Price of P = $.10/lb. Price of Wheat = $1.60/bu.
	Pounds			Bushels	Dollars	
1	29.2	57.2	50.9	46.9	93.21	62.18
2	32.3	86.8	76.6	52.2	100.72	65.72
3	57.4	53.2	55.1	42.2	80.69	50.86
4	51.9	93.4	66.2	47.3	88.46	55.10

[1/] Price of K equals $.06 per pound for both sets of prices.

2. Generally, the yields obtained in the controlled-survey from the whole plot were more closely related to N and P applied than were the yields from the subplots.
3. Yields from the subplots in the controlled-survey were not closely related to yields from the whole plots.
4. The analysis of the 1961 and 1962 controlled-survey data indicated that about 80 pounds of N and from zero to 60 pounds of P would have probably returned the most above fertilizer costs. The farmers in the surveys who applied about 40 pounds of N and about 80 pounds of P received the highest return above fertilizer costs. General fertilizer recommendations, based on part on other information, are found on p. 99.
5. The survey data were useful as measures of representativeness; however, the less strict controls imposed upon the survey farms allowed a range in soil fertility to exist in the wheat fields among farms. This resulted possibly in farmers with the more fertile fields applying less fertilizer and those with less fertile fields applying more fertilizer. The 1962 controlled-survey produced more representative data than did the "typical" experiment conducted that year.
6. The subplot data from the controlled-survey yield data were characterized by less response to applied N and P. The whole plot data were thought to be more representative of the defined universe than data from the subplots.
7. The marginal physical products of the nutrients in the production of wheat approached zero at the high profit point as the price of wheat increased relative to the price of nutrients. In addition to testing the null hypothesis that the universe MPP = 0 at the estimated high profit points, two other statistical procedures were utilized. In one, confidence

limits were placed on the high profit amounts of nutrients. In the other case, the null hypotheses that $\beta_1 = \beta_2 = \beta_5 = 0$ and $\beta_3 = \beta_4 = \beta_5 = 0$ were tested.[1] These procedures are felt to be more meaningful than either testing the significance of individual coefficients or testing whether or not the marginal physical product at the high profit combination of nutrients differs significantly from zero. These tests for both the 1961 and 1962 data generally indicated that N affected yield more than did P.

[1]The first hypothesis is that the effect of N on yield is zero; the second is that the effect of P on yield is zero.

CHAPTER V

SOME ECONOMICS OF EXPERIMENTATION WITH REFERENCE TO SIZE, SHAPE, REPLICATION AND LOCATION OF EXPERIMENTAL PLOTS

The costs and benefits associated with varying size, shape, replication and location of experimental plots are estimated and compared in this chapter. Answers are given to certain questions about the appropriate experimental designs to use in doing agronomic-economic research. The costs to consider in setting up an experiment include (1) the actual experimental costs and (2) the opportunity costs of using a certain experimental procedure. Some of the benefits to consider include (1) the reduction in the levels of within-treatment and/or unexplainced variance and (2) the increased representativeness of estimates.

The cost estimates for conducting various experiments are made first. The costs associated with plots varying in size and located within a single field are estimated. Next, estimates are made of the costs associated with varying plot sizes and varying number of replications in an experiment located within a 12 acre field. The costs of locating acre plots on 18 randomly chosen sites in the controlled-survey are estimated. Finally, the cost of conducting a survey is given.

The benefits associated with varying the size and shape of plots located within a single field include comparisons of the means from samples and the standard deviations from samples. For each size and shape, samples of sixty plots were obtained by replacement sampling of combinations of 1/100 acre plots from the plot harvested in 1/100 acre segments. Means and standard deviations were computed for each of these samples. Next, the benefits associated with varying plot sizes and varying number of replications in an experiment located within a 12 acre field were calculated. The means of the samples of various size plots were compared with the actual whole plot yield. The standard deviations of the samples were compared with each other. The controlled-survey was evaluated using data obtained from the surveys conducted in 1961 and 1962 and the "typical" experiment conducted in 1962.

Comparisons were made of the costs and benefits of using various sizes and shapes of plots, various numbersof replications, and experimental procedures involving location of plots, i.e., the controlled-survey versus the "typical" experiment.

The Costs of Varying Size, Replication and Location of Experimental Plots

The cost estimates are based, in part, on the author's experiences with the "typical" and controlled-survey experiments and the surveys conducted in 1961 and 1962. Chapter III contains a description of these studies. The costs of varying plot sizes within a single experimental field were estimated with help from the Farm Crops and Soil Science Departments at Michigan State University.[1]

The following includes cost estimates for (1) plots varying in shape and size using the "typical" experimental procedure, (2) plots varying in size and number of replications for the "typical" experimental procedure, (3) acre plots located on 18 randomly chosen sites for the controlled-survey procedure, and (4) the survey of a randomly selected group of farmers.

Cost Estimates for Plots, Varying in Size, Located within a Single Field[2]

The following is a description of costs for the various operations

---

[1]Professor Hubert Brown and Dr. Lynn Robertson helped make the estimates.

[2]See Table 27 for these estimates.

associated with experimental plot work. These estimates are for plots varying in size from 1/100 to one acre, assuming that six replications of ten treatments were included in an experiment laid out in a single field. It was also assumed that an experimental site as large as 60 acres[1] could be obtained as readily as one an acre in size. A plot shape that would facilitate planting and harvesting was assumed. Not included in the cost estimates was the wage of the researcher as this project would be only a portion of his total research load.

Location of plot area.--The researcher, along with a county agent, was assumed to take two eight-hour days to locate a suitable plot site.

Land rental.--A rental rate of $10 cash per acre was used as the cost of land for the experimental plots. In addition, each farmer kept the wheat harvested from the plot area. Border areas were estimated and included in the land rental. Table 23 contains the land rental costs as they vary with plot size.

Table 23. Derivation of cost estimates for land rental and seed for the various size plots.

Sixty plots of size	Acres			Land rental costs	Seed costs
	For plots	For border	Total		
	Acres			Dollars	
1/100	.6	.4	1.0	10.00	6.00
2/100	1.2	.4	1.6	16.00	9.60
5/100	3.0	.5	3.5	35.00	21.00
10/100	6.0	.5	6.5	65.00	49.00
20/100	12.0	1.0	13.0	130.00	78.00
50/100	30.0	1.5	31.5	315.00	189.00
100/100	60.0	2.0	62.0	620.00	372.00

[1]It would be difficult, if not impossible, to locate an acceptable area this large.

Seed costs.--Certified seed at $3 per bushel was assumed to be used for planting the plots and the border area at the rate of two bushels per acre. Table 23 includes these cost estimates.

Table 24. Soil sampling costs for various plot sizes.

Sixty plots of size	Days	Probes per plot	Cost
Acres	---------Number---------		Dollars
1/100	1	6	30
2/100	1	12	30
5/100	1	30	30
10/100	2	60	60
20/100	2	80	60
50/100	2.5	120	75
100/100	4	160	120

Fertilizer costs.--A composite design with six additional check observations at the 0-0 level of N and P was used. Forty pounds of K was assumed to be applied to all plots. A 30 percent excess of fertilizer nutrients was purchased to insure an adequate amount of nutrients for the plot area, after taking into account wastes in mixing fertilizer. The following prices of nutrients were assumed: $0.10, $0.09, and $0.06 per pound for N, P and K, respectively.

Soil sampling.--The number of probes per unit area was assumed to diminish as plot size increased. The number of days for the researcher to sample probe the plot area was estimated. Travel and subsistence were assumed to be $30 per day. Table 24 contains these cost estimates.

Soil testing.--It was assumed that the soil samples from the 60 plots could be tested at $3 per sample or $180 for each experiment.

Moving the fertilizer to the experimental site.--For the 1/100 and 2/100 acre plots, the fertilizer could be moved to the experimental site at planting time. When the cost of the 5/100 and 10/100 acre plots was determined, an additional separate operation was required to transport the N, P and K to the plot area. This involved one day at $20 per day for one truck and $12 per eight-hour day for each of two men. The 2/100 acre plots were estimated to require 1 1/2 days and the 5/100 and one-acre plots two days.

Planting and fertilizing the plots.--This operation assumed the use of three men, including the researcher. The other two men were paid $12 each per day. As the drill used was assumed to be owned by the University, no direct charges were made for its use. Travel and subsistence were included. Table 25 includes the derivation of the estimates of these costs.

Table 25. Derivation of cost estimates for planting and fertilizing the various sized plots.

Sixty plots of size	Time to complete planting	Wages	Travel and subsistence for the 3 men[1]	Total costs
Acres	Hours		Dollars	
1/100	3.00	9.00	30.00	39.00
2/100	3.25	9.75	30.00	39.75
5/100	4.00	12.00	30.00	42.00
10/100	5.25	15.75	30.00	45.75
20/100	7.75	23.25	30.00	53.25
50/100	15.25	45.75	60.00	105.75
100/100	27.75	83.25	90.00	173.25

[1]Includes moving machinery to the plot area.

Observing the plots.--It was assumed that the researcher could adequately observe the plots up to the one-acre size in three days. Four days were required for the acre plots. Travel and subsistence were assumed to equal $30 per day.

Harvesting, weighing and recording.--It took the author, two men and the combine operator 2 1/2 hours to complete the harvest of the 1962 1/100 acre plot experiment. It was assumed that an additional quarter hour per 1/100 acre increase in size would suffice to allow the larger plots to be harvested. The wages paid included $1.50 per hour for each of two men and $20 per hour for the combine, its operator and a truck. Table 26 contains cost and time information for the harvesting procedure.

Table 26. Derivation of cost estimates for the harvesting procedure of the various plot sizes.

Sixty plots of size	Time to complete harvesting	Cost at $23 per hour	Travel and subsistence	Total cost
Acres	Hours	Dollars		
1/100	2.50	57.50	30.00	87.50
2/100	2.75	63.25	30.00	93.50
5/100	3.50	80.50	30.00	110.50
10/100	4.75	109.25	30.00	139.25
20/100	7.25	166.75	30.00	196.75
50/100	14.75	339.25	60.00	399.25
100/100	24.75	569.25	90.00	659.25

Cost Estimates for Substituting Larger Plots for Replications, for Plots Located within a Twelve Acre Field

The costs associated with varying the size of plots and number of replications were derived in a manner similar to costs estimated earlier in the chapter. These estimates are contained in Table 27. Certain costs remained constant as plot size and number of replications varied; these included the costs of (1) locating the plot area, (2) land rental, (3) seed, (4) fertilizer, (5) soil testing, (6) moving fertilizer to farms, and (7) observing the plots. A brief description follows, explaing why the other costs varied.

Soil sampling.--Two days were assumed to be used to probe the twelve hundred 1/100 acre and six hundred 2/100 acre plots. One day was used for the other plots. The charge for travel and subsistence equaled $30 per day.

Table 27. Cost estimates for various sized plots located within a twelve acre field.

Operation	Plots, in one location, of indicated size			
	1/100 (1,200)[1/]	2/100 (600)	5/100 (240)	10/100 (120)
	Dollars			
Locating plot area	60	60	60	60
Land rental	130	130	130	130
Seed	78	78	78	78
Fertilizer	143	143	143	143
Soil sampling	60	60	30	30
Soil testing	180	180	180	180
Moving fertilizer to farms	44	44	44	44
Planting and fertilizing the plots	210	99	54	38
Observing the plots	90	90	90	90
Harvesting, weighing and recording	750	298	191	139
Estimated total cost	1,745	1,182	1,000	932

[1/] The number in parentheses is the number of replications for each plot size so that a 12 acre-field could be utilized.

Planting and fertilizing the plots.--

The 1/100 acre plots - Two men, thirty hours each to plant the 1,200 plots. With wages at $1.50 per hour per man and travel and subsistence equal to $60 per man, the total cost equaled $210.

The 2/100 acre plots - Two men, thirteen hours each to plant the 600 plots. With wages the same as above and $30 travel and subsistence per man, the total cost equaled $99.

The 5/100 acre plots - Two men, eight hours each to plant the 240 plots. With wages the same as above and travel and subsistence equal to $15 per man, the total cost equaled $54.

The 10/100 acre plots - Two men, six hours each to plant the 120 plots. With wages the same as above and travel and subsistence equal to $10 per man, the total cost equaled $38.

Harvesting, weighing and recording.--

The 1/100 acre plots - Thirty hours at $23 per hour plus $60 for travel and subsistence equals $750.

The 2/100 acre plots - Eleven hours at $23 per hour plus $45 for travel and subsistence equals $298.

The 5/100 acre plots - Seven hours at $23 per hour plus $30 travel and susbsistence equals $191.

The 10/100 acre plots - Four and three-quarters hours at $23 per hour plus $30 travel and subsistence equals $139.

Cost Estimates for the Controlled-Survey Experiment Utilizing 72 One-Acre Size Plots Located on 18 Sites

The controlled-survey experiment was conducted in Michigan in 1961 and 1962. The costs of conducting experiments in these two years were used as the basis for the costs that appear in Table 28.

Location of the plot area.--It took the author approximately ten days to complete this operation. Travel and subsistence were priced at $30 per day.

Land rental.--The 18 farmers were paid $50 each, with the total land rental cost equal to $900.

Seed cost.--Approximately five acres, including the border area, were seeded on each farm at a rate of two bushels per acre. The cost of the certified seed was approximately $3 per bushel.

Fertilizer cost.--This was calculated based on a 30 percent excess. The excess was used on the border area. An additional 12 check plots were planted, increasing the amount of the K carrier needed over the one-acre plots planted on one site. The prices of nutrients used were the same as those given previously--$0.10, $0.09 and $0.06 per pound for N, P and K, respectively.

Table 28. Cost estimates for various sized plots with experimental site varying in size, and for the controlled-survey one-acre plots.

Operation	Sixty plots, in one location, of indicated size							72 1-acre plots -[1/] 18 locations -- controlled-survey 1961
	1/100	2/100	5/100	10/100	20/100	50/100	100/100	
	Dollars							
Locating plot area	60.00	60.00	60.00	60.00	60.00	60.00	60.00	300.00
Land rental	10.00	16.00	35.00	65.00	130.00	315.00	620.00	900.00
Seed	6.00	10.00	21.00	49.00	78.00	198.00	372.00	540.00
Fertilizer	7.00	14.00	36.00	72.00	143.00	358.00	716.00	760.00
Soil sampling	30.00	30.00	30.00	60.00	60.00	75.00	120.00	210.00
Soil testing	180.00	180.00	180.00	180.00	180.00	180.00	180.00	216.00
Moving fertilizer to farms	0	0	44.00	44.00	66.00	88.00	88.00	152.00
Planting and fertilizing the plots	39.00	40.00	42.00	46.00	53.00	106.00	173.00	875.00
Observing the plots	90.00	90.00	90.00	90.00	90.00	90.00	120.00	180.00
Harvesting, weighing and recording	88.00	93.00	111.00	139.00	197.00	399.00	659.00	1,200.00
ESTIMATED TOTAL COST	510.00	533.00	649.00	805.00	1,057.00	1,860.00	3,108.00	5,333.00

[1/] Includes 12 extra check plots to permit one on each farm for use in eliminating between-farm differences.

Soil sampling.--This procedure would take approximately five days, if conducted so that 160 probes per acre were made. Thirty dollars were assumed to cover daily travel and subsistence.

Soil testing.--Seventy-two samples were tested at a cost of $3 per sample. The total cost for soil testing was $216.

Moving the fertilizer to the farms.--This operation utilized two trucks for two days at a cost of $20 per day per truck. Four men, one the author and three others hired at $12 per man per day, carried out this operation. The total cost equaled $152.

Planting and fertilizing the plots.--Three crews conducted this phase of the project. Each was responsible for six farms. The machinery used by each crew included a drill, a tractor, and a truck at a cost of $25, $25 and $75 each. Each crew included two men at a cost for wages, travel and subsistence of $40 per man per day. It took three days to complete this operation. The total cost equaled $875.

Observing the plots.--The author used approximately six days to observe the plots at a cost of $30 per day for travel and subsistence.

Harvesting, weighing and recording.--Three crews were utilized for this particular operation. Each crew contained two men hired at a cost of $40 each per day for wages, travel and subsistence. A total of two days was needed to complete the harvest.[1] A combine, its operator and a truck were rented at a cost of $40 per farm. The total cost was $1,200.

Cost Estimates for the Survey

These estimates were based on actual experiences encountered at Michigan State University in 1961 and 1962. The costs are presented not

---

[1] Three days were actually needed to complete this operation; however, each acre plot was sub-sampled, thus requiring an extra day per crew for harvesting the plots.

so that they can be compared with the costs of the "typical" or controlled-survey experiments. Rather, they are presented so that any interested researcher can get an estimate of the cost of obtaining a measure of representativeness. One hundred-sixteen observations were obtained in 1961 and 70 in 1962. The total costs for 1961 and 1962 were $320 and $120, respectively. Table 29 contains an explanation of the cost estimates.

Table 29. Costs associated with the survey initiated in 1960.

Operation	1961	1962
	Dollars	
One man interviewing; 8 days at $30 per day for subsistence and travel	240	0 1/
The procedure to obtain information about the fertilizer applied in the spring:		
One secretary, one day on campus	15	30 2/
Materials (stamps, envelopes, etc.)	25	50 2/
The procedure to obtain yields in the early fall:		
One secretary, one day on campus	15	15
Materials (stamps, envelopes, etc.)	25	25
	$320	$120

1/ As the same sample was used, the 1961 interviewing did not have to be repeated in 1962.

2/ An extra day was required for this operation in 1962.

A Summary of Cost Estimates

Cost estimates have been made for four different situations: (1) for plots varying in size with 60 replications for each size and with these plots located within an experimental field; (2) for plots varying in size and with varying numbers of replications located within a 12-acre experimental site; (3) for acre size plots located on 18 randomly chosen sites (the controlled-survey procedure); and (4) for farm fields randomly selected from a universe of farms (the survey).

The estimated costs for plots varying in size and located within an experimental site began at $510 for the 1/100 acre plots and increased to $3,108 for the acre plots (see Table 28). The costs which were responsible for most of this increase were land rental, seed, fertilizer and harvesting costs.

The costs were estimated for plots varying in size and in number of replications located within a 12-acre field. Cost estimates were made for four plot sizes, 1/100, 2/100, 5/100 and 10/100 acre. The costs for the 1,200 replications of the 1/100 acre plots equaled $1,745. The costs decreased to $932 for 120 replications of the 10/100 acre plots (see Table 25). The decreasing planting and harvesting costs accounted for the decrease in costs as plot size increased and number of replications decreased.

The controlled-survey procedure utilizing 72 one-acre plots located on 18 sites cost $5,333 (see Table 28). Land rental, planting and harvesting costs made up more than half of the costs in conducting this experiment.

The survey of farmers cost $320 in 1961 and $120 in 1962. The costs decreased, since the same sample of farmers was used in 1962 as in 1961. The interviewing did not have to be repeated.

The Benefits of Varying Size, Shape, Replication and Location of Experimental Plots

The benefits of varying size, shape and number of replications were measured (1) by considering the closeness of the sample mean yield to the yield from the whole plot area and (2) by considering the size of the standard deviation for each sample. The benefits of the controlled-survey procedure were determined by comparisons with (1) the 1962 "typical" experimental results and (2) the survey results in 1961 and 1962.

Benefits from Varying Size of Plots Located within a Single Field

One plot was harvested in 1/100 acre segments in 1961. This plot yielded 54.69 bushels per acre. See page 18 for a more detailed description of this procedure. This plot received an application of 48.5 pounds of N, 22.0 pounds of P, and 43.7 pounds of K per acre. This whole plot contained seventy-eight 1/100 acre plots, each 8 feet by 54 1/2 feet in size. These 1/100 acre plots were arranged 13 end to end and 6 side by side. (Appendix II contains this data.) Tile lines were located across the plot area and were 64 feet apart. Tile lines were located under two of the rows of six 1/100 acre plots side by side.

Plots of different sizes and rectangular shapes were formed synthetically, using the data from the 1/100 acre plots.[1] The shapes, which are described in Table 30, were limited by the boundary of the whole plot area. The sizes formed included the following: 1/100 acre, 2/100 acre, 5/100 acre, 10/100 acre, 20/100 acre and 50/100 acre. Random sampling, with replacement, was performed with the various sizes and shapes of plots. The sample size in each case equaled sixty. This is the same number of observations as that of the "typical" experiment conducted in 1962.

The mean and standard deviation were calculated for each sample to ascertain the benefits derivable from larger plots of varying shapes.[2] These are included in Table 30. The actual yield from the whole plot equaled 54.69 bushels per acre.

The means of the samples approached the whole plot yield, and the standard deviations of the sample diminished as the plot size increased.

---

[1]This procedure allowed the artificial creation of a population of wheat yields for each of the plot sizes and shapes considered.

[2]The sampling procedure followed was a factor influencing the means and standard deviations. These data are consistent with the results

Table 30. Analysis of samples of various sizes and shapes of plots located within an experimental field.

Shape	Plot size	Mean yield	Standard deviation
	Acre	----------Bushels----------	
Single	1/100	52.50	5.45
End to end	2/100	54.80	5.40
Side x side	2/100	54.70	4.12
End to end	5/100	55.19	4.03
Side x side	5/100	54.51	3.59
End to end	10/100	54.76	2.83
2 down x 5 across	10/100	54.94	2.98
5 down x 2 across	10/100	54.31	3.53
2 down x 10 across	20/100	54.78	1.22
4 down x 5 across	20/100	54.85	3.15
5 down x 4 across	20/100	54.69	3.48
5 down x 10 across	50/100	54.77	.99

For plots equal in size but varying in shape, no general statements can be made. For 2/100 and 5/100 acre plots, the sample means for the widest plots more closely approximated the whole plot yield than the sample means

---

from the following:

C. M. Loesell, "Size of Plot and Number of Replications Necessary for Varietal Trials with White Pea Beans," Journal of the American Society of Agronomy, Vol. 28, No. 7, June, 1936, pp. 534-547.

H. F. Robinson, J. A. Rigney, and P. H. Harvey, "Investigations in Plot Technique with Peanuts," Agricultural Experiment Station, North Carolina State College, Technical Bulletin 86, January, 1948.

Jonathan W. Wright and F. Dean Freeland, "Plot Size and Experimental Efficiency in Forest Genetic Research," Agricultural Experiment Station, Michigan State University, Technical Bulletin 280, July, 1960.

K. J. Frey and W. D. Baten, "Optimum Plot Size for Oat Yield Tests," Agronomy Journal, Vol. 45, No. 10, October 1953, pp. 502-504.

E. E. Down and J. W. Thayer, Jr., "Plot Technic Studies with Navy Beans," Journal of the American Society of Agronomy, Vol. 34, No. 10, October, 1942, pp. 919-922.

for the longer plots. The standard deviations were lower for the wider plots than for the longer ones. For the 10/100 and 20/100 acre plots, the sample means differed little as shape varied; however, the standard deviations increased as the plots became wider. Diagram 3 illustrates that for the longest plot for each size, the standard deviations decreased at a diminishing rate as plot size increased.

The Benefits of Substituting Larger Plots for Replications, for Plots Located within a Twelve-Acre Field

The plots considered were 1/100, 2/100, 5/100 and 10/100 of an acre in size. The longest shapes of these sizes were formed, using the acre plot that was harvested in 1/100 acre segments. Samples of each of the different plot sizes were chosen with replacement from this acre plot. See footnote on page 85. The number in each sample was equal to the number of replications that were necessary to utilize a 12-acre experimental area. The 1/100 acre plot was replicated 1,200 times, the 2/100 acre plot 600 times, the 5/100 acre plot 240 times, and the 10/100 acre plot 120 times. The means and standard deviations of the samples were calculated and included in Table 31. As would be expected, the means of the samples of the various sized plots were quite uniform. The 1/100 acre plot sample mean was the closest to the whole plot yield of 54.69 bushels per acre. The sample mean yields of the 5/100 and the 10/100 acre plots were closer to the whole plot yield than was the 2/100 acre plot sample mean. However, the standard deviations decreased as plot size increased and as number of replications decreased except for the 120 replications of the 10/100 acre plots. The standard deviation, in this case, was the largest, 9.24 bushels, of any of the other standard deviations (see Table 31).

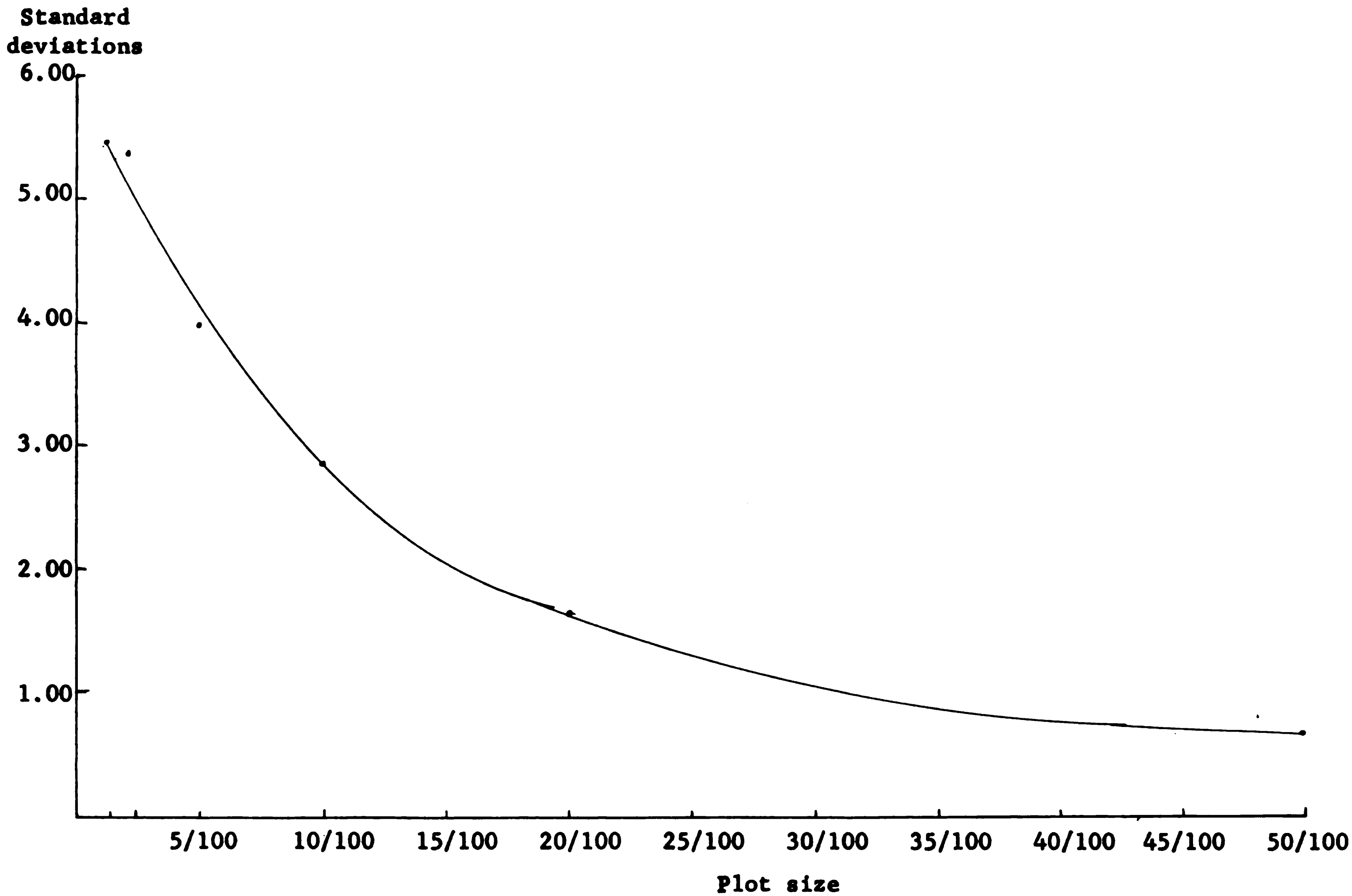

Diagram 3. Standard deviations of samples of sixty for selected plot sizes.

Table 31. Analysis of samples of various sized plots and varying numbers of replications.

Plot size	Replications	Standard deviation of the sample	Mean of the sample
Acres	Number	---------------Bushels---------------	
1/100	1,200	6.62	54.68
2/100	600	6.41	55.07
5/100	240	4.89	54.84
10/100	120	9.24	54.98

Benefits of Using the Controlled-Survey Procedure of Locating Acre Plots on Eighteen Sites

A survey was conducted to obtain data to use as a measure of representativeness. The 1961 controlled-survey data were compared with the data obtained from the 1962 "typical" experiment and the survey conducted in 1962. The whole plot S_S^2 values[1] from Tables 9 and 19 for the 1961 and 1962 controlled-survey experiments equaled 11.46 and 71.14 bushels, respectively. The S_S^2 value from Table 20 based on the results of the 1962 "typical" experiment equaled 205.18 bushels. The controlled-survey experimental results were considerably closer to the survey results of the particular years than were the results of the 1962 "typical" experiment.

In 1962, the standard error of estimates for the equation fitted to the whole plot controlled-survey data equaled 5.75 bushels. The standard error of estimates of the equation fitted to the "typical" experimental data equaled 7.23 bushels. It should be remembered, however, that the data both from the "typical" experiment and the controlled-survey were adversely affected by an incidence of winterkill in 1962.

The superiority of the controlled-survey procedure was due to the fact that data from acre sized plots were used in the analysis. This is

[1]See footnote 1 of Table 8 for the definition of this value.

demonstrated by the higher standard errors of estimates found in the computations utilizing the subplot yield data. (see Tables 4 and 13).

Some Cost and Benefit Comparisons

Costs and benefits have been developed:

1. for plots varying in size and located within a single field
2. for substituting larger plots for replications for plots located within a 12-acre field
3. for acre plots located at 18 different sites using the controlled-survey procedure as compared to the "typical" experimental procedure.

Some Comparisons of Costs and Benefits of Different Plot Sizes Located within a Single Field

When considering the longest possible plot for each of the plot sizes in Table 32, the means of samples approach the whole plot yield and the standard deviations diminish as plot size increases. Table 32 matches the decreases in standard deviations with increases in costs as size of plot increases. The size of plot for the researchers to choose depends upon the value attached to reduction in within-treatment variation and to the costs associated with attaining these reductions. These values will depend on the particular problem situation being investigated.

Table 32. Comparisons of means, standard deviations and costs for different plot sizes.

Changes in plot size		Changes in standard deviations			Changes in costs[1/]
From	To	From	To	Difference	
------Acres------		------------Bushels--------------			Dollars
1/100	2/100	5.45	5.40	-.05	23
2/100	5/100	5.40	4.03	-1.37	116
5/100	10/100	4.03	2.83	-1.20	156
10/100	20/100	2.83	1.22	-1.61	252
20/100	50/100	1.22	.99	-.23	803

[1/] Estimated cost for 1/100 acre plot size experiment equaled $510.

Without a value to attach to the standard deviations, no optimal solution can be determined. The value of increased accuracy (reduction in within-treatment variance) is not constant and, in fact, generally decreases after within-treatment differences reach moderately acceptable levels. Nor is the value uniform among experiments as the purpose of experiments may vary. When a researcher decides to use a certain plot size, he is implicitly assigning a value to this accuracy which he, in turn, judges is matched with costs so that the plot size he has specified is optimal. Table 32 should help researchers judge optimal plot sizes.

Some Comparisons of Costs and Benefits of Substituting Larger Plots for Replications

Table 33 contains the standard deviations and costs for the different sizes of plots with varying numbers of replications. It also contains the difference between the actual plot yield and the sample mean yields for the different plot sizes and for different numbers of replications of plots located within a synthetically formed 12-acre field. The standard deviations of the samples tended to increase as plot size increased and number of replications decreased. The differences between the actual yield and sample yields were not related to changes in plot size and number of replications. The costs decreased from $1,745 for the twelve hundred 1/100 acre plots to $932 for the one hundred-twenty 10/100 acre plots. An analysis of the information in Table 33 suggests that no benefits were lost when plot sizes were increased up to the 5/100 acre size with fewer replications; however, the costs decreased $745.

The Comparisons of Costs and Benefits for the Controlled-Survey Utilizing 72 Acre Plots Located on Eighteen Sites and for the "Typical" Experiment

The results of the survey conducted in 1961 permitted an evaluation of the representativeness of the 1961 controlled-survey. The 1962 survey data were used to evaluate the representativeness of the 1962 controlled-survey data and the 1962 "typical" experimental data. In 1962, comparisons of the controlled-survey and the "typical" experiment revealed a lower standard error of estimate for the whole plot data from the controlled-survey than for the data from the "typical" experiment. The cost of conducting the controlled-survey was $5,333, as compared to $510 for the "typical" experiment (see Table 28).

The analysis of the benefits of using various sizes of plots contained in this chapter indicates generally that larger plots produced data with the most benefits. This, along with the ability of the controlled-survey procedure to produce data representative of a broad, meaningful universe of farms, would indicate that some experimental procedure utilizing large plots located on randomly chosen sites would produce data characterized by relatively low levels of unexplained variance and which would be representative of a broad, useful universe of farms.

Table 33. Costs and benefits for samples of various sized plots and different numbers of replications.

Plot size	Replications	Standard deviations of the samples	Actual plot yield minus sample mean yield	Cost
Acres	Number	Bushels	Bushels	Dollars
1/100	1,200	6.62	.01	1,745
2/100	600	6.41	-.38	1,182
5/100	240	4.89	-.15	1,000
10/100	120	9.24	.29	932

CHAPTER VI

SUMMARY, CONCLUSIONS AND IMPLICATIONS

The main objectives of conducting agronomic-economic experiments are (1) to obtain data which lend themselves to statistical and economic analysis, i.e., which contain relatively low levels of unexplained variance when used to estimate fertilizer production functions and (2) to produce results which can be applied to a practical group of farms, i.e., which are representative of a broad, useful universe. In designing the experiments conducted in Michigan before 1961, attention was concentrated on the first objective under the assumption that the second would be attained rather automatically. In fact, modifications such as those discussed in Chapter II were made from time to time so that this objective could be better attained. These modifications included the reduction in plot size and the reduction in the number of treatments in the experimental design so that smaller experimental sites could be used. Some researchers at Michigan State University thought that more uniform soils would exist on these small experimental sites and thus, experimental error would be lowered. Experimental error or unexplained variance, however, was not lowered.

Small experimental sites of uniform soils were not easily found. When found, they were not representative of the soil contained in any large group of farm fields. Thus, the results of the experiments conducted on these sites were not applicable to a practical group of farms. In addition, the smaller experimental sites increased the possibility of introducing other sources of experimental error.

The controlled-survey procedure was developed in 1961 to attain better both of the above stated objectives. The effect of N and P on wheat yields was studied. This procedure included the use of acre size plots. These plots were located on randomly selected farm fields. Each field had to meet certain soil specification and rotational, drainage and management conditions specified in Chapter III. The larger plots of the controlled-survey procedure were selected to average out the experimental error due to nonuniform soil. The procedure of locating the plots on randomly selected farm fields was followed so that the results would be applicable to the universe from which the fields were selected.

A "typical" experiment was conducted in 1962 in order to compare its level of unexplained variance with that of the 1962 controlled-survey. This "typical" experiment was located within a field that met the same requirements as those imposed upon the fields included in the controlled-survey. The levels and signs of the coefficients in the equations that were fitted to the sets of data were also compared.

Surveys were conducted in both 1961 and 1962 to determine the representativeness of data obtained from the controlled-survey and "typical" experiments. Each farm included in the survey was intended to have the same general characteristics as the farms included in the controlled-survey. The characteristics of the survey farms, as discussed in Chapter III, were not so carefully checked as were those of the controlled-survey farms.

Summary and Conclusions for the 1961 and 1962 Experiments and Surveys

In an attempt to attain the two objectives stated earlier, the agronomic-economic experimentation conducted in Michigan in 1961 and 1962 was designed (1) to evaluate the controlled-survey procedure as a method of obtaining more representative and less heterogeneous data, (2) to study the effect of plot size by comparing data from the whole plot with that from subplots contained within each whole plot, (3) to obtain data using a survey of farmers that could be used to measure the representativeness of experimental data, (4) to compare the results from a "typical" experiment conducted in 1962 with both the controlled-survey and survey results, (5) to conduct an economic analysis using all the data, and (6) to make fertilizer recommendations to farmers, utilizing data from all the experiments and surveys conducted in 1961 and 1962.

Summary and Conclusions for the Controlled-Survey Experiments

Controlled-survey experiments were conducted in Michigan in 1961 and 1962. A check plot was located within each field. Following this procedure allowed adjustments to be made for the rather large between-farm differences that existed. The data, when adjusted for between-farm differences, yielded smaller unexplained variances for estimated functions than characterized results from the "typical" experiments conducted between 1954 and 1961. Further, the controlled-survey data are thought to be representative of a broader universe of farms than those early experiments.

Comparisons of the Whole Plot and Subplot Data from the Controlled-Survey Experiments

Each whole plot in the controlled-survey was sub-sampled so that comparisons could be made among various sized plots for the controlled-survey procedure. Within the controlled-survey experiments for both 1961 and 1962, the $\bar{R}^2$ values increased and the S values decreased for the equations fitted to data from the larger plot areas. Further, the signs of the coefficients in the estimated functions were, in general, more consistent with the law of diminishing returns for the larger harvested areas. Few individual coefficients in the equations fitted to the controlled-survey data differed significantly from zero at the ten percent level. More important than the effect of a single coefficient are the total effects of N or P on yield. The total effect of N on yield equal zero was considered by testing the null hypothesis $\beta_1 = \beta_2 = \beta_5 = 0$ for the equation Y = a +

$b_1N + b_2N^2 + b_3P + b_4P^2 + b_5NP + b_6K$. For the whole plot data, this null hypothesis was rejected at a level of significance which lay between the five percent and one percent levels. This same hypothesis was generally rejected at a level of significance between the 25 percent and five percent levels for the analysis of the data from the subplots. The total effect of P on yield equal zero was evaluated by testing the null hypothesis $\beta_3 = \beta_4 = \beta_5 = 0$. In general, this hypothesis was rejected at a level of significance which lay between the 25 percent and ten percent levels.

The above comparisons indicate that the estimates based on the whole plot data, as compared with those based on the subplot data (1) were more consistent with the law of diminishing returns, (2) were statistically more reliable, and (3) explained more variation in the yield data. The data from the whole plot proved superior to that from the subplots.

Summary and Conclusions of the "Typical" Experiment

The analysis based on the 1962 "typical" experiment produced a low $\bar{R}^2$ value, a high S value, and coefficients with signs that were inconsistent with the law of diminishing returns. The data obtained from the "typical" experiment did not provide any information that could be used by farmers.

Summary and Conclusions of the Comparisons of the Survey, Controlled-Survey, and the "Typical" Experiment Results

In 1961, data from the controlled-survey experiment were compared with the results of the survey of farms. Each equation derived from data from the whole plot and the subplots in the controlled-survey experiment was used in Chapter IV to estimate yields for the average levels of fertilizer nutrients applied by various groups of the survey farms. This procedure gave an estimate of the representativeness of the controlled-survey data.

The predicted yields were similar to the yields obtained by the farmers surveyed. The estimated variation of survey from predicted yields was lowest for the analysis that used the 1/50 acre subplot. The highest estimated variation calculated was for the analysis using the 1/5 acre subplot. Similar results were obtained from the 1962 data.

The smallest controlled-survey subplots proved to be the best predictors of yields for the extreme average applications of fertilizer from the survey because (1) the input data from the smaller subplots contained more random error than did those from the larger plot area, and this reduced the regression coefficients for the production functions estimated from data for the smaller plot segments, and (2) the farmers surveyed probably applied rates of fertilizer inversely to the levels of nutrients in the soil, i.e., the less nutrients in the soil, the higher the rate of fertilizer applied and vice versa. This would account for the small differences in yields associated with differences in fertilizer applied by the farmers surveyed and for the agreement with the less responsive functions based on the small subplot data.

For the controlled-survey, the whole plot data were superior to the subplot data in both 1961 and 1962. This indicates that a controlled-survey procedure of locating large plots on randomly selected farms would produce better data than other procedures. Whole farm fields with a one-acre check plot located within it might provide data that would be superior to the acre size plots utilized in the 1961 and 1962 controlled-survey experiments.

The controlled-survey experiment in 1962 proved to be superior to the "typical" experiment conducted that year. Both experiments were adversely affected by an incidence of winterkill as discussed in Chapter III. Despite the winterkill, the controlled-survey provided some useful information; however, the information obtained for the "typical" experiment was useless.

Summary and Conclusions for the Economic Analysis of the Controlled-Survey and Survey Data

The controlled-survey and survey data obtained in 1961 and 1962 provided information about the optimal amounts of N and P to apply in these years. In 1961, the optimal amounts equaled 92 pounds of N and 87 pounds of P. These were derived from the equation fitted to the whole check plot yield difference data for the controlled-survey, assuming the price of wheat equal to $2.20 per bushel and the price of N and P equal to $.08 each per pound. The optimal amounts of N and P for the other set of prices considered in Chapter IV were about 20 pounds less for each of N and P. For the optimal amounts of N and P, the marginal physical product of neither differed significantly from zero at the ten percent level of significance. Ninety percent confidence limits were calculated for the high profit levels of N and P. The lower limit crossed the price ratio line at 50 pounds of N; the upper limit did not cross the price ratio line (see Diagram 1). Neither confidence limit for the high profit level of P crossed the price ratio line at positive levels of P (see Diagram 2). The returns above fertilizer cost based on an equation fitted to the same controlled-survey data are contained in Chapter IV. The returns are calculated for the amounts of N and P that fell within the limits of the actual applications between 0 and 60 pounds of N and between 0 and 80 pounds of P. The combination of N and P that produced the highest return was 60 pounds of N and 70 pounds of P.

The 1961 survey data were grouped according to the amounts of N and P the farmers applied. The farmers that applied, on the average, 49 pounds of N and 88 pounds of P per acre received the highest returns above fertilizer costs. The general recommendation based on all of the 1961 data would call for an application of between 50 and 70 pounds of N per acre and between 50 and 90 pounds of P per acre.

In 1962, the optimal amounts of N and P were derived from the equation fitted to the 1/50 acre subplot data as this equation was the only one that agreed with the law of diminishing returns. These optimal amounts equaled 29 pounds of N and 37 pounds of P per acre, assuming the same prices as above. For these amounts, the MPP of N and P did not differ significantly from zero at the ten percent level. The 90 percent confidence limits at the optimal amounts of N and P did not cross the price ratio line at positive levels of P. The 1962 survey data were grouped according to the amounts of N and P the farmers applied. The group that obtained the highest return above fertilizer costs applied 32 pounds of N per acre and 87 pounds of P per acre. The general recommendation based on the 1962 data would call for an application of about 30 pounds of N and at least 40 pounds of P per acre.

A General Fertilizer Recommendation for Wheat Using the Survey and Controlled-Survey Data

The general fertilizer recommendation for wheat grown on a clay-loam soil under the management conditions specified in Chapter III would call for an application of between 40 and 60 pounds of N and between 60 and 80 pounds of P per acre. This is based partly on this research, and in the case of P, partly on other research and experiences. A minimal application of both N and P would return about as much per acre as higher applications; however, the higher applications would not diminish net returns and would give the farmer a chance to "cash in" in a particularly good year. The importance of this depends on the value of the "cash in." A high price of wheat would make the value of the "cash in" high and worth obtaining. A low wheat price would make the value of the "cash in" less worthwhile. Further, the carry-over of N and P for use by the next crop would have to be considered as a benefit for applying higher amounts of nutrients. On the other hand, farmers who have limited capital should consider the opportunity costs of investing their capital for fertilizer.

Summary and Conclusions for the Analysis of Costs and Benefits Associated with Varying the Size, Shape, Number of Replications, and Location of Plots

Exposte analysis of the experiment and survey data permitted some conclusions to be reached about the costs and benefits of varying size, shape, number of replications, and location of experimental plots. Data from the 1961 and 1962 surveys and controlled-surveys and the 1962 "typical" experiment, as well as data from an acre size plot that was harvested in 1/100 acre segments, were used as the basis for these conclusions.

One plot within the 1961 controlled-survey experiment was harvested in 1/100 acre segments. Using this data, plots of various sizes and rectangular shapes were synthetically formed. Means and standard deviations were calculated for samples of the various sizes and shapes of rectangular plots to determine the benefits associated with various plot sizes, shapes and replications.

Plot Size and Shape Comparisons

Some information about the appropriate size of plot resulted (see Chapter V). However, little information about the appropriate shape of an experiment plot was obtained. The costs and benefits were estimated for different plot sizes in experiments theoretically located within a single field. These estimates indicated that increased benefits are associated with increased plot sizes when number of replications is held constant. Costs also increased as plot size increased. Some balance between the costs and the value of the benefits can be reached by a researcher using the information in Chapter V. The decision he reaches will depend on his research outlook, the amount of funds he has, and the problem with which he is concerned. However, the data presented demonstrate clearly the advantages of using larger plots, for certain purposes at least.

Substitution of Larger Plots for Replication

Estimates were made for the costs and benefits of substituting larger plots for replications on an experimental site that was assumed to remain the same size. The benefits increased as plot size increased and number of replications decreased up to the largest plot with the fewest replications. The costs decreased as the plot size increased and the number of replications decreased. No benefits were lost, and costs decreased from $1,745 to $1,000 when two hundred-forty 5/100 acre plots were used instead of the one thousand two hundred 1/100 acre plots. Thus, a researcher would use the two hundred-forty 5/100 acre plots instead of the one thousand two hundred 1/100 acre plots.

Cost and Benefit Comparisons of the Controlled-Survey with the "Typical" Experiment

The cost of the controlled-survey procedure in 1961 of locating 72 one-acre plots on 18 randomly selected sites was estimated to equal $5,333. The "typical" experiment that contained sixty 1/100 acre plots located within one field cost $510. The benefits of the controlled-survey were determined, using the results of the surveys conducted in 1961 and 1962 and the results of the "typical" experiment conducted in 1962. The controlled-survey procedure produced data representative of a broad universe of farms as indicated by the data obtained in the surveys. The results of the controlled-survey proved to be much more applicable to a practical universe of farms than the results of the "typical" experiment. Furthermore, the estimates based on the controlled-survey data were subject to less variance than those based on the "typical" experiment.

Some General Conclusions and Implications

The controlled-survey technique provides a possible means by which both research and extension personnel may jointly approach a problem. The needs of the "extender" can be partially met if he and the researcher mutually design the project. The random group of farmers cooperating in the project would generally provide new contacts for the "extender." Both the researcher and the "extender" would become more aware of the problems each face in their work. Research information can be attained, while the applicability of the results will benefit the "extender." It is the author's opinion that one of the primary results of the two years of experimentation has been to demonstrate the joint extension-research potentialities of the controlled-survey experiment.

In fact, such a project was initiated in Michigan in the fall of 1962. TVA, county agents in Michigan, and researchers at Michigan State University mutually designed the experiment. Certain plots on each of the 24 farms are utilized by TVA to test and demonstrate the potentials of new TVA fertilizers. Others are used by county agents to test and demonstrate the effects on wheat yields of zinc applications and top-dressing with N and a complete fertilizer. The remaining plots are used by researchers to obtain yield data for various levels and combinations of N and P applications.

While this thesis has been organized about the fertilization of wheat, the author feels that the controlled-survey technique has wider applicability. The possibilities of applying this general technique within the other agricultural sciences appear to be great. Animal herds, for example, could be randomly chosen from a broadly specified group of farms to test the effect various feeding programs might have on milk or meat production. More research needs to be undertaken to determine the extent of the applicability of the controlled-survey as a research-extension technique in other agricultural fields.

When research and extension funds are limited, the application of the controlled-survey technique could prove to be the optimum way to allocate these funds. The author believes that the controlled-survey technique should be considered as an approach when an underdeveloped country is attempting to obtain a maximum amount of both research and extension information from a given outlay of funds.

Historically, a problem which has faced farm planners and budgeters, and more recently linear programmers, has been that of obtaining reliable input-output coefficients. The author believes that input-output information obtained via the controlled-survey approach will be more reliable and more generally applicable than that obtained in the past.

Finally, the author believes that the most important contribution of this thesis is the explicit specification of the general population from which the sample farms were chosen. This should encourage future researchers to explicitly define the population about which they hope to make inferences.

BIBLIOGRAPHY

Books and Theses

Baum, E. L., Heady, Earl O., Pesek, John T., and Hildreth, Clifford G. (editors). Fertilizer Innovations and Resource Use. Ames: The Iowa State College Press, 1957.

_________., Heady, Earl O., Blackmore, John (editors). Economic Analysis of Fertilizer Use Data. Ames: The Iowa State College Press, 1956.

Bertolotto, Hernan. "Economic Analysis of Fertilizer Input-Output Data from the Cauca Valley, Colombia." Unpublished Master's thesis, Department of Agricultural Economics, Michigan State University, 1959.

Cochran, William G. Sampling Techniques. New York: John Wiley & Sons, Inc., 1953.

Delgado C., Enrique. "Economic Optima from an Experimental Corn-Fertilizer Production Function, Cauca Valley, Colombia, S.A." Unpublished Master's thesis, Department of Agricultural Economics, Michigan State University, 1962.

Federer, Walter T. Experimental Design. New York: The Macmillan Company, 1955.

Fisher, Ronald A. The Design of Experiments. 6th edition. London: Oliver and Boyd, 1953.

_________. Statistical Methods for Research Workers. 13th edition. London: Oliver and Boyd, 1958.

Heady, Earl O., Dillon, John L. Agricultural Production Functions. Ames: Iowa State University Press, 1961.

Hoel, Paul G. Introduction to Mathematical Statistics. 2nd edition. New York: John Wiley & Sons, Inc., 1954.

Knetsch, Jack L. "Methodological Procedures and Applications for Incorporating Economic Considerations into Fertilizer Recommendations." Unpublished Master's thesis, Department of Agricultural Economics, Michigan State University, 1956.

Love, Harry H. Experimental Methods in Agricultural Research. Rio Piedras, Puerto Rico: The Agricultural Experiment Station of the University of Puerto Rico, 1943.

Mahalanobis, P. C. Experiments in Statistical Sampling in the Indian Statistical Institute. Bombay: Asia Publishing House, 1961.

Sundquist, Wesley Burton. "An Economic Analysis of Some Controlled Fertilizer Input-Output Experiments in Michigan." Unpublished Ph.D. dissertation, Department of Agricultural Economics, Michigan State University, 1957.

Wright, Philip A. "An Economic Analysis of Potato Yields on Certain Ontario Mineral Soils in Controlled Fertilizer Experiments, 1954-1956." Unpublished Ph.D. dissertation, Department of Agricultural Economics, Michigan State University, 1962.

Bulletins and Articles

Box, G. E. P. and Draper, Norman R. "A Basis for the Selection of a Response Surface Design," Journal of the American Statistical Association, Vol. 54, No. 287 (September, 1959), 622-654.

Doll, John P., Jebe, Emil H. and Munson, Robert D. "Computation of Variance Estimates for Marginal Physical Products and Marginal Rates of Substitution," Journal of Farm Economics, XLII, No. 3 (August, 1960), 596-607.

Down, E. E. and Thayer, J. W., Jr. "Plot Technic Studies with Navy Beans," Journal of the American Society of Agronomy, Vol. 34, No. 10 (October, 1942), 919-922.

Frey, K. J. and Baten, W. D. "Optimum Plot Size for Oat Yield Tests," Agronomy Journal, Vol. 45, No. 10 (October, 1953), 502-504.

Hoffnar, Bernard and Johnson, Glenn L. "Agronomic-Economic Experimentation at Michigan State University--A Summary Emphasizing the Cooperative Research with T.V.A.," Agricultural Economics Mimeographed Report 888, 1962.

Jessen, Raymond J. "Statistical Investigation of a Sample Survey for Obtaining Farm Facts," Agricultural Experiment Station, Iowa State College, Research Bulletin 304, June, 1942.

Johnson, Glenn L. "A Critical Evaluation of Fertilization Research," Farm Management in the West--Problems in Resource Use, Report No. 1, The Economics of Fertilizer Application. Conference Proceedings of the Farm Management Research Committee of the Western Agricultural Economics Research Council, Corvallis: (1956), 33-45.

Loesell, C. M. "Size of Plot and Number of Replications Necessary for Varietal Trials with White Pea Beans," Journal of the American Society of Agronomy, Vol. 28, No. 7 (June, 1936), 534-547.

Robinson, H. F., Rigney, J. A., and Harvey, P. H. "Investigations in Plot Technique with Peanuts," Agricultural Experiment Station, North Carolina State College, Technical Bulletin 86 (January, 1948).

Sundquist, W. B. and Robertson, L. S., Jr. "An Economic Analysis of Some Controlled Fertilizer Input-Output Experiments in Michigan," Agricultural Experiment Station, Michigan State University, Technical Bulletin 269 (1959).

Wassom, C. E. and Kalton, R. R. "Estimations of Optimum Plot Size Using Data from Bromegrass Uniformity Trials," Agricultural Experiment Station, Iowa State College, Research Bulletin 396 (March, 1953), 296-320.

Wright, Jonathan W. and Freeland, F. Dean. "Plot Size and Experimental Efficiency in Forest Genetic Research," Agricultural Experiment Station, Michigan State University, Technical Bulletin 280 (July, 1960).

APPENDIX I

Controlled-survey data, Michigan, 1961.

Treatment			Soil tests		Yields, different sized plots			
					Whole (approx. 1 acre)	1/5 acre	1/100 acre	1/100 acre
N	P	K	Pr	Kr				
Pounds					Bushels			
25.3	0	34.3	36	162	60.0	60.5	58.4	63.5
9.8	38.9	26.1			58.4	51.0	45.6	46.3
0	0	39.3			57.5	49.4	45.1	47.6
15.6	28.7	24.9			73.5	65.0	64.5	64.1
93.6	135.7	118.0			83.0	72.6	68.5	73.5
15.0	20.3	40.1	58	223	67.0	66.5	61.4	59.0
15.4	61.4	40.7			65.0	58.5	48.8	50.6
0	0	49.5			49.5	44.2	52.2	48.4
53.9	36.2	35.8			74.3	59.5	73.8	66.7
0	51.0	51.9	43	113	55.6	56.0	59.1	62.7
0	0	54.5			52.7	52.7	57.6	50.2
36.6	16.6	32.5			64.3	63.4	51.4	48.1
56.9	76.2	50.5			63.0	60.1	48.1	55.8
34.4	0	46.1	40	152	56.1	56.9	47.9	51.2
27.2	36.5	36.1			66.5	63.0	51.2	46.8
0	0	63.8			48.4	55.1	33.2	36.8
30.1	80.2	40.6			63.6	68.2	57.0	61.3
0	44.2	43.8	40	223	49.4	49.7	52.4	56.9
0	0	78.0			42.8	45.2	46.2	50.0
31.2	41.4	40.9			51.1	50.3	35.6	44.5
64.7	43.6	42.6			59.4	66.8	64.3	69.4
13.6	19.4	40.6	46	122	61.6	64.2	61.9	54.8
55.9	25.6	49.6			72.3	69.3	65.7	61.6
0	0	48.1			58.7	61.1	55.6	56.8
24.7	65.9	32.6			70.6	55.4	70.6	79.5
34.7	0	46.4	23	148	49.5	52.4	56.6	53.4
0	0	31.6			41.3	45.6	46.9	46.9
51.9	23.2	46.4			56.5	56.5	51.8	56.6
17.3	23.2	46.4			49.6	47.3	45.3	48.5
34.8	46.6	30.9	43	271	63.1	60.9	57.6	49.3
30.0	40.4	40.2			59.6	59.7	70.7	49.3
0	0	29.7			55.3	56.6	52.6	50.9
22.4	73.8	36.6			65.3	65.6	52.6	64.2

APPENDIX I - continued

Treatment N	Treatment P	Treatment K	Soil tests Pr	Soil tests Kr	Yields, different sized plots: Whole (approx. 1 acre)	1/5 acre	1/100 acre	1/100 acre
Pounds					Bushels			
67.0	45.0	44.8	33	207	62.7	62.1	63.4	63.4
0	0	42.6			58.0	59.5	63.4	65.1
16.7	67.5	45.9			61.2	64.9	68.3	71.6
0	53.5	53.3			59.5	59.6	63.4	60.2
0	38.5	38.5	58	192	61.1	60.5	67.1	60.6
38.0	40.8	40.8			63.9	65.4	72.1	78.6
0	0	33.6			56.2	54.6	63.9	63.9
30.6	84.0	42.7			61.9	65.4	63.9	80.3
49.9	22.1	44.1	34	179	64.5	59.3	67.7	72.5
0	0	31.3			49.0	48.0	53.2	56.4
16.6	22.4	44.8			55.8	52.0	53.2	59.6
49.9	67.3	45.2			61.8	69.8	69.3	72.5
31.8	0	44.8	33	152	46.8	46.2	50.2	40.8
64.6	44.6	46.0			59.3	65.2	65.9	50.2
0	0	40.6			42.6	47.0	44.0	39.2
15.9	21.9	44.8			48.7	57.8	45.5	45.5
29.7	0	37.4	28	122	61.8	58.1	60.8	51.4
0	0	61.9			55.8	56.0	60.0	57.5
49.1	21.5	43.7			71.4	69.6	70.6	65.3
60.8	41.1	40.8			72.9	82.5	78.7	80.4
55.8	74.7	49.3	23	45	60.2	59.0	56.8	48.8
39.3	52.7	52.2			56.4	55.0	48.8	37.9
0	0	62.2			43.7	43.2	38.8	28.2
21.0	28.4	55.3			54.8	53.0	45.9	48.3
0	44.6	43.7	43	148	54.7	51.9	49.1	51.9
0	0	78.9			45.2	45.0	41.6	43.8
17.5	70.0	46.3			56.0	53.1	59.9	57.2
34.5	92.2	45.4			51.6	65.0	67.2	54.7
33.3	0	43.8	54	96	47.1	49.1	50.2	43.3
17.8	23.8	47.1			49.4	47.3	41.3	41.7
0	0	55.4			42.5	44.9	48.5	21.8
0	44.3	43.9			41.0	40.7	44.1	36.8
48.5	22.0	43.7	41	122	58.9	-	-	-
0	0	74.2			48.3	40.2	44.8	45.6
31.5	43.0	41.6			56.5	51.0	50.6	49.4
16.4	65.5	44.0			53.9	50.9	50.6	45.2

APPENDIX I - concluded

Treatment			Soil tests		Yields, different sized plots			
N	P	K	Pr	Kr	Whole (approx. 1 acre)	1/5 acre	1/100 acre	1/100 acre
----------------Pounds----------------					-------------Bushels------------			
63.4	42.3	41.8	50	64	61.4	59.9	56.0	49.4
31.7	38.0	41.6			57.4	59.5	52.7	47.3
0	0	67.1			47.4	49.6	45.3	40.8
32.4	86.2	42.4			60.7	53.4	53.9	56.4

APPENDIX II

Data from plot harvested in 1/100 acre segments, Michigan, 1961.[1]

Yield[2]					
Bushels per acre					
46.2	52.5	57.5	60.0	56.2	60.0
46.7	54.6	55.4	60.4	56.7	63.3
49.6	58.3	57.5	60.8	61.7	64.6
52.5	59.2	58.3	60.0	57.9	55.4
55.4	60.0	62.1	55.8	55.4	65.8
54.6	55.8	56.2	58.3	53.7	66.7
52.5	52.1	60.0	58.3	60.4	64.6
50.0	54.6	52.9	53.3	52.9	65.4
52.9	55.0	51.7	52.5	44.6	57.1
51.2	51.7	48.3	48.3	41.7	48.3
51.7	52.1	50.0	53.3	45.0	47.9
52.5	53.3	53.7	53.7	47.9	46.7
50.0	52.1	55.4	56.2	45.0	54.2

[1]Total yield from the area equals 54.69 bushels per acre.

[2]Plots were 8 feet wide and 54 1/2 feet long.

APPENDIX III

Survey of farmers, Michigan, 1961

Treatment			Yield
N	P	K	
---Pounds---			Bushels
39.0	39.0	39.0	60.0
39.0	39.0	39.0	57.3
45.0	72.0	54.0	60.0
82.0	30.0	30.0	75.0
34.0	64.0	44.0	60.0
34.0	64.0	44.0	60.0
53.5	70.0	70.0	70.3
17.5	70.0	70.0	52.5
39.0	39.0	39.0	60.8
42.0	96.0	60.0	55.0
10.0	40.0	20.0	57.7
10.0	40.0	20.0	58.3
48.0	48.0	48.0	50.0
48.0	48.0	48.0	45.0
48.0	48.0	48.0	50.0
30.0	30.0	30.0	69.2
36.0	36.0	36.0	68.0
43.5	84.0	57.0	58.0
43.5	84.0	57.0	57.0
39.0	84.0	54.0	73.3
37.8	79.2	51.6	70.4
48.5	40.5	40.5	37.0
36.5	74.0	74.0	61.3
32.0	56.0	56.0	50.0
32.0	56.0	56.0	81.3
54.0	72.0	36.0	71.0
54.0	72.0	36.0	68.0
54.0	72.0	36.0	70.0
36.0	36.0	36.0	50.0
36.0	36.0	36.0	56.7
40.0	40.0	40.0	55.5
46.5	72.8	60.0	64.2
39.0	34.0	84.0	62.1
52.0	80.0	80.0	66.9
52.0	80.0	80.0	62.4
72.9	72.9	72.9	67.0
60.0	60.0	60.0	45.0
18.6	38.4	25.2	71.0
20.4	45.6	28.8	67.0
45.0	108.0	66.0	65.0
42.0	96.0	60.0	70.0

APPENDIX III - continued

Treatment N	Treatment P	Treatment K	Yield
Pounds			Bushels
42.0	96.0	60.0	60.0
10.0	40.0	20.0	63.0
34.0	64.0	44.0	55.0
49.8	49.8	49.8	65.0
49.8	49.8	49.8	59.0
34.0	64.0	64.0	52.7
69.6	36.0	36.0	62.5
34.0	64.0	64.0	62.5
33.0	78.0	78.0	52.7
42.8	99.0	99.0	63.0
74.0	108.0	72.0	88.0
20.0	80.0	80.0	62.0
17.5	70.0	70.0	72.0
20.0	80.0	80.0	37.3
34.0	64.0	64.0	65.0
24.0	96.0	48.0	64.0
24.0	96.0	48.0	67.9
20.0	80.0	80.0	65.0
20.0	80.0	80.0	63.0
19.3	77.0	77.0	68.7
38.0	98.0	98.0	68.2
39.0	93.0	57.0	62.1
48.0	48.0	48.0	64.0
30.5	68.0	68.0	75.0
30.5	68.0	68.0	70.0
36.5	74.0	74.0	66.0
36.5	74.0	74.0	63.0
35.5	88.0	88.0	62.3
52.0	96.0	256.0	50.0
25.0	100.0	100.0	48.5
52.0	96.0	136.0	70.0
52.0	96.0	136.0	70.0
32.0	56.0	56.0	62.0
35.0	40.0	40.0	61.0
31.5	54.0	54.0	91.8
84.5	70.0	70.0	67.0
34.0	82.0	82.0	64.0
34.0	82.0	82.0	60.0
12.0	48.0	48.0	71.9
42.2	108.8	64.4	56.8
45.0	60.0	60.0	64.2
10.0	40.0	40.0	58.0
36.0	106.0	36.0	54.0
36.0	72.0	72.0	55.0
38.0	32.0	32.0	60.0
32.0	56.0	56.0	50.0
63.0	63.0	63.0	53.0

APPENDIX III - concluded

Treatment			Yield
N	P	K	
--------------- Pounds ---------------			Bushels
28.8	95.0	49.5	60.0
76.0	38.1	38.1	48.3
74.6	37.4	37.4	49.4
41.5	70.0	70.0	60.9
47.6	46.4	46.4	44.0
27.0	63.0	63.0	55.0
25.0	70.0	70.0	40.0
25.0	70.0	70.0	45.0
48.0	48.0	48.0	50.0
14.0	56.0	56.0	58.0
19.5	19.5	79.5	65.6
28.0	58.0	58.0	55.0
30.0	60.0	40.0	41.3
51.0	60.0	30.0	70.2
51.0	105.0	69.0	60.0
51.0	105.0	69.0	60.0
47.0	76.0	76.0	60.0
43.8	74.4	44.4	60.0
45.0	108.0	66.0	76.9
45.0	90.0	90.0	60.0
42.0	42.0	42.0	70.0
36.0	90.0	54.0	81.3
36.0	90.0	54.0	65.0
45.0	90.0	60.0	53.0
39.6	93.6	57.6	66.0
65.0	30.0	30.0	67.0
65.0	30.0	30.0	69.0
75.0	30.0	30.0	62.0

APPENDIX IV

Controlled-survey data, Michigan, 1962.

Treatment			Soil tests		Yields, different sized plots			
N	P	K	Pr	Kr	Whole (approx. 1 acre)	1/10 acre	1/100 acre	1/100 acre
----------------	Pounds	----------------			-------------	Bushels	-------------	
24.7	0	33.0			44.2	49.1	51.7	51.7
16.0	21.3	42.6			44.2	42.6	61.8	48.4
0	46.5	46.5			44.8	46.4	53.4	45.1
48.4	21.5	43.0	13	174	50.6	51.9	55.1	60.1
45.4	60.5	40.3			50.4	51.3	51.7	53.4
0	0	43.4			38.8	40.9	53.4	50.1
58.9	39.3	39.3			52.8	49.9	58.5	55.1
16.0	63.9	42.6			51.9	49.8	53.4	50.1
15.8	21.1	42.1			45.5	33.4	51.8	46.8
0	50.8	50.8			43.5	42.9	45.1	48.4
62.7	41.8	41.8	18	167	48.4	42.6	43.4	45.1
30.3	40.4	40.4			46.4	47.3	45.1	48.4
0	0	46.4			45.2	45.1	40.1	45.1
31.6	84.3	42.1			52.8	49.1	43.4	50.1
34.7	46.3	46.3			39.4	48.3	56.8	50.1
18.0	71.9	47.9			46.0	50.8	56.8	55.1
36.2	96.6	48.3			43.9	45.9	43.4	40.1
0	0	38.8	33	181	38.8	46.3	48.4	46.8
51.1	22.7	45.5			47.6	47.9	49.3	49.3
52.3	69.7	46.5			47.4	45.9	45.1	41.8
33.0	0	44.0			45.6	37.4	48.4	50.1
34.8	0	46.4			70.6	-	64.2	58.3
15.8	63.3	42.2			-	-	-	-
46.8	62.5	41.6			64.7	51.9	56.7	60.8
0	49.3	49.3	18	223	49.1	41.0	45.8	47.5
29.4	39.2	39.2			55.8	46.8	58.3	54.2
0	0	45.5			55.0	42.8	52.5	44.2
33.5	89.4	44.7			55.3	51.3	40.0	54.2
52.8	70.4	46.9			46.4	53.0	65.0	66.7
69.7	31.0	62.0			52.3	28.5	26.7	56.7
0	58.5	58.5			51.3	47.3	60.0	66.7
73.7	49.1	49.1	19	167	60.4	49.1	71.7	60.0
0	0	49.1			50.1	45.2	60.8	67.5
18.4	73.6	49.1			54.7	47.1	56.7	67.5
18.4	24.5	49.1			36.6	48.0	49.2	73.3

APPENDIX IV - concluded

Treatment			Soil tests		Yields, different sized plots			
N	P	K	Pr	Kr	Whole (approx. 1 acre)	1/10 acre	1/100 acre	1/100 acre
Pounds					Bushels			
83.5	55.6	55.6			57.1	-	68.3	-
60.2	26.8	53.5			55.9	44.7	57.5	52.5
0	0	59.3			42.6	-	58.3	37.0
25.1	33.4	66.9	22	160	47.1	-	60.8	39.7
52.1	139.1	69.5			52.3	39.4	49.2	16.4
46.8	62.4	62.4			60.5	49.7	51.7	47.7
44.6	0	59.5			57.9	50.2	65.0	40.1
18.9	75.8	50.5			66.5	-	-	-
75.6	50.4	50.4			74.5	61.3	66.7	61.7
38.7	0	51.6			45.1	-	41.7	38.3
57.8	100.9	50.5	17	237	73.6	46.3	58.3	53.3
0	0	55.4			55.4	41.7	41.7	48.3
34.9	46.5	46.5			69.1	55.0	50.0	66.7
0	55.5	55.5			54.2	41.0	35.0	70.0
35.7	95.3	47.7			49.2	-	45.0	41.7
0	0	49.7			36.7	-	28.3	31.7
53.4	71.2	47.4			47.3	-	38.3	45.0
30.7	40.9	40.9	15	237	43.9	-	35.0	40.0
17.1	22.8	45.7			40.7	-	33.3	36.7
47.3	21.0	42.1			43.6	-	35.0	36.7
34.7	0	46.3			36.0	-	33.3	33.3
48.0	63.9	42.6			48.6	43.8	49.2	43.3
17.4	23.2	46.4			43.1	33.6	51.7	37.5
45.3	20.1	40.3			44.1	31.9	48.3	27.5
0	50.8	50.8	14	188	39.2	24.1	51.7	14.2
16.6	66.5	44.3			45.8	25.4	55.0	31.7
65.9	43.9	43.9			50.9	27.2	59.2	32.5
0	0	41.2			47.3	26.4	56.7	30.0

APPENDIX V

Survey of farmers, Michigan, 1962.

Treatment			Yield
N	P	K	
--------------------Pounds	----------------------		Bushels
51.0	60.0	30.0	42.6
51.0	60.0	30.0	40.7
35.0	60.0	30.0	50.0
22.5	90.0	90.0	50.0
22.5	90.0	90.0	45.0
45.8	104.3	65.3	49.0
44.9	100.7	63.5	46.0
44.9	100.7	63.5	40.0
54.0	54.0	54.0	54.0
54.0	54.0	54.0	47.0
54.0	54.0	54.0	38.8
54.0	54.0	54.0	48.0
36.5	74.0	74.0	47.0
72.0	100.0	66.0	48.9
60.0	60.0	60.0	33.0
37.0	58.0	58.0	30.0
54.0	72.0	36.0	52.0
49.5	54.0	54.0	35.0
30.0	66.0	42.0	46.3
30.0	46.0	46.0	41.8
30.0	44.0	44.0	48.8
30.0	40.0	40.0	49.4
58.0	72.0	36.0	36.0
50.0	80.0	80.0	56.0
73.6	123.4	61.7	42.5
68.0	52.0	52.0	24.2
45.0	108.0	66.0	40.0
42.0	96.0	60.0	43.0
39.0	84.0	54.0	37.0
25.6	51.8	51.8	43.6
126.0	36.0	36.0	46.6
36.5	74.0	74.0	50.0
36.5	74.0	74.0	67.5
42.8	99.0	99.0	50.0
34.0	64.0	64.0	60.0
34.0	64.0	64.0	58.0
25.0	100.0	100.0	55.0
25.0	100.0	100.0	50.0
64.5	92.0	92.0	50.0
64.5	92.0	92.0	50.0
36.0	36.0	36.0	48.8
60.0	60.0	60.0	46.0
60.0	60.0	60.0	32.0

APPENDIX V - concluded

Treatment			Yield
N	P	K	
---------Pounds---------			Bushels
39.5	75.5	75.5	56.3
39.5	75.5	75.5	54.0
36.5	74.0	74.0	70.5
36.5	74.0	74.0	66.3
24.0	96.0	72.0	67.0
44.0	64.0	160.0	52.0
34.0	64.0	64.0	51.0
25.5	66.0	66.0	55.0
17.5	70.0	70.0	45.0
30.0	94.0	30.0	40.0
46.5	33.0	33.0	32.0
46.5	33.0	33.0	28.0
54.0	54.0	54.0	45.5
41.5	94.0	59.0	43.8
54.0	54.0	54.0	50.0
54.0	54.0	54.0	50.0
47.0	76.0	46.0	60.0
27.0	63.0	39.0	50.0
27.0	63.0	39.0	40.0
30.0	75.0	75.0	40.0
50.0	60.0	60.0	48.0
45.0	99.0	63.0	50.0
47.0	76.0	76.0	43.9
31.0	76.0	46.0	51.9
30.0	142.5	142.5	50.0
15.0	60.0	60.0	35.0
42.0	96.0	60.0	47.4

APPENDIX VI

"Typical" experiment data, Michigan, 1962.

Treatment	Theoretical N	Theoretical P	Theoretical K	Approximate actual N	Approximate actual P	Approximate actual K	Yield
	Pounds						Bushels
A	0	0	40	0	0	72.8	35.8
	0	0	40	0	0	72.8	35.8
	0	0	40	0	0	72.8	26.7
	0	0	40	0	0	72.8	28.3
	0	0	40	0	0	72.8	27.5
B	0	40	40	0	61.2	61.2	40.0
	0	40	40	0	61.2	61.2	46.7
	0	40	40	0	61.2	61.2	40.0
	0	40	40	0	61.2	61.2	32.5
	0	40	40	0	61.2	61.2	20.8
	0	40	40	0	61.2	61.2	43.3
C	15	20	40	19.7	26.2	52.4	46.7
	15	20	40	19.7	26.2	52.4	36.7
	15	20	40	19.7	26.2	52.4	33.3
	15	20	40	19.7	26.2	52.4	31.7
	15	20	40	19.7	26.2	52.4	30.8
D	15	60	40	17.0	67.8	45.2	40.0
	15	60	40	17.0	67.8	45.2	50.0
	15	60	40	17.0	67.8	45.2	30.8
	15	60	40	17.0	67.8	45.2	26.7
	15	60	40	17.0	67.8	45.2	27.5
	15	60	40	17.0	67.8	45.2	35.0
E	30	0	40	31.2	0	41.6	37.5
	30	0	40	31.2	0	41.6	42.5
	30	0	40	31.2	0	41.6	25.0
	30	0	40	31.2	0	41.6	31.7
	30	0	40	31.2	0	41.6	18.3
	30	0	40	31.2	0	41.6	36.7
F	30	40	40	36.0	48.0	48.0	38.3
	30	40	40	36.0	48.0	48.0	40.8
	30	40	40	36.0	48.0	48.0	26.7
	30	40	40	36.0	48.0	48.0	32.5
	30	40	40	36.0	48.0	48.0	26.7
	30	40	40	36.0	48.0	48.0	35.0

APPENDIX VI - concluded

Treatment	Theoretical			Approximate actual			Yield
	N	P	K	N	P	K	
	Pounds						Bushels
G	30	80	40	38.4	102.4	51.2	40.8
	30	80	40	38.4	102.4	51.2	43.3
	30	80	40	38.4	102.4	51.2	35.0
	30	80	40	38.4	102.4	51.2	32.5
	30	80	40	38.4	102.4	51.2	36.7
	30	80	40	38.4	102.4	51.2	22.5
H	45	20	40	58.1	25.8	51.6	36.7
	45	20	40	58.1	25.8	51.6	37.5
	45	20	40	58.1	25.8	51.6	30.0
	45	20	40	58.1	25.8	51.6	25.0
	45	20	40	58.1	25.8	51.6	26.7
	45	20	40	58.1	25.8	51.6	25.8
I	45	60	40	53.6	71.4	47.6	35.0
	45	60	40	53.6	71.4	47.6	41.7
	45	60	40	53.6	71.4	47.6	32.5
	45	60	40	53.6	71.4	47.6	25.8
	45	60	40	53.6	71.4	47.6	35.8
	45	60	40	53.6	71.4	47.6	22.5
J	60	40	40	73.8	49.2	49.2	31.7
	60	40	40	73.8	49.2	49.2	41.7
	60	40	40	73.8	49.2	49.2	35.0
	60	40	40	73.8	49.2	49.2	20.8
	60	40	40	73.8	49.2	49.2	20.8
	60	40	40	73.8	49.2	49.2	33.3