FACTORIAL DESIGN ANALYSIS OF CAULIFLOWER FERTILIZATION DATA

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THESIS

FACTORIAL DESIGN ANALYSIS OF CAULIFLOWER FERTILIZATION DATA

by

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A THESIS

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INTRODUCTION

The method of analyzing and interpreting the information gathered from an experiment has been done of the most difficult problems confronting both the experimenter and the mathematician. The classical interpretations of data showing the response of plants to fertilizers have been unsatisfactory because different analyses as well as different levels of the same analysis have been dealt with. The use of two separate but interacting factors is not as discouraging as determining the significance of any differences in the results.

The purpose of this paper is to present several methods of analysis and their interpretation from data of an actual fertilizer experiment with cauliflower. Yield results from all combinations of three levels of the three main elements of fertilizer are analyzed by several methods and the analyses are discussed. Since the original data cover the results of only one season's work on the problem, no attempt has been made to make general recommendations for the fertilization of cauliflower.

REVIEW OF LITERATURE

The mathematician has been instrumental in furnishing the experimenter methods by which to analyze and interpret his data. The first outstanding contribution applicable to comparing results of two or more plots in a field experiment was made in England in 1923 when R. A. Fisher introduced the Analysis of Variance. This essentially is a technique for segregating from comparable groups of data the variation traceable to specified sources. Every year sees the introduction of improvements in Fisher's system both in the direction of field practice and in the statistical interpretation. It is unfortunate that the technique is becoming more complicated but it is gratifying that gradually predictions and recommendations are getting more accurate.

In 1926 Fisher (3) made an important advance in his technique, introducing methods of analyses for Latin square and several complex plot arrangements, including factorial design. Many articles concerning statistical analysis were published during the next four years and in 1930 Fisher (4) published a simple explanation of the numerical procedure of the analysis of randomized block and Latin square experiments. In this article he presented an affirmative case for mathematical analysis and gave further information on the statistical reduction of results by plot arrangement of field experiments.

A contribution in factorial design analysis was made in 1937 by F. Yeats (14) a co-worker of Fisher. In his publication Yeats presented a new method of analysis and interpretation of a factorial designed experiment which is essentially the comparison of results from all the combinations of several different sets of factors with or without each factor at different levels. This type of plot design and analysis is best used where it is desirable to determine jointly the effect of several factors in one experiment. For example, analysis of fertilizer, the quantity of fertilizer, the cultivation methods, the variety, etc. could all be determined in one experiment. The classical procedure would be to use different experiments for each factor; one experiment to determine the best type of fertilizer, another the best quantity of fertilizer, another the best cultivation methods, etc. The experimenter would conduct the fertilizer test on one of the several varieties but the variety used might not be the same as the one he chose to recommend; if there was a varietal difference in the response to fertilizer, the experiment would have to be repeated on the recommended variety. Thus every combination of the single factors might result in similar complications and the experimenter would be at a loss to reach conclusions.

Although the factorial designed experiment is complicated, when completed it can be analyzed so that conclusions about all combinations of all factors can be drawn immediately. The main objections to such experiments are that many combinations are used which are impractical in the field. There is no argument in favor of an estimate of low precision although if the experiment is properly designed the precision should be of little importance. The preconceived notions that certain factors would be impractical are too frequently based on inadequate evidence and are well worth experimental tests.

Previous fertilizer work with cauliflower has been very general and not very comprehensive. Jones (8) found in California that it was the lack of nitrogen that limited the growth of cauliflower. He drew his conclusions from the fact that nitrogenous fertilizer gave the greatest growth response. Later experiments seemed to show that there was also a response obtained by the use of superphosphate. Nitrate of soda applied at the rate of a teaspoonful per plant was found to improve noticeably the growth of plants in poor soil in the production regions of Colorado (10).

The Connecticut station (13) recommends a 4-8-4 fertilizer applied at the rate of 2000 pounds per acre where no barnyard manure is used and at the rate of 1200-1500 pounds per acre where manure is used. This station reported that the best results were obtained where quickly available plant nutrients were applied. A report from the New York station (1) states that "the cauliflower is a gross feeder and responds to liberal fertilization," and that manure alone was not a satisfactory source of plant nutrients. They recommend 10 to 15 tons of manure supplemented with 1000 pounds of 5-10-5 or 4-16-4 fertilizer per acre and that if the supply of manure is limited, 1500 to 2000 pounds per acre of 5-10-5.

In fertilization studies with cauliflower in New Jersey during 1923 and 1924 Huber (6) found that manure alone in amounts up to 20 tons per acre does not furnish enough plant nutrients for a good crop of cauliflower. Huber made practically the same recommendations as the New York station.

Underwood (12) in a survey of Delaware County, New York, found that about 80 per cent of the cauliflower growers questioned used fertilizer with a 4-8-7 analysis and that 13 per cent used a 5-8-7. The total amounts of fertilizer used ranged from 2000-4000 pounds per acre with an average of 3213 pounds per acre.

Lloyd and Lewis (9) in Illinois carried out a comprehensive fertilizer test with cauliflower. Their experiment included many combinations of manure, nitrogen, phosphorus and potassium and they were able to draw some rather definite conclusions from their data. Nitrogen without phosphorus or potash showed fair increases over the check. Phosphorus alone failed to produce high yields but was much better than potash alone. Exceptionally good yields were secured from the use of complete fertilizer without manure.

MATERIALS AND METHODS

The experiment reported on here was conducted at the Upper Peninsula Experiment Station at Chatham, Michigan, during the summer of 1938. The cauliflower variety used was Dan America Super-snowball furnished by Madsen.

Plot Arrangement

Each plot was a square 10 feet on each side containing 15 plants planted two feet apart within the row and three feet apart between rows.

There were 27 treatments with three replications of each treatment, making a total of 81 plots. The plots were laid out in a square with nine in each direction with no treatment being employed in some rows in either direction.

Analysis and Rate of Fertilizers Applied

All the fertilizers were applied at the rate of 1000 pounds per acre. There had been no fertilizer or manure added to the soil during the two seasons preceding the experiment and the soil was rather depleted in available nitrogen, phosphorus, and potassium. Soil tests taken throughout the plots uniformly showed low nitrogen, low phosphorus and low potassium. The land had been summer-fallowed the season previous to this experiment and two years before it had been in alfalfa.

Every combination of 20 per cent and 10 per cent and no available nitrogen, phosphorus, and potassium were used. The analysis combinations were:

0-0-0 (Check)	10-0-0	20-0-0
0-10-0	10-10-0	20-10-0
0-20-0	10-20-0	20-20-0
0-0-10	10-0-10	20-0-10
0-10-10	10-10-10	20-10-10
0-20-10	10-20-10	20-20-10
0-0-20	10-0-20	20-0-20
0-10-20	10-10-20	20-10-20
0-20-20	10-20-20	20-20-20

Hereafter in this paper 10 per cent of available nitrogen will be noted as n_1, a 20 per cent as n_2, a 10 per cent and 20 per cent phosphorus as p_1 and p_2, and a 10 and 20 per cent of potassium as k_1 and k_2. Thus a 10-20-10 analysis fertilizer will be designated as $n_1\ p_2\ k_1$. If there is no nitrogen in the analysis the n will be omitted from the symbol and likewise the same will be true of either phosphorus or potassium. Thus the 0-20-2 fertilizer will be designated as p_2. These symbols are used since the interest is mainly in the level of the available materials and not in the exact percentage composition of fertilizer applied.

The different analysis fertilizers were all prepared from ammonium sulphate, super phosphate and muriate of potash. The procedure in mixing the fertilizer using for an example $n_1\ p_2\ k_1$ was as follows:

Raw Product	Per cent of n, p, or k in raw product	Analysis of fertilizer desired per cent	Pounds of raw material required to furnish the desired % per 1000 lbs.
Ammonium sulphate	20	10	500
Superphosphate	20	20	1000
Muriate of Potash	50	10	200
			1700

It requires 1700 pounds of the mixed fertilizer per acre to furnish 1000 pounds of the $n_1\ p_2\ k_1$. The amount of this mixture to apply to the 10x10 plot is readily calculated as follows:

$$\frac{1700}{43,560} \times 100 = 3.902 \text{ pounds}$$

The analysis and quantity of fertilizer to be applied was determined in a similar manner for each treatment. Below are given the amounts of fertilizer applied to the plots calculated as above.

c	(check)	n_1	1.15 lbs.	n_2	2.30 lbs.
p_1	1.15 lbs.	$n_1\ p_1$	2.30 lbs.	$n_2\ p_1$	3.44 lbs.
p_2	2.30 lbs.	$n_1\ p_2$	3.44 lbs.	$n_2\ p_2$	4.58 lbs.
k_1	.46 lbs.	$n_1\ k_1$	1.61 lbs.	$n_2\ k_1$	2.75 lbs.
$p_1\ k_1$	1.61 lbs.	$n_1\ p_1\ k_1$	2.75 lbs.	$n_2\ p_1\ k_1$	3.90 lbs.
$p_2\ k_1$	2.75 lbs.	$n_1\ p_2\ k_1$	3.90 lbs.	$n_2\ p_2\ k_1$	5.05 lbs.
k_2	.92 lbs.	$n_1\ k_2$	2.07 lbs.	$n_2\ k_2$	3.20 lbs.
$p_1\ k_2$	2.07 lbs.	$n_1\ p_1\ k_2$	3.20 lbs.	$n_2\ p_1\ k_2$	4.35 lbs.
$p_2\ k_2$	3.20 lbs.	$n_1\ p_2\ k_2$	4.35 lbs.	$n_2\ p_2\ k_2$	5.51 lbs.

Method of Fertilizer Application

The fertilizer was applied two weeks after the plants were set into the field. It was placed in two six inch bands, four inches from each side of the plant and two inches deep. In order to keep the amount of fertilizer constant for each plant in the plot, every analysis was divided into fifteen lots by weight, one lot being applied to each plant. At the time of the application, all the plants had become well established and any missing plants had been replaced.

Cultural Methods

The cauliflower seed was treated with a 1-1000 corrosive sublimate and hot water solution according to the recommendations of Michigan State College. The seeds were planted in the seedbed June 5th and every attempt was made to keep the plants growing rapidly. The seedbed was fertilized at the rate of 1000 pounds of 5-10-5 fertilizer per acre. The plants were watered heavily whenever the ground became dry and corrosive sublimate at the rate of 1-1000 in water was used weekly to control maggots in the seedbed. On July 12, the healthiest plants were transplanted into the field and irrigated immediately afterward.

In the upper peninsula of Michigan, it has been previously shown (2) that transplanting young cauliflower plants into the field about July 10th, is most satisfactory. At that time the cabbage maggot infestations are the lightest of any period during the summer and shortly thereafter cabbage worm infestations are much reduced. The plants set at that time usually suffer no check in their growth since weather conditions after that date are extremely favorable and also during the time of harvest the curd development is rapid and the color and quality of the crop as a whole is excellent.

After being transplanted into the field the plants were treated weekly with corrosive sublimate to prevent damage from the cabbage maggot. Whenever the ground became packed from rains, it was cultivated. Cabbage worms were controlled by dusting weekly with dried pyrocide dust. No fungicides were necessary since there was no disease evident in the planting.

Method of Harvest

Since the entire cauliflower crop cannot be harvested at one time it was necessary to employ a systematic method for determining the fertilizer response. When several of the curds had grown to a size of two inches in diameter the outside leaves were tied up in order to blanch the curd and the plant was marked. Several days later all the heads tied on any one day were harvested and the weights were recorded individually. The weight of the curd has been shown to be closely correlated to the diameter (2). Therefore it may be assumed that at the time of tying the leaves over the curd, the weight of every curd was approximately the same. Since the plants marked on any one day were harvested at the same time several days later, the increase of weight was taken as the response of the plant to the fertilizer treatment.

RESULTS

Analysis of Variance

If the variations in the results are considered, it is obvious that the variation due to the fertilizer must be differentiated from the variation caused by all other factors. The analysis of variance gives a method of partially segregating these variations.

The first step in the analysis is to find the total yield for each replication, for each treatment, and for the entire experiment. The means of the treatment yields play no part in the computation but are recorded for the convenience of the reader. The actual calculation is as follows:

First, the correction term:

$$\text{Correction term} = \frac{(\text{grand total})^2}{\text{number of treatments x number of replications}}$$

$$= \frac{3320.9}{81} - 136,152.80$$

Second, the total sum of squares is found by summing the square of each plot yield and subtracting the corrections.

Total S. S. 141,094.86 - 136,152.80 = 4,942.06

Third, the sum of squares between the means of replications is calculated by dividing the sum of the totals for replications by the number of treatments and subtracting the correction.

$$\text{Replication S. S.} \quad \frac{(1131.0)^2 + (1127.8)^2 + (1062.1)^2}{81}$$

136,152.80 = 112.02

Fourth, the sum of squares between the means of treatments is found by dividing the sum of the totals for replications by the number of replications and subtracting the correction.

Treatment S. S. $(81.3)^2 + (103.6)^2 + \ldots + (142.7)^2 -$

136,152.80 $\doteq$ 3,884.24

Fifth, the error or remainder sum of squares:

Total S. S. - Treatment S. S. - Block S. S. $\doteq$ Error S. S.
4942.06 - (112.02 - 3,884.24) $\doteq$ 945.80

It is now possible to record the results in a table as follows:

TABLE II

Source of Variation	Degrees Freedom	Sum of Squares	Variance
Total	80	4942.06	
Replication	2	112.02	56.010
Treatment	26	3884.24	149.394
Error	52	945.80	18.188

The total degrees of freedom are the number of plot yields in the entire experiment minus one (81 - 1 $\doteq$ 80). The replication degrees of freedom are the number of replications minus one (3 - 1 $\doteq$ 2). Those for treatments are (27 - 1 or 26). Those for the error term are the remainder 80 - (2 - 26) = 52.

The variance or mean square is calculated in each case by dividing the sum of squares by the number of degrees of freedom. For example

$$\text{Error variance} = \frac{945.80}{52} = 18.188$$

$$\text{Treatment variance} \doteq \frac{3884.24}{26} \doteq 149.394$$

Determining Significance

It will be noticed that the treatment variance is relatively high in comparison with the error variance. By using Snedecor's F (11) we can show immediately that there are to be expected some significant differences within the means for treatments.

$$F - \frac{\text{larger variance}}{\text{smaller variance}} \doteq 149.394 = 8.214$$

There are 26 degrees of freedom for the greater variance and 52 degrees of freedom for the smaller variance. By Snedecor's table it is found that the F value must exceed 1.74 to be significant to the 5 per cent point and 2.18 to be significant to the 1 per cent.

Therefore an F value of 8.214 would be very highly significant and significant differences may be expected between treatment means.

To show whether one mean differs significantly from another several calculations are required.

1. Standard deviation, $\sigma = \sqrt{\text{Error variance}} = 4.264$

2. Standard deviation of any mean, $\sigma_m = \dfrac{\sigma}{\sqrt{\text{number of replications}}} = \dfrac{4.264}{\sqrt{3}} = 2.462$

3. Standard deviation of the difference between means

$$\sigma \text{ dif. of means} = \sqrt{2 \ (\sigma_m)^2} = \sqrt{2 \times (2.462)^2} = 3.482$$

From the standard deviation of the difference between means the difference required between means to be significant may readily be calculated.

The actual difference between means divided by the σ (dif. bet. means) must be greater than the t value if the difference in means is significant.

If $\dfrac{m_1 - m_2}{\sigma \text{ dif. bet. means}} > 2.008$, the difference between $m_1 - m_2$ is significant.

Therefore t x σdif. between means = difference between means to be significant. For example:

t for 52 degrees of freedom

5% = 2.008

1% = 2.678

$2.008 \times 3.482 = 6.99$ (the difference in pounds between treatment means to be significant at 5% point.)

$2.678 \times 3.482 = 9.32$ (the difference in pounds between treatment means to be significant at 1% point.)

By the analysis of variance (Table I and Table II) certain generalizations can be drawn.

1. All plots fertilized with either 10 or 20% nitrogen yielded highly significantly more than the check.
2. Fertilized plots containing no nitrogen did not highly significantly outyield the check.
3. No other results are outstanding.
4. Conclusions about each individual treatment compared with every other treatment could be calculated, but from this type of experiment it is desired to obtain the responses to nitrogen, phosphorus and potassium and any interaction responses between these elements. From this original simple analysis of variance this information cannot be obtained.

Factorial Analysis

By examination of Table II it can readily be seen that the 26 degrees of freedom for treatment can be divided into less degrees of freedom. Therefore Table III is set up whereby the treatment effects can be analyzed with the following degrees of freedom.

TABLE IV

Source	Degrees Freedom
N	2
P	2
K	2
NK	4
NP	4
KP	4
NPK	8
Total (treatment)	26

Before the variances can be determined for the above factors (Table IV) three further tables must be set up, each combining two factors.

Thus:-

Combining n and p

TABLE Va

	p_o	p_1	p_2	n Totals	m Means
n_o	283.9	309.5	307.2	900.6	33.35
n_1	339.1	379.3	390.9	1109.3	41.09
n_2	408.6	439.1	463.3	1311.0	48.55
p Totals	1031.6	1127.9	1161.4	3320.9	
p Means	38.20	41.77	43.01		

TABLE Vb

Analysis of Variance

Source	DF	Sum of Squares
Total	8	3495.09
N	2	3119.34
P	2	336.34
NP	4	49.41

Combining n and K

TABLE VI

	n_o	n_1	n_2	k Totals	k Means
k_o	284.5	349.2	441.2	1074.9	39.81
k_1	318.8	380.1	459.1	1158.0	42.89
k_2	297.3	380.0	410.7	1088.0	40.30
n Totals	900.6	1109.3	1311.0	3320.9	

TABLE VIb

Source	DF	Sum of Squares
Total	8	3389.68
N	2	3119.34
K	2	147.87
NK	4	122.43

Combining p and k

TABLE VII

	p_o	p_1	p_2	k Totals
k_o	330.8	356.3	387.8	1074.9
k_1	360.5	399.0	398.5	1158.0
k_2	340.3	372.6	375.1	1088.0
p Totals	1031.6	1127.9	1161.4	3320.9

TABLE VIIa

Analysis of Variance

Source	DF	Sum of Squares
Total	8	512.10
P	2	336.34
K	2	147.87
PK	4	46.89

Without going further than this simple analysis of the above three tables, several important relationships have shown up. The difference between means necessary to be significant has already been presented previously and by applying this information it is seen that:-

1. n_1 is significantly greater than no n and n_2 is significantly greater than n_1.
2. p_2 is greater than no p although not quite significantly, but that there is no difference between p_1 and p_o and none between p_1 and p_2.
3. There are no evident differences between no k k_1 and k_2.

These analyses in themselves come closer to bringing the desired effects into prominence than the simple analysis of variance. The 26 degrees of freedom for treatment have been broken down and the sums of squares and variance desired in Table IV may be incorporated.

The only sum of squares missing is the triple interaction NPK and this is readily found by the following formula:

Total S. S. for Treatment - S.S.N. - S.S. P - S. S. K - S. S. NP - S.S. NK - S.S. PK $\doteq$ S.S. NPK

Finally all 26 degrees of freedom for treatment are accounted for and the variance determined.

TABLE VIII

Source (Treatment)	D.F.	Sum of Squares		Variance
N	2	3119.34	Table V & VI	1559.67
P	2	336.34	" V & VII	168.17
K	2	147.87	" VI & VII	73.93
NP	4	49.41	" V	12.35
NK	4	122.43	" VI	30.61
KP	4	46.89	" VII	11.72
NPK (remainder)	8	61.96		7.75
Total	26	3884.24		

The degrees of freedom can be broken down still further.

For example N has two degrees of freedom showing the total response to the addition of nitrogen; one degree stands for the linear response and the other for quadratic. If the response is linear the effect of addition of nitrogen is a straight line effect; if it is quadratic the effect is not linear.

Thus the graph of the effect of the addition of nitrogen approaches a straight line.

If this response is calculated rather than graphed it would be expected that most of the variance would be due to linear response.

The amount of linear or regression is found by applying the formula

$$\frac{(n_2 - n_0)^2}{54} = \frac{(1310.0 - 900.6)^2}{54} = \frac{(410.4)^2}{54} \doteq 3119.04$$

To determine the amount of quadratic response or the deviation from the linear response we apply the formula

$$\frac{(n_2 + n_0 - 2n_1)^2}{162} \doteq \frac{(1310.0 + 900.6 - 2218.6)^2}{162} \doteq \frac{(-7)^2}{162} \doteq$$

.30

Adding the variance single degrees of freedom

$$\begin{array}{r} 3119.04 \\ .30 \\ \hline 3119.34 \end{array}$$

the same figure is obtained that was previously obtained for the total response to nitrogen.

Thus in a similar manner the linear or regression and the quadratic or deviation responses may be obtained for each of the elements taken individually.

The interaction between elements taken two at a time have 4 degrees of freedom and these may be divided into four separate degrees of freedom as follows

		DF	
NP	4	1	Reg. N x Reg. P
		1	Reg. N x Dev. P
		1	Dev. N x Reg. P
		1	Dev. N x Dev. P

The elements taken three at a time have eight degrees of freedom and these may be divided into eight separate degrees of freedom.

		DF	
NPK	8	1	Reg. N x Reg. P x Reg. K
		1	Reg. N x Reg. P x Dev. K
		1	Reg. N x Dev. P x Reg. K
		1	Reg. N x Dev. P x Dev. K
		1	Dev. N x Reg. P x Reg. K
		1	Dev. N x Reg. P x Dev. K
		1	Dev. N x Dev. P x Reg. K
		1	Dev. N x Dev. P x Dev. K

The final table can now be presented covering the analysis of all data.

DIAGRAM OF A SINGLE PLOT

Figure 1

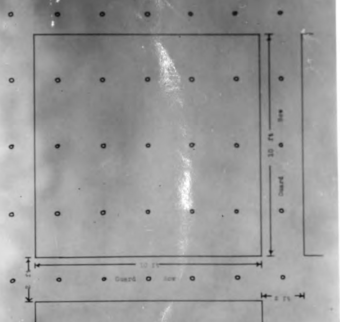
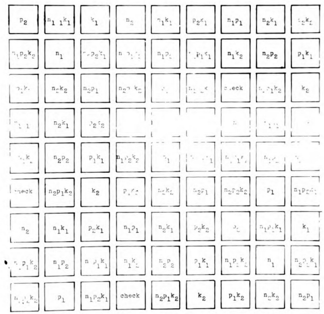
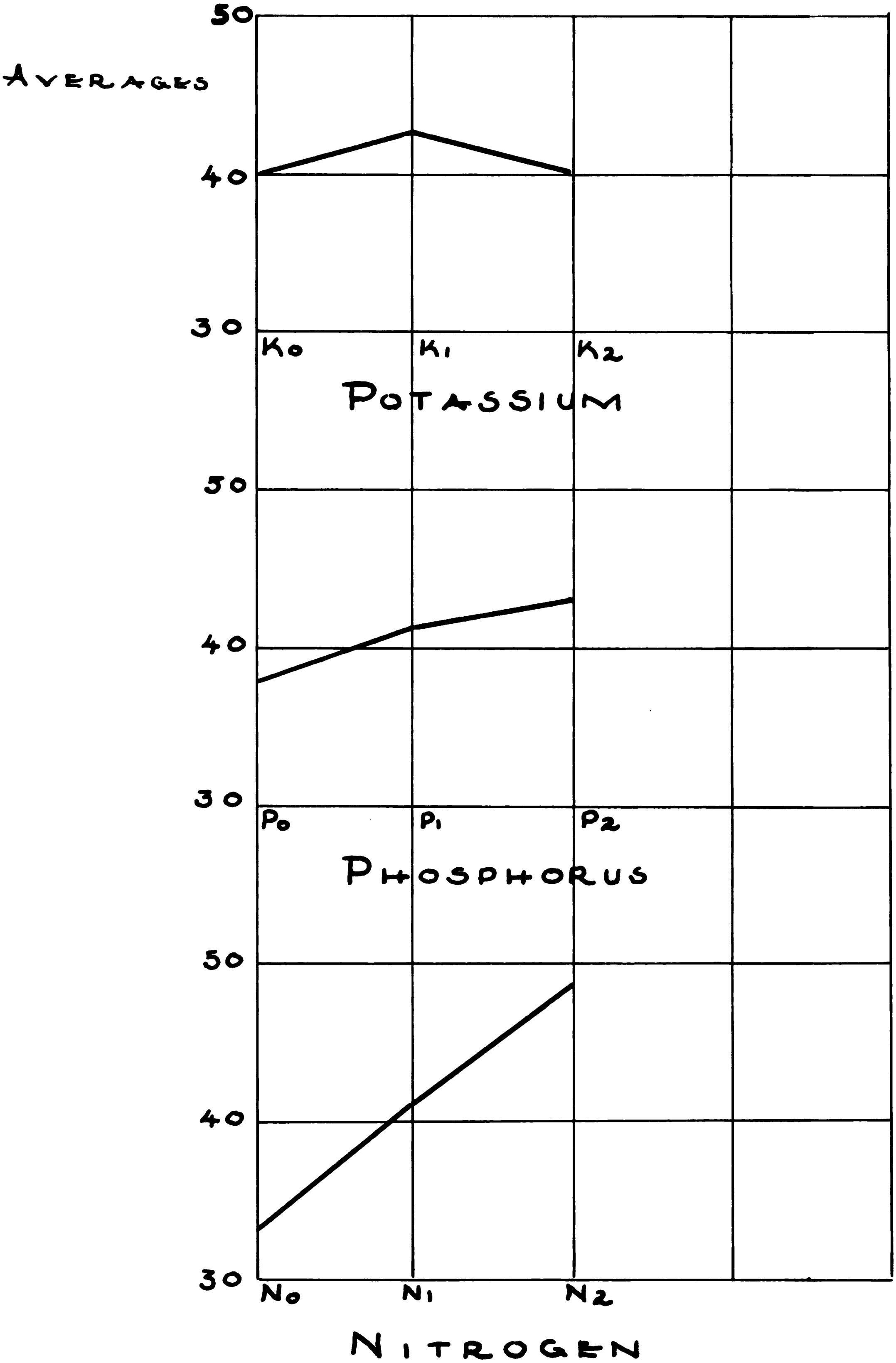


DIAGRAM OF PLOT ARRANGEMENT

Figure 2



ELEMENT RESPONSE CURVES



Source	DF	Sum of Squares			Variance
Total	80		4942.06		
Replication	2		112.02		56.01
Treatment					3119.04**
N Reg. 2	1	3119.34	3119.04		
Dev.	1		.30		.30
P Reg. 2	1	336.34	312.00		312.00**
Dev.	1		24.34		24.34
K Reg.	1	147.87	3.18	3884.24	3.18
Dev.	1		144.69		144.69**
NP	4		49.41		12.35
NK	4		122.43		30.61
PK	4		46.89		11.72
NPK	8		61.96		7.75
Error	52		945.80		18.188

*Since none of the double or triple interactions are significant even before breaking down into their single degrees of freedom, it would be impractical to do so.

From this final table the following generalizations may be made:

1. That the addition of n_1 over n_0, and that the addition of n_2 over n_1 both highly significantly increased the yield.

2. Increasing the nitrogen to the level of n_2, there was a linear response.

3. That the addition of p_1 over p_0 and p_2 over p_0 but not p_2 over p_1 significantly increased the yield. The response was linear.

4. That the addition of k_1 over k_0 increased the yield, and the addition of k_2 over k_1 decreased the yield. The response was quadratic.

5. There were no interactions either double or triple that are important.

DISCUSSION

Two methods of analysis and their interpretation have been presented -- first, the analysis of variance as originated by Fisher, second, the factorial analysis as presented by R. A. Fisher and F. Yeats. The first technique segregated the variation caused by the treatment and took out the variation from other sources. The second technique further segregated the treatment variation into variation caused by the combination of several different factors all at different levels.

With use of the analysis of variance the generalizations that can be made are very limited. All that can be shown is the fact that all the plots fertilized with either n_1 or n_2 yielded significantly more than the check. No other general results were outstanding. However, from this original analysis of variance, the correction term and the error variance were determined and these two figures are essential throughout the entire experiment. It is therefore impossible to do away completely with the analysis of variance, but it is essential to go further.

By applying a factorial analysis it was found that in addition to the above generalizations that:

1. The addition of n_1 over no n and the addition of n_2 over n_1 both highly significantly increased the yield.
2. The response to nitrogen was practically a straight line effect.
3. The addition of p_1 over p_o and p_2 over p_o but not p_2 over p_1 significantly increased the yield.
4. The response was linear, with considerable deviation.
5. The addition of k_1 over k_o increased the yield, and k_2 over k_1 decreased the yield and k_o over k_2 was the same.
6. There were no double or triple interactions.

In comparison of one general indication using the analysis of variance, there are six general indications pointed out by the factorial analysis, and these indications are practically the exact things desired by the experimentor. Thus every combination of three factors is accounted for in a single experiment and conclusions can be drawn about all combinations at once.

Since the original data cover only one year's work in one location, and on one soil with the fertilization of cauliflower no general fertilizer recommendations can be made. The preliminary evidence agrees with the work of Jones in California and McGinty in Colorado in that nitrogen seemed to give the greatest growth response and is likely to be one of the limiting factors in the production of cauliflower. The recommendation of Enzie in New York demands a high phosphorus content of the fertilizer which is in partial disagreement with the fertilization in the upper peninsula. Although responses were shown from the use of phosphorus they were practically as great at lower levels as at higher.

The recommendation of Lloyd and Lewis in Illinois is practically in agreement with the results secured from this experiment. Their experiments showed that nitrogen without phosphorus or potash gave fair increases over the check, that phosphorus alone failed to produce high yields and that potash alone resulted in poor yields. In general these are practically the same conclusions that can be drawn from the preliminary work reported in this paper.

SUMMARY

1. A comparison of two methods of statistical analysis, namely analysis of variance and factorial analysis as applied to data from a cauliflower fertilization experiment conducted at Chatham, Michigan are reported.

2. The analysis of variance, although essential, does not furnish a satisfactory analysis of a problem with several factors, each at a different level.

3. The factorial analysis determined jointly the effect of all factors in the experiment.

4. The factorial analysis pointed out the essential effects of all combinations in a single analysis.

5. The preliminary fertilizer results may be summarized as follows:

   a. A great response to nitrogen at the levels used.

   b. Some reponse to phosphorus.

   c. Little response to potassium

   d. No response to interactions of these elements.

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TABLE III

YIELD OF CAULIFLOWER ARRANGED FOR FACTORIAL ANALYSIS

	k_0			k_1			k_2	
p_0	p_1	p_2	p_0	p_1	p_2	p_0	p_1	p_2
30.0	34.6	35.5	35.6	39.9	37.1	36.8	38.1	38.0
25.8	31.3	39.8	30.6	34.9	35.3	32.9	30.4	29.4
25.5	32.9	29.1	37.4	37.1	30.9	29.3	30.3	32.1
81.3	98.8	104.4	103.6	111.9	103.3	99.0	98.8	99.5
36.3	34.8	42.5	38.4	44.3	47.0	40.8	50.3	50.1
38.6	37.7	45.9	40.7	45.4	44.0	38.5	40.3	42.7
35.7	39.9	37.8	36.0	43.5	40.8	34.1	43.1	40.1
110.6	112.4	126.2	115.1	133.2	131.8	113.4	133.7	132.9
46.5	48.5	51.9	48.5	49.4	43.3	45.5	45.8	41.5
48.1	46.1	61.5	54.0	54.4	58.1	44.1	49.4	47.9
44.3	50.5	43.8	39.3	50.1	62.0	38.3	44.9	53.3
138.9	145.1	157.2	141.8	153.9	163.4	127.9	140.1	142.7

TABLE I

YIELD OF CAULIFLOWER
PER PLOT

Treatments	Replication I	Replication II	Replication III	Treatment Totals	Treatment Means
c	30.0	25.8	25.5	81.3	27.10
k_1	35.6	30.6	37.4	103.6	34.53
k_2	36.8	32.9	29.3	99.0	33.00
p_1	34.6	31.3	32.9	98.8	32.93
p_1k_1	39.9	34.9	37.1	111.9	37.30
p_1k_2	38.1	30.4	30.3	98.8	32.93
p_2	35.5	39.8	29.1	104.4	34.80
p_2k_1	37.1	35.3	30.9	103.3	34.43
p_2k_2	38.0	29.4	32.1	99.5	33.17
n_1	36.3	38.6	35.7	110.6	36.87
n_1k_1	38.4	40.7	36.0	115.1	38.37
n_1k_2	40.8	38.5	34.1	113.4	37.80
n_1p_1	34.8	37.7	39.9	112.4	37.47
$n_1p_1k_1$	44.3	45.4	43.5	133.2	44.40
$n_1p_1k_2$	50.3	40.3	43.1	133.7	44.57
n_1p_2	43.5	45.9	37.8	126.2	42.06
$n_1p_2k_1$	47.0	44.0	40.8	131.8	43.93
$n_1p_2k_2$	50.1	42.7	40.1	132.9	44.30
n_2	46.5	48.1	44.3	138.9	46.30
n_2k_1	48.5	54.0	39.3	141.8	47.27
n_2k_2	45.5	44.1	38.3	127.9	42.63
n_2p_1	48.5	46.1	50.5	145.1	48.37
$n_2p_1k_1$	49.4	54.4	50.1	153.9	51.30
$n_2p_1k_2$	45.8	49.4	44.9	140.1	46.70
n_2p_2	51.9	61.5	43.8	157.2	52.40
$n_2p_2k_1$	43.3	58.1	62.0	163.4	54.47
$n_2p_2k_2$	41.5	47.9	53.3	142.7	47.57
				grand total	
replication totals	1,131.0	1,127.8	1,062.1	3,320.9	