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# ESTIMATION OF OPTIMUM PLOT SIZE, SHAPE AND NUMBER OF REPLICATIONS FOR WHEAT YIELD TRIALS UNDER DIFFERENT FERTILIZATION CONDITIONS

**NASR. S.M.**

*Central Laboratory for Design and Statistical Analysis, Agricultural Research Center Giza, Egypt .*

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***Abstract***

This investigation was undertaken to study the optimum plot size and number of replications in fertilization experiments for wheat yield trials at Sakha Experimental Station during 1994/95 and 1995/96 seasons. The experiment included 24 treatments which were the combinations of two wheat cultivars, three organic manure level and four nitrogen levels. A split-split plot design with five replications was selected. The sub-sub plot unit area was 16 m2. The harvesting area was 9.0 m2. The grain yield data were recorded for each plot (kg/plot). They were subjected to two procedures of statistical analysis to estimate the optimum plot size. The first was developed by Smith (1938), the second was the maximum curvature devloped by Lessman and Atkins (1963).

The results obtained could be summarized as follows :

1. increasing the plot size decreased the variance per basic unit and the coefficient of variability. However, the reduction was not in proportion with the increase in plot size.
2. The index of soil variability ranged from 0.456 to 0.363 with an average of 0.409.
3. The exponential relationships between the coefficient of variability (C.V.) and plot size (X) were :

   C.V. = 20.57 X -0.3214 for the first season.

   C.V. = 17.55 X -0.3129 for the second season.
4. The optimum size of plot ranged from 1/229 to 1/140 faddan.
5. plot shape was important for small sized plot only, square plots were recommended in fertilization experiments.
6. Increasing plot size and/or number of replications reduced the magnitude of the difference detected at specified level of significance. The reduction of difference with increasing plot size was less than that obtained by equivalent increase in the number of replications.

## INTRODUCTION

In fertilization experiments, soil fertility gradients has been recognized as a major factor affecting the accuracy and sensitivity of experimental realties. The local control mainly deals with the size and shape of individual plots, the division of blocks and their position in the experimental fields, which depends on the distribution of fertility gradients in the experimental area and the nature of the crop under test.

In previous studies, uniformity trial have been used to determine optimum plot size and shape. In the current investigation data from replicated field experiments had been used to measure the smith's index of soil heterogeneity. Experiments most suitable for this procedure are those involving designs with several plot sizes, such as split-plot and split-split-plot design.

Smith (1938) reported a linear relationship between the logarithm of the variance among plots of a given size and the logarithm of plot size. He used this relationship together with cost function to estimate plot size.

Results on wheat of Kassem et al (1971), demonestrated that the optimum plot size ranged from 1.2-2.4 m2 (i.e. 1/3500-1/1750 fad.) at Alexandria. They stated that long narrow plots reduced significantly the variability among plots than short wide squared plots. They also reported that, as the plot size increased, but the variance per basic unit and the coefficient of variability decreased. At Gemmeize and Sids, El-Kalla and Gomaa (1977) reported an optimum plot size for wheat 3.0 m2 (1/1400 fad.), using Smith's procedure for the two utilized locations. However, it was 7.0 and 5.0 m2 by using modified maximum curvature technique for the previous two locations respectively. Plot shape had an effect on plot-to-plot variability. El-Bakry (1980), recorded that wheat needs plots of medium size. He found that the optimum size of plot at Sids ranged from (1/933 to 1/169 fad). He also added that a long and narrow shape was generally more efficient as compared to the square or nearly square shape.

Abdel-Halim and Hanna (1980) using kach and Rigney technique found that soil heterogeneity index experimental fields for wheat ranged from 0.42 to 0.68, with an average of 0.58. The optimum plot size was found to range from 1/620 to 1/240 with an average of 1/350 faddan computed from all trials.

El-Rassas (1982) at Giza, found that the optimum plot size ranged from 3.2 to

6.4 m2 (1/1300-1/650 fad.). He stated that long and narrow plots were more effective in reducing variance per basic unit area, comparable variance and coefficient of variability.

Nasr (1994) reported that experimental results from fertilization trials are affected by systematic variation, this variation is directly related to the position and size of the plot depending mainly on soil fertility gradients. Therefore, the magnitude of experimental error can be reduced by using optimum plot size and shape in the experimental design.

The objective of the present study is to determine the optimum size of plots for wheat grown under the fertilization conditions at Sakha Experimental Station which represent the Noth Delta region.

## MATERIALS AND METHODS

### Lay out of the experiment :

The present investigation was carried out at Sakha Experimental Station during 1994/95 and 1995/96 seasons. The experiment included 24 treatments which were the combination of two cultivars of wheat namely; (Giza 155 and Sakha 8), three organic manure levels were zero, 30 and 60 m2/feddan and four nitrogen levels, i.e, 30, 50, 70 and 90 kg N/feddan. A split-split plot design with five replications was selected. The main plots were assigned for the two cultivars and the subplots were devoted to organic manure and the sub-sub plots were devoted to nitrogen levels. The sub-sub plot unit area was 16 m2. The harvesting area was 9.0 m2. The grain yield data were recorded for every plot (kg/plot).

### Statistical Analysis :

### A. Soil variability index:

The procedure (reported by Gomez and Gomez, 1983) involves the use of the basic analysis of variance to estimate the variance for plots of different sizes, and the use of these estimates to derive a relationship between plot variance and plot size. The number of plot variances that can be estimated through this procedure is only as many as the number of plot sizes available in the design used.

### The steps of procedure are :

1- The basic formats of the analysis of variance for a split-split-plot design are shown in Table 1.

2- Compute estimates of the variance associated with the different plot sizes, following the formulas given in Table 1. In this study, the design is a split-split-plot design. Hence, there are four between-plot variances corresponding to the four plot sizes as follows .

V'1 = the variance between plots of a block size

V'2 = the variance between plots of a main plot size

V'3 = the variance between plots of a subplot size

V'4 = the variance between plots of a sub-subplot size

The computation of these variances is based on the mean square values in the analysis of variance (Table 1) and the formulas given in Table 2.

Table 1. Basic format of the analysis of variance for split-split-plot design and formulas for the computation of variances between plot of various sizes.

| Source of Variation | Degree of Freedom | Mean Square | Mean Square |
|---|---|---|---|
| Replication | r-l | M1 | Vl = M1 |
| Factor A | a-l | | |
| Error (a) | (a-1) (r-1) | M2 | $V2 = \frac{r\,(a-1)\,M2 + (r-1)\,M1}{ra-1}$ |
| Factor B | b-1 | | |
| A X B | (a-1) (b-1) | | |
| Error (b) | a (r-1) (b-1) | M3 | $V3 = \frac{ra\,(b-1)\,M3 + r\,(a-1)\,M2 + (r-1)\,M1}{rab-1}$ |
| Factor C | c-1 | | |
| A x C | (a-1) (c-1) | | |
| B x C | (b-1) (c-1) | | |
| A x B x C | (a-1)(b-1)(c-1) | M4 | $V4 = \frac{rab\,(C-1)\,M4 + ra\,(b-1)\,M3 + r\,(a-1)\,M2 + (r-1)\,M1}{rabc-1}$ |
| Error (c) | ab (r-1)(c-1) | | |
| Total | raba-1 | | |

3- For each variance estimate Vi obtained in step 2, compute the corresponding comparable variance Vi with the size of the smallest plot in the particular experiment as the base :

$$Vi = \frac{V'i}{X}$$

Where : x is the size of the i th plot in terms of the smallest plot involved.

4- Apply the appropriate regrestechnique to estithe regression coefficient b (the index of soil h) from the equation.:

log Vi = log V4 - b log Xi

where Vi and Xi are defined in step 3.

### B- Optimum plot size (X opt.)

The weight index of soil variability, b, as published by Federer (1955), was calculated. Ignoring cost factors the optimum plot size ( x opt.) was determined, using the method developed by Smith (1938), by the equation :

### 1. X opt. = b l (1-b)

The exponential relationship between the coefficient of variability (C.V.) and plot size (X), C.V. = A X-B, was transformed into the logarithmic form :

### 2- Log C.V. = Log A-B log X

where A and B are the Y-intercept (constant of the equation) and regression coefficient, respectively. The values of A and B in the above equation were estimated from the values of C.V. of replications, main plot, sub-plot and sub-sub-plot. To determine the point of maximum curvature (C max.). The values of A and B were substituted in the following formula which was developed by Galal and Abou-El-Fittouh (1971). C max = (A2B2 (2B+1) / (B+2) } 1/ (2B+2) The point of maximum curvature indicates a critical value of the optimum plot size.

### C- Optimum plot shape:

Optimum plot shape, as mentioned by Lessman and Atkins (1963), was determined using "F" test by dividing the largest variance values for (replication, main plot and sub-plot) on the smallest variance (sub-sub-plot), to obtain the calculated F values at the corresponding degres of freedom.

### D- Magnitude of detected differences:

The true difference between two treatment means which can be detected at a

5% level of significane in 90% of the wheat experiments was estimated for different plot sizes and number of replications. The estimates were calculated according to the formula presented by Hatheway (1961). D2 = 2 (t1 + t2)2 C2/RXb

where:

D = true difference desired to be detected (measured as percent of mean.

t1 = the significant value of t from its table corresponding step 2 (1-p)

where p is the probability of obtaining a significant difference

C = the coefficient of variation for plots of one basic unit size

R = the number of replications

X = the number of multiples of the basic unit

b = index of soil variability

## RESULTS AND DISCUSSION

The different combinations of plot size and shape were determined as well as the number of basic units across and along for each plot shape in each combination (Table 2) in 1994/95 and 1995/96.

Table 2. Description of the different combinations of plot size and shape for wheat in 1994/95 and 1995/96 seasons.

| Plots various size | No. of basic units | Plot shape across x along | Plot dimension width x length | Plot a rea m2 | Area/fadd. |
|---|---|---|---|---|---|
| 1- Sub-sub-plot | 1 | 1x1 | 3x3 | 9 | 1/466.6 |
| 2- Sub-plot | 4 | 2x2 | 6x6 | 36 | 1/116.7 |
| 3- Main plot | 12 | 2x6 | 6x18 | 108 | 1/38.8 |
| 4- Replication | 24 | 4x6 | 12x18 | 216 | 1/19.4 |

Fertility gradient in the field used was calculated by the analysis of variance conducted on the original data. The results of basic format of the analysis of variance for a split-plot design are shown in Table 3. To determine the difference among mean squares between replications and experimental errors, variance ratios (F) were calculated by dividing mean squares of replications, error (a) and error (b) on mean square of error (c). These values were compared with the tabulated (F) value at the corresponding degrees of freedom. The results given in Table 3 indicated that there are significant difference in most of the cases, for the two seasons, showing the effect of plot shape. This however was expected, soil variability and fertility gradient are unavoidable factors in field plot technique. They affect the experimental design and both size of plot and number of resplications. Therefore, the variance was increased, when the plot size increased. Similar results were obtained by Kassem et al (1971).

Table 3. The analysis of variance results for split-split-plot design and "F" values for 1994/95 and 1995/96 season.

| Source of Variation | Degree of Freedom | Mean Square 1994/95 | F-value | Mean Square 1995/96 | F-value |
|---|---|---|---|---|---|
| Replication | 4 | 3018.697 | 8.043** | 2267.923 | 8.568** |
| Cultivars A | 1 | 523373.930 | | 533850.052 | |
| Error (a) | 4 | 1883.512 | 5.019** | 1133.400 | 4.282** |
| Organic manur (B) | 2 | 264166.575 | | 255053.297 | |
| A X B | 2 | 13232.907 | | 11646.672 | |
| Error (b) | 16 | 603.884 | 1.609ns | 494.434 | 1.860* |
| Nitrogen (C) | 3 | 253049.099 | | 248913.522 | |
| A x C | 3 | 155.346 | | 555.855 | |
| B x C | 6 | 11260.374 | | 11344.889 | |
| A x B x C | 6 | 6557.810 | | 7760.504 | |
| Error (c) | 72 | 375.296 | | 264.680 | |
| Total | 119 | 16815.021 | | 16561.878 | |

## 1. Soil variability index :

The weighted index of soil variability "b" was found to be 0.456 and 0.363 for the two successive seasons 1994/95 and 1995/96. These results indicated that soil heterogeneity was intermediate in the fields. These results are in agreement with those obtained by Abdel-Halim and Hanna (1980).

## 2. Optimum plot size :

Results presented in Table 4 indicated that plot variance increased due to increment in plot size. while coefficient of variability (C.V.), was reduced when number of plots increased. Many investigators confirmed these results, among them Lessman and Atkins (1963), Kassem et al (1971) and El-Kalla and Gomaa (1977). However, this reduction is not in proportion with the increase in the size of plots, the rate of reduction decreases as the plots become larger. this confirms the fact that the relationship between plot size and the coefficient of variability is exponen-tionship between plot size and the coefficient of variability is exponential in nature.

The coefficient of variability decreased rapidly at first in the two seasons and then decreased slowly as plot size increased (Figures 1 and 2).This relationship was similar to that previously reported by all investigators studying the same problem. The equaation describing this relationship has the gerneral form :

C.V. = A X-B. The values of A and B were estimated and found to be 20.572, -.3214 for the first season and 17.557, -0.3129 for the second season. Therefor. The equations were defined as :

C.V. = 20.572 X-0.3407

C.V. = 17.557 X-0.3342

Table 4.Variance and coefficient of variability (C.V.) of different plot sizes and shape of four combination from 120 basic units of wheat in 1994/95 and 1995/96 seasons.

| | | | 1994/95 | | | 1995/96 | | |
|---|---|---|---|---|---|---|---|---|
| Plots various size | Plot size (m2) | Plot of plots | Plot Variance | observed C.V.% | estimated C.V.% | plot varoamce | observed C.V.% | estimated C.V.% |
| 1- Sub-sub-plot | 9 | 120 | 125.779 | 4.006 | 4.319 | 94.496 | 3.390 | 3.862 |
| 2- Sub-plot | 36 | 30 | 199.003 | 5.081 | 4.936 | 136.469 | 4.635 | 4.214 |
| 3- Main plot | 108 | 10 | 289.396 | 8.974 | 7.816 | 212.304 | 7.018 | 6.847 |
| 4- Replication | 216 | 5 | 565.937 | 11.36 | 12.35 | 304.000 | 9.927 | 10.530 |

The optimum plot size was calculated by the two following methods:

## 1. Smith's method : (Smith 1938)

The results indicated that (Table 5), the optimum plot size using Smith's meh-tod was 0.838 and 0.571 basic units in the first and second seasons respectively. Consequently, the optimum plot size was 1/556.8 faddan (0.838 x gm2 = 7.542 m2) in the first season and 1/817.3 faddan (0.571 x 9 m2 = 5.139 m2) in the second season.

## 2. Maximum curvature method :

According to the Modified Maximum Curvature procedure, the optimum plot size was 5.433 and 3.321 basic units in the first and second season, respectively (Table 5). Consequently, the optimum plot size was 1/85.9 Faddan (5.433 x 9m2 = 48.897 m2) in the first season and 1/140.5 Faddan (3.321 x 9 m2 = 29.889 m2) in the second season.

The index of soil variability, b, was 0.456 in 1994/95 season and 0.0.363 in 1995/96s. Theoretically, this index varies between zero and one. A zero value in-perfect the basic units. On the other hand, unit index mean completely independence. In the two trials, the b values indicate that an intermediate degree of correlation is present.

Table 5.Optimum plot size for wheat in fertilization experiments as calculated by Smith's and maximum curvature methods.

| | Smith's method Optimum plot size | | | | Maximum curvature method Optimum plot size | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Season | b | In basic unit | Area/ m2 | Area/ faddan | A | B | In basic unit | Area/ m2 | Area/ faddan |
| 1994/95 | -0.456 | 0.838 | 7.542 | 1/556.8 | 20.570 | -0.341 | 5.433 | 18.27 | 1/229.8 |
| 1995/96 | -0.363 | 0.571 | 5.139 | 1/817.3 | 17.557 | -0.334 | 3.321 | 29.89 | 1/140.5 |
| Mean | | 0.705 | 6.341 | 1/662.4 | | | 4.337 | 24.08 | 1/174.4 |

Using the obtained value of b in computing the optimum plot size for the two trials, it was found to be less than a basic unit. Consequently, it was conculcded that the optimum plot size was one basic unit (9 m2 = 1/466.6 faddan). It should be noted that Smith (1938), pointed out that areas half or double the optimum plot size would be 96% as efficient as the optimum plot size, when b=0.5. The mean of optimum plot size over all two seasons was 6.341 m2 = 1/662.4 faddan by using Smith procedure. These results are in accordance with the findings of Abdel-Halim and Hanna (1980) and El-Rassas (1982).

Applying the maximum curvature method, the optimum plot size, was calculated as 5.433 and 3.321 basic units in the two seasons with a mean of 4.337 basic unit. Therefore, the recommend size of plot is (24.08 m2 = 1/174.4 faddan). El-Bakry (1980) confirmed these results.

The results of applying the two methods of determining the optimum plot size were different. The maximum curvature method resulted in larger plot sizes than Smith's method for the two seasons. Therefore, it would be better to adopt the larger optimum plot sizes, because the results of fertilization related to the position of the plot in the field depending mainly on soil fertility gradients. In such cases, the systematic variability is removed by the larger plot size.

## Detection of significant difference between treatment means :

The results obtained in this study as presented in Table (6), clarify the effect of soil variability on the magnitude of the true differences which can be detected for varying plot sizes and number of replications. These results clearly indicate that increasing plot size and /or number of replications reduced the magnitude of differences detected at a specified probability level. The information indicates that the rate of reduction in the differences error per plot is large in relation to the mean.

Table 6. Magnitude of detected differences between treatment means (% of the mean) for different plot sizes and number of replications.

| No. of Replications | | 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|
| No. of basic Units | | | | | | |
| 1994/95 | 1 | 69.80 | 34.90 | 23.26 | 17.45 | 13.94 |
| | 4 | 47.04 | 23.52 | 15.68 | 11.76 | 9.41 |
| | 12 | 46.71 | 23.35 | 15.57 | 11.57 | 9.34 |
| | 24 | 46.39 | 23.19 | 15.46 | 11.60 | 9.27 |
| 1995/96 | 1 | 72.70 | 36.35 | 24.23 | 18.17 | 14.54 |
| | 4 | 67.00 | 33.49 | 22.34 | 16.75 | 13.40 |
| | 12 | 60.97 | 30.48 | 20.32 | 15.42 | 12.19 |
| | 24 | 60.13 | 30.06 | 20.04 | 15.30 | 12.02 |

Furthermore, it can be noticed from the results that reduction in the magnitude of differences that could be detected, with increasing plot size was less than that obtained by equivalent increase in number of replications.

The results obtained in this study indicate that the research worker has a considerable range in selecting size and replications of plots, depending on the amount of land under his disposal. Where the amount of land is not limited, the use of large plots (5x5 = 25 m2), replicated 4 to 6 times would be satisfactory to obtain reasonable accuracy. In cases where only small amount of land is available smaller plots (3x3 = 9m2) with more replications should be used to give the same accuracy that would result in more efficient use of land.

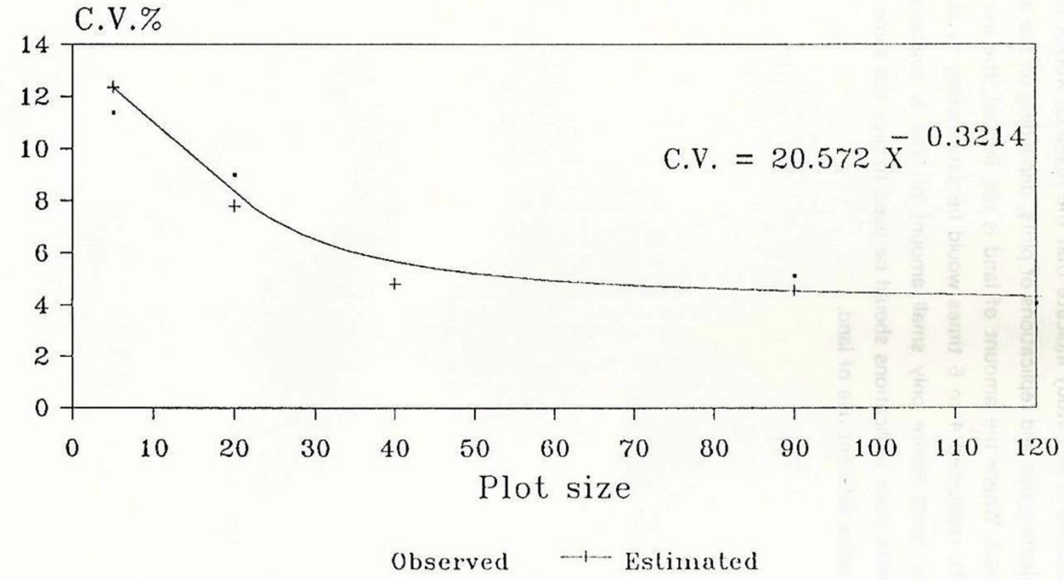


Fig.1. Relationship between plot size and coefficient of variability (C.V.) for wheat in season 1994/95.

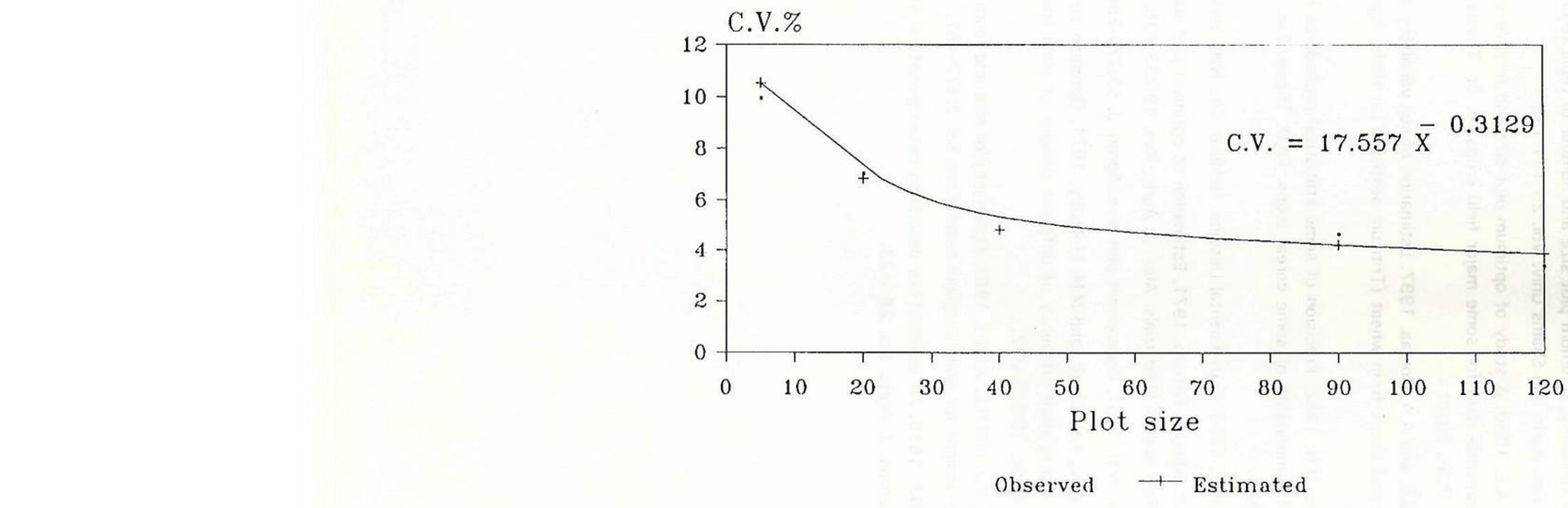


Fig.2. Relationship between plot size and coefficient of variability (C.V.) for wheat in season 1994/95.

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# تقدير أنسب مساحة وشكل للقطعة التجربية وعدد المكررات لمحصول القمح تحت مستويات مختلفة من التسميد

سعيد محمد نصر

المعمل المركزى لبحوث التصميم والتحليل الإحصائى - مركز البحوث الزراعية - الجيزة .

اجرى هذا البحث لدراسة أنسب شكل ومساحة للقطعة التجريبية وأنسب عدد من المكررات وذلك فى تجارب التسميد لمحصول القمح. وقد أقيمت لذلك تجربة بمحطة بحوث سخا خلال موسمى ٩٤ / ١٩٩٥، ٩٥ / ١٩٩٦ وقد إشتملت التجربة على ٢٤ معاملة (٢ صنف X ٣ مستوايات تسميد عضوى x ٤ مستويا تسميد نيتروجينى) فى تصميم قطع منشقة مرتين باستخدام خمس مكررات وكانت مساحة القطعة التجريبية ١٦ م٢ أخذت قطعة وسطية مقدارها ٩م٢ وقدرت صفة المحصول منها.

أتبع فى الدراسة طريقتان إحصائيتان لتقدير أنسب مساحة للقطعة التجريبية.

الطريقة الأولى : هى طريقة سميث التى تعتمد أساساً على العلاقة الخطية بين لوغاريتم مساحة القطع ولوغاريتم التباين لوحدة المساحة.

الطريقة الثانية : هى طريقة اقصى انحناء التى تعتمد على تقدير العلاقة الأسية بين مساحة القطع التجريبية ومعامل الأختلاف.

ويمكن تلخيص أهم النتائج المتحصل عليها فيما يلى :

١ - أدت زيادة مساحة القطع التجريبية الى تناقص التباين لوحدة المساحة وكذا معامل الأختلاف إلا أن النقص لم يكن متناسباً مع الزيادة فى مساحة القطع.

٢ - كانت قيم دليل عدم تجانس التربة فى ٤٥٦ ,. فى الموسم الأول و ٣٦٣ ,. فى الموسم الثانى بمتوسط ٤٠٩ ,. .

٣ - أمكن وضع العلاقة بين معامل الأختلاف (خ) ومساحة القطعة التجريبية (س) فى صورة رياضية بالمعادلة الآتية :-

خ = ٢٠,٥٧ س -٣٢١٤ ,. للموسم الاول

خ = ١٧,٥٥ س -٣١٢٩ ,. للموسم الثانى

٤ - وجد ان أنسب مساحة للقطع التجريبية تتراوح بين ٢٢٩ / ١ الى ١٤٠ / ١ من الفدان

٥ - وجد ان شكل القطع لة أهمية فى حالة القطع الصغيرة وبصفة عامة فان الشكل المربع يوصى به فى تجارب التسميد

٦ - لوحظ ان النقص الحادث فى التباين يكون أقل بزيادة عدد المكررات عن زيادة مساحة القطع التجريبية.