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INFLUENCE OF PLOT SIZE AND NUMBER OF REPLICATIONS ON PRECISION OF FIELD EXPERIMENTS WITH MAIZE GROWEN UNDER DIFFERENT FERTILIZATION CONDITIONS AND PLANT DENSITIES.

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ABSTRACT

This study was conducted during 2003 and 2004 seasons at the Agricultural Research Station of Gemmiza, to estimate optimum plot size and number of replications in fertilization and plant densities experiments for maize cultivars. The experiment included 30 treatments which were the combinations of two maize hybrids (Single cross 155 and Three way cross 327), Three plant densities (20000, 25000 and 30000 plant / fed) and five nitrogen levels (0, 40, 80, 120 and 160 Kg N / fed). A split-split plot design with four replications was selected. The basic unit area was 10.5 m^2. The grain yield data were recorded for each plot (Kg / plot). Data were subjected to two procedures of statistical analysis, the first was exponential relationship (Smith; 1938) and the second was the maximum curvature (Lessman and Atkins; 1963).

The results can be summarized as follows:

1- Increasing plot size decreased variance per basic unit and coefficient of variability (C. V). However, the reduction was not in proportion with the increase in plot size. Index of soil heterogeneity ranged from 0.449 to 0.523 with an average of 0.486 indicating moderate variation in the soil.

2- The exponential relationships between the coefficient of variability (C. V.) and plot size (X) were:

C. V. = 7.907 $X^{-0.647}$ for the first season.

C. V. = 13.804 $X^{-0.756}$ for the second season.

3- The optimum plot size ranged from 0.815 to 1.096 basic units (8.557 to 11.512 m^2) for both seasons, respectively, by using Smith method. While it was 2.58 to 3.7 basic units (27.1 to 38.85 m^2) by using maximum curvature method.

4- 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 field experiments, randomization and replication are necessary for the valid inference and accuracy in probability, but a local control is equally important for increasing the precision of the field experiments. 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 chiefly depend on the distribution of fertility gradients in the experimental area and the nature of the crop under test.

To investigate these problems, several workers had used either the maximum curvature method or smith's method on data collected from uniformity trials. Others had used data obtained from experiments which had included differential treatments such as incomplete block designs or split plot and split split plot designs (Koch and Rigney; 1951, Hanna; 1972, Abd El – Halim and Hanna; 1980, Abd El – Halim et al; 1989, Nasr; 1997 and Salem and Salama 2001).

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.

Shehata *et al.* (1974), working on maize in Egypt, reported that coefficient of variability decreased from 12.9 to 5.9 % as plot size increased from one row plot to eight rows plot and was more sensitive to the number of replications than to the number of plants.

Results of Wassouf (1977) indicated that the optimum plot size, estimated using the modified method reported by Hatheway (1961), ranged from 4.91m^2 to 7.03 m^2. When the comparable variance method was practiced, the optimum size of plot was 19.3 m^2. Furthermore, he concluded that values of variance per basic unit, coefficient of variability and standard error decreased as the plot size increased. He found also that five replications were suitable for corn trials. Increasing number of replications decreased the standard error more rapidly than increasing plot size.

Values of soil heterogeneity index were 0.8 and 0.85 in corn trials conducted by El-Rassas (1982). Coefficient of variation decreased by increasing plot size from one basic unit to 300 units. The optimum plot size ranged from 4 to 8 basic units (1/300 to 1/150 fed) including two border rows. He found that long and narrow plots were more effective in reducing variance per basic unit area, comparable variance and coefficient of variation. A plot size of 4 to 6 basic units and 6 to 8 replications were recommended for corn yield trials.

Using thirty nine corn yield trials, Galal *et al.* (1985) studied the soil heterogeneity and convenient plot size. The results indicated that increasing number of replications reduced soil variability index and coefficient of variability.

The objective of the present study is to determine the optimum plot size for maize grown under the fertilization conditions and plant densities at Gemmiza Experimental Station which represent the Middle Delta region.

MATERIALS AND METHODS

Two maize field experiments were conducted at Gemmiza Agricultural Research Station during the two successive growing seasons of 2003 and 2004.The experiment included 30 treatments which were the combination of two hybrids of maize namely; (Single cross 155 and Three way cross 327), three plant densities (20000, 24000 and 30000 plants / fed) and five nitrogen levels, i. e, zero, 30, 60, 90 and 120 kg N / fed. A split-split plot design with four replications was selected. The main plots were assigned for the two hybrids and the sub-plots were devoted to plant densities and sub-sub plots were devoted to nitrogen levels. The sub-sub plot unit area was 10.5 m^2. The grain yield data were recorded for each plot (kg/plot).

Statistical Analysis:

A- Soil variability index:

The procedure(reported by Gomez and Gomez .1984) involves the use of the basic analysis of variance to estimate the variance per plots of different size, and the use of these estimates to derive a relationship between plot variance and plot size. 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 main plot size

V'3 = the variance between plots of a sub plot size

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

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

Table1: Basic format of the analysis of variance for split – split plot design and formulas for the computation of variances between plots of various size.

Source of Variation	Degrees of Freedom	Mean square	Variance between plots various size
Replications	r – 1	M1	V1 = M1
Factor A	a – 1		
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)		
Error (c)	ab(r – 1)(c – 1)	M4	$V4 = \frac{rab(c-1)M4 + ra(b-1)M3 + r(a-1)M2+(r-1)M1}{rabc-1}$
Total	rabc – 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 regression technique to estimate the regression coefficient *b*

(the index of soil h) from the equation

$\log Vi = \log V4 - b \log Xi$

where Vi and Xi are as 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)- $X_{(opt.)} = b / (1 - b)$

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 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 (X_{0pt}). The values of A and B were substituted in the following formula which was modified by Lessman and Atkins (1963), Meier and Lessman (1971) and developed by Galal and Abou-El-Fittouh (1971).

$$X_{(0pt)} = [A^2 B^2 (2B + 1) / (B + 2)]^{1/(2B+2)}.$$

Using the principles of linear regression, values of A and B were estimated as follows:

$$B = \frac{n \Sigma \log(C.V) \log X - \Sigma \log(C.V) \Sigma \log X}{n\Sigma (\log X)^2 - (\Sigma \log X)^2}$$

$$\text{Log } A = \frac{\Sigma \log (C.V)}{n} - B \frac{\Sigma \log X}{n}$$

Then the equation used to determine $X_{(0pt)}$ was converted to logarithmic form as follows:

$$\text{Log } X_{(opt)} = \frac{2 \log A + 2 \log B + \log (2B + 1) - \log (B + 2)}{(2B + 2)}$$

Plot size directly beyond the $X_{(0pt)}$ value on the curve is considered optimum. Also, cost estimates were not considered in this method.

C- Magnitude of detected differences:

The true difference between two treatment means which can be detected at a 5% level of significance in 90% of the maize experiments was estimated for different plot sizes and number of replications. The estimates were calculated according to the formula presented by Hatheway (1961):

$D^2 = 2(t1 + t_2)^2 C^2 / R X^b$

Where:

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

t_1 = the significant value of t in the test of significance.

t_2 = the 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 in size.

R = the number of replications.

X = the number of multiples of the basic unit.

b = index of soil variability.

RESULTS AND DISCUSSIONS.

The different combinations of plot size were determined as well as the number of basic units (Table2) in 2003 and 2004 seasons.

Table 2: Description of the different combinations of plot size for maize in 2003 and 2004 seasons.

Plots various size	No. of basic units	Plot dimension Width X Length	Plot area M^2
1- Sub-sub-plot	1	3 X 3.5	10.5
2- Sub-plot	5	3 X 17.5	52.5
3- Main plot	15	9 X 17.5	157.5
4- Replication	30	18 X 17.5	315.0

The results of basic format of the analysis of variance for a split- split-plot design are shown in Table 3 indicated that there are significant difference in most of the cases, for the two seasons, showing the effect of plot size. 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 replications. Therefore, the variance was increased when the plot size increased. Similar results were obtained by kassem et al (1971) and Ashmawy (2004).

Table 3: The analysis of variance results for split-split plot design and "F" values for 2003 and 2004 seasons.

Source of variation	Degrees of freedom	2003		2004	
		Mean square	F - value	Mean square	F - value
Replications	3	0.510	8.79**	0.533	
Hybrids (A)	1	130.167		120.809	
Error	3	0.369	6.36**	0.304	4.01*
Densities(B)	2	15.922		19.023	
A X B	2	1.117		2.116	
Error	12	0.162	2.79**	0.293	2.29*
Nitrogen (C)	4	19.159		1.266	
A X C	4	1.253		0.697	2.20**
B X C	8	0.528		0.624	
A X B X C	8	0.208		1.194	
Error	72	0.058		0.133	

1- Soil variability index:

The weighted index of soil variability "b" was found to be 0.449 and 0.523 for the two successive seasons 2003 and 2004. These results indicated that soil heterogeneity was intermediate in the fields. These results are in agreement with those obtained by Ashmawy (2004).

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 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 Nasr (1997) and Salem and Salama (2001).

The equation describing this relationship has the general from :

$C. V. = A X^{-B}$. The values of A and B were estimated and found to be 7.907, -.647 for the first season and 13.804, -0.756 for the second season. Values of A differed in both seasons due to the difference in the soil fertility of the experimental site. Therefore, the equations were defined as:

$C. V. = 7.907 X^{-0.647}$

$C. V. = 13.804 X^{-0.756}$

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

1- Smith's method (Smith 1938):

The results in Table 5, indicated that, the optimum plot size using Smith's method was 0.815 and 1.096 basic units in the first and second seasons respectively.

Table 4: Variance and coefficient of variability (C. V) of different plot size of four Combinations from 120 basic units of maize in 2003 and 2004 seasons.

Plots various size	Plot size (m^2)	No. of plots	2003			2004		
			Plot variance	Observed C. V %	Estimated C. V %	Plot variance	Observed C. V %	Estimated C. V %
1- Sub-sub-plot	10.5	120	0.017	5.010	3.619	0.018	5.000	4.520
1- Sub-plot	52.5	24	0.065	8.373	5.667	0.057	7.420	7.634
3- Main plot	157.5	8	0 122	12.637	11.533	0 154	7.550	17.512
4- Replications	315.0	4	0.146	14.857	32.674	0.220	10.000	59.158

Consequently, the optimum plot size was ($0.815 \times 10.5\ m^2 = 8.557\ m^2$) in the first season and ($1\ 096 \times 10.5\ m^2 = 11.512\ m^2$) in the second season.

2- Maximum curvature method:

According to the modified maximum curvature procedure, the optimum plot size was 2.58 and 3.7 basic units in the first and second seasons, respectively (Table 5). Consequently, the optimum plot size was (2.58 x 10.5 m^2 = 27.1 m^2) in the first season and (3.7 x 10.5 m^2 = 38.85 m^2) in the second season,

The index of soil variability, b, was 0.449 in 2003 season and 0.523 in 2004 season. Theoretically, this index varies between zero and one. A zero value inperfect correlated among the basic units. One the other hand, unit index mean completely independence. In the two trials, the b values indicate that an intermediate degree of correlation is present.

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 concluded that the optimum plot size was one basic unit (10.5 m^2). 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 tow seasons was 10.03 m^2 by using Smith procedure, these results are in accordance with the findings of El-Rassas (1982).

Applying the maximum curvature method, the optimum plot size, was calculated as 2.58 and 3.70 basic units in the tow seasons with a mean of 3.14 basic units. Therefore, the recommend size of plot is (32.97 m^2).

The results of applying the tow methods of determining the optimum plot size were differ. 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 experiments are affected by systematic variation. This variation is directly 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.

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

Season	Optimum plot size						
	Smith's method			Maximum curvature methods			
	B	In basic unit	Area /m^2	A	B	In basic unit	Area/ m^2
2003	0.449	0.815	8.557	7.907	-0.647	2.58	27.10
2004	0.523	1.096	11.512	13.804	-0.756	3.70	38.85
Mean		0.955	10.03			3.14	32.97

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 is always greater when soil is more variable and when the standard error per plot is large in relation to the mean.

Furthermore, it can be noticed from the results that the 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.

Table 6: Magnitude of detected differences between treatments means (% of the mean) for different plot size and number of replications

No. of replications	2	4	6	8	10
No. of basic units					
2003 1	55.030	27.515	18.343	13.758	11.006
5	26.716	13.358	8.905	6.679	5.343
15	16.313	8.156	5.438	4.078	3.263
30	11.950	5.975	3.983	2.987	2.390
2004 1	70.497	35.249	23.499	17.624	14.099
5	30.382	15.191	10.127	7.595	6.076
15	17.103	8.552	5.701	4.276	3.421
30	11.903	5.951	3.968	2.976	2.381

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 (5 x 5 = 25 m^2), replicated 4 to 6 times would be satisfactory to obtain reasonable accuracy. In cases where only small amount of land is available smaller plots (3.5 x 3 = 10.5 m^2) with more replications should be used to give the same accuracy that would result in more efficient use of land.

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تأثير مساحة القطعة وعدد المكررات على دقة التجارب الحقلية فى الذرة الشامية المزروعة تحت ظروف مختلفة من التسميد الأزوتى والكثافة النباتية

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أجرى هذا البحث لدراسة أنسب مساحة للقطعة التجريبية وأنسب عدد للمكررات وذلك فى تجارب التسميد والكثافة النباتية لمحصول الذرة الشامية . وقد اقيمت لذلك تجربة بمحطة البحوث الزراعية بالجميزة خلال موسمى ٢٠٠٣ و٢٠٠٤ اشتملت على ٣٠ معاملة (٢ هجين هما هجين فردى أصفر ١٥٥ ، هجين ثلاثى أبيض ٣٢٧ X ٥ مستويات من التسميد الأزوتى صفر، ٤٠ ، ٨٠، ١٢٠، ١٦٠ X ٣ معدلات من الكثافة النباتية ٢٠٠٠٠ ،٢٥٠٠٠، ٣٠٠٠٠ نبات/فدان). تم تنفيذ التجربة فى تصميم القطع المنشقة مرتين وباستخدام ٤ مكررات وكانت مساحة القطعة التجريبية ١٠,٥ م٢.

وقد استخدمت طريقتان لحساب أنسب مساحة للقطعة التجريبية هما: طريقة سميث (التى تعتمد على العلاقة الخطية بين لوغاريتم مساحة القطع ولوغاريتم التباين لوحدة المساحة) وطريقة أقصى انحناء (التى تعتمد على تقدير أقصى انحناء بين مساحة القطع التجريبية ومعامل الاختلاف).
ومن الدراسة يمكن استخلاص النتائج التالية:

أدت زيادة مساحة القطعة التجريبية إلى إنخفاض التباين لوحدة المساحة ومعامل الاختلاف وان كان معدل الانخفاض لايتناسب مع زيادة مساحة القطعة التجريبية .

تراوحت قيم دليل تجانس التربة بين ٠,٤٤٩ فى الموسم الأول و ٠,٥٢٣ فى الموسم الثانى بمتوسط ٠,٤٨٦ مما يشير إلى أن تجانس التربة كان متوسط تحت ظروف التجربة.

أمكن تمثيل العلاقة بين معامل الاختلاف (خ) ومساحة القطعة التجريبية (س) فى صورة رياضية بالمعادلة التالية: خ = ٧,٩٠٧ س $^{-٠.٦٤٧}$ فى الموسم الأول
خ = ١٣,٨٠٤ س $^{-٠.٧٥٦}$ فى الموسم الثانى

أوضحت النتائج أن أنسب مساحة للقطعة التجريبية كانت ٨,٥٥٧، ١١,٥١٢ متر مربع للموسمين الأول والثانى على الترتيب باستخدام طريقة Smith بينما تراوحت بين ٢٧,١ ، ٣٨,٨٥ متر مربع باستخدام طريقة أقصى انحناء فى الموسمين.

لوحظ أن النقص الحادث فى التباين يكون أقل بزيادة عدد المكررات عن زيادة مساحة القطع التجريبية. وبناء على ذلك عند توافر مساحة كافية للتجربة بفضل زيادة عدد المكررات عن زيادة مساحة القطعة التجريبية.