AN EVALUATION OF MULTIPLE COMPARISONS PROCEDURES IN AGRICULTURAL EXPERIMENTS

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BY

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE AWARD OF THE DEGREE OF MASTER
OF SCIENCE IN STATISTICS

DEPARTMENT OF MATHEMATICS
FACULTY OF SCIENCE
AHMADU BELLO UNIVERSITY
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FEBRUARY, 2008

DEDICATION

Dedicated to my late father Alhaji Mohammad Galadima.

DECLARATION

I, Mohammad Sani Galadima, declare that this thesis is entirely my own work and not a published or an unpublished work of another author. No part of this dissertation has been submitted for a degree in any other University.

Information derived from published or unpublished works of others have been duly acknowledged in the text.

Signature……

Mohammad Sani Galadima

FEBRUARY 2008

CERTIFICATION

This thesis entitled "**AN EVALUATION OF MULTIPLE COMPARISONS PROCEDURES IN AGRICULTURAL EXPERIMENTS**" by Mohammad Sani Galadima meets the regulations governing the award of the degree of Masters of Science of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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ACKNOWLEDGEMENT

I thank God the Almighty for making this study a success. My sincere appreciation goes to my supervisor Professor Asiribo for his tireless efforts towards guiding me through this research. I am grateful to my Head of Department, Prof. G. U. Garba; other lecturers and staff of the Mathematics Department A.B.U Zaria; and my course mates; Mohammad Dauda, Abdullahi Zahraddin and Idris Haruna.

I sincerely acknowledge the support, both moral and other wise of my brother, Mohammad Awwal Galadima and his family. I also appreciate the

support and understanding of my wives: Fati and Fatima and my children. May God reward them abundantly (Ameen).

My thanks go to Mal. Yahaya Awoshiyan and my other colleagues in Fedpodam for their understanding and encouragement.

Finally, I thank all the people that contributed directly or indirectly towards the success of this work.

Mohammad Sani Galadima
FEBRUARY 2008

ABSTRACT

The main objective of this study is to test and evaluate the different Methods (or Procedures) of Multiple Comparisons by determining the conditions under which each of them is suitable especially in terms of protection against errors. Data used for this study were generated by means of computer simulation. The Experiment (Simulation) was repeated 500 times for every set of conditions, so that empirical estimates for the Error Rates and the Correct Decision Rate can be computed for each Comparison Procedure. The result of the study shows that the Methods of Multiple Comparisons can be classified into two. The first group consist of LSD, SNK and Duncan, these differ significantly from the MCPs in the second group and are characterized by high levels of Experimentwise and Comparisonwise type I Error Rates. The second group consists of Tukey's HSD, Scheffe, Bonferroni, Sidak, Gabriel and Hochberg, characterized by relatively low type 1 error rates.

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DEFINITION OF TERMS

Multiple Comparisons Procedures (MCP): These are procedures used to decide which pairs of treatment means are different or to contrast one treatment effect with the average of some other treatments.

Type I Error: This is the error committed when a true null hypothesis is rejected, i.e. when a false significance is declared.

Type II Error: This is the error of accepting a null hypothesis that is false.

Experimentwise Error Rate (EER): This is the ratio, multiplied by 100, of the number of experiments in which at least one type I error is committed to the total number of experiments in which at least one true difference equals zero.

Comparisonwise Error Rate (CER): This is the ratio of the number of comparisons in which a false significance (i.e. Type I error) is reported to the total number of non significant comparisons tested.

Correct Decision Rate (CDR): This is the percentage of comparisons in which neither type I nor type II error is committed.

CHAPTER I

1.0 Introduction

The object of an agricultural experimenter is generally to measure the effect of varying some factor, for example the level of protein in poultry

diets. It is logical to expect that if different levels of protein are applied to different birds, the variation in the weight gains observed would be due partly to the different levels of feeding and partly to the basic variation between birds fed at the same level. The first problem for the experimenter is to disentangle these two parts of the variation i.e. to carryout an analysis of variance (ANOVA) so as to obtain an estimate of the true difference caused by his treatments, i.e. the feeding levels. A significant F-value from the ANOVA indicates that there are differences in the treatment means.

The second problem of the experimenter may be to draw some further conclusions. He may want to decide which pairs of treatments are different, or he may want to contrast one treatment effect with the average of some other treatments.

To identify where the differences are, he could do a series of pairwise t-tests. The major set back here is that the significance levels can be misleading. If you have 6 groups for example, there will be 15 pairwise comparisons of means; it has long been recognized, however, that if several t-tests have been performed at 5% level of significance, say, the probability that at least one of these is apparently significant is greater than 0.05 (Cochran & Cox 1957). If the t-tests are independent, this probability is 0.23 for 5 tests, 0.4 for 10 tests and 0.64 for 20 tests.

Multiple Comparison Procedures (MCPs) give more detailed information about the differences among the treatment means, while controlling the probability of making an incorrect decision. Several multiple comparison procedures are available to researchers. Some notable ones are:

1. Fisher's least significant Difference;
2. Duncan's New Multiple range test;
3. The Student-Newman Keuls' Procedure;
4. Tukey's Honestly Significant Difference;
5. Scheffe's Method.

Which procedure should be used depends upon which type of error is more serious (Schirley & Wearden 1985). Where a type I error is not serious, a very powerful test like Fisher's Least Significant Difference (LSD) could be used, otherwise more conservative tests like Tukey's or Scheffe's are preferable.

The Fisher's multiple comparison procedure is based on a t-test. If the treatment groups are all of equal size n, then two sample averages ($\bar{y}_1$ and $\bar{y}_2$) can be tested for a significant difference by a t-statistic. In order to protect the overall type I error rate for the experiment, Fisher's procedure requires a prior significant F-test in the analysis of variance. With this condition, the overall error rate (comparison wise error Rate, CER) has been

shown to be approximately the α of the F test (Shirley & Stanley 1985).

Duncan (1975) considers the error rate for each pairwise comparison and allows a higher rate for pairs of sample averages that are further apart when ordered by size. This method also is believed to control the C E R.

All the other procedures of multiple comparisons also aim at reducing the error rates so that valid conclusions can be drawn at the end of the analysis of variance.

1.1 **Purpose of the Study**

The purpose of this study is to come up with concise criteria for choosing a suitable method for multiple comparisons of means in Agricultural experiments. This will go along way towards reducing the problem of subjective choice of method being faced by experimenters.

1.2 **Objectives of the Theses**

The objectives of this thesis are:

To identify the different Multiple Comparison Procedures;

To use simulation methods to generate results of Agricultural Experiments for the purpose of testing and evaluating the different methods of multiple comparison of means and

To determine the conditions under which each of the various methods is suitable.

1.3 **Significance of the Study**

With any of the multiple comparison procedures, the observed difference between any two means is compared to the appropriate critical value for that procedure. Since the magnitudes of the critical values vary among procedures, results obtained from the application of one procedure to a given set of data will often differ from those obtained if another procedure is utilized. This has led to disagreement among statisticians concerning the appropriate criteria for choosing a procedure for pairwise multiple comparisons of means.

It is our sincere hope that at the end of this study, we will come up with a guideline that will help Agricultural researchers and indeed all other scientific researchers, to choose objectively from among the numerous multiple comparison procedures, so that there will be no basis for doubt about the appropriateness of the MCP adopted by any researcher. The significance of this study therefore, cannot be over emphasized.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

In this section we discuss different procedures for deciding which pairs of means are different. We also review literatures related to the topic as presented by various statisticians over the years.

2.2 Fisher's Least Significance Difference (LSD)

This multiple comparison procedure is based on a t-test. If the treatment groups are all of equal size n, then two sample averages, $\bar{y}_i$ and $\bar{y}_j$ can be tested for a significant difference by the statistic:

$t_{ij} = (\bar{y}_i - \bar{y}_j)/\sqrt{[(S_p^2/n + S_p^2/n)]} = (\bar{y}_i - \bar{y}_j)/\sqrt{(2S_p^2/n)}$

Where S_p^2 is the pooled sample variance (Steel and Torrie 1960).

The null hypothesis is rejected if

$|\bar{y}_i - \bar{y}_j| \geq t_{\alpha/2}$, $k(n-1)\sqrt{(2Mse/n)}$ or $|t_{ij}| \geq t(\varepsilon,\nu)$, where $\varepsilon = \alpha/2$ and ν is Error d.f.

This follows from the fact that Mse in the analysis of variance is a pooled estimate of the common variance of the treatment groups and MSE has k(n-1) degrees of freedom.

Although it protects the overall Type I error rate (or experiment wise error rate) by requiring a prior significant F-test in the analysis of variance (Chew 1976) and its computation is simple, its requirement that the null hypothesis be rejected in the ANOVA procedure and the fact that it does not take into account the closeness of the means after ranking i.e. it uses a single significant difference as against the use of a set of significant differences of increasing size are its major set backs. This is because in a case where the F-test fails to detect a single significant difference among treatment groups the Fishers Least Significance Difference cannot be used.

2.3 **Duncan's New Multiple Range Test:**

In this method, an attempt is made to overcome one of the problems of Fisher's LSD (i.e. the problem of a single significance difference) by developing a set of significant differences of increasing size, the size to depend upon the closeness of the means after ranking, with the smallest value for adjacent means and the largest for the extremes (Steel and Torrie 1960).

The procedure involves ranking the treatment means in order of magnitude and the test is carried out as follows:

To reject Ho: $\mu_i=\mu_j$ when $\bar{y}_i$, $\bar{y}_j$ span r ranked sample averages, it is necessary that $|\bar{y}_i - \bar{y}_j| \geq d\alpha, r, k(n-1) \sqrt{(Mse/n)}$

Where $d\alpha,r,k(n-1)$ is found in Duncan's table of significance ranges and α stands for the significance level set by the experimenter.

The new multiple range test does not require a preliminary significant overall F-test and it uses a set of significant ranges each range depending upon the number of means in the comparison. However, it does not give real protection to the significance level. Several published studies (for example, Carmer and Swanson 1973) have claimed that Duncan's method is superior to Tukey's because of greater power without considering that the greater power is due to its higher type 1 error rate (Einot and Gabriel 1975). When 'm' independent tests of true null hypotheses are carried out at some level α, the probability that none are statistically significant is $(1-\alpha)^m$ and the Type I error is $1-(1-\alpha)^m$. Therefore, to conduct three tests at 0.05 level, the true level of significance would be 0.143. It is also slightly more conservative than Fisher's test, that is, it will sometimes find fewer significant differences.

2.4 **The Student-Newman-Keul's (SNK) procedure**

Like Duncan's test, different critical values are used depending on the span of the two ranked averages being compared. It is applicable only in situations where all k treatments are equally replicated n-times (Chew 1976). To apply the method, we arrange the means in ascending order.

Two sample averages which span r ranked averages are significantly different if:

$|\bar{y}_i - \bar{y}_j| \geq q\alpha, r, k(n-1) \sqrt{(Mse/n)}$ or $|t_{ij}| \geq (q\alpha, r, k(n-1))/\sqrt{2}$

where the q-values are found in tables.

The method is relatively easy to apply, it takes into account the number of treatments in the experiment and it protects the Type I error rate. The problem with this method is that it cannot be used to construct confidence intervals for difference between means and it is less sensitive than the LSD and Duncan's procedures in detecting real difference.(Chew 1976)

2.5 **Tukey's Honestly Significant Difference (HSD)**

This method of pairwise comparisons is based on the studentized range that controls the maximum experimentwise error rate (MEER) when the sample sizes are equal. Tukey (1953) and Kramer (1956) independently proposed a modification for unequal cell sizes. This method has fared

extremely well in Monte Carlo studies (Dunnett 1980). In addition, Hayter (1984) gives a proof that the Tukey-Kramer procedure controls the MEER for means comparisons, and Hayter (1989) describes the extent to which the Tukey-Kramer procedure has been proven to control the MEER for LS-Means comparisons.

Two means are considered significantly different by the Tukey-Kramer method if:

$|\bar{y}_i - \bar{y}_j| \geq q\alpha, k, k(n-1) \sqrt{(Mse/n)}$ or $|t_{ij}| \geq (q\alpha, k, k(n-1))/\sqrt{2}$

Where $q\alpha, k, k(n-1)$ is the α-level critical value of a studentized range distribution of 'k' independent normal variables with k(n-1) degrees of freedom.

The Tukey confidence limits for all pairwise comparisons with confidence coefficient of at least 1-α are:

$$\bar{y}_i - \bar{y}_j \pm (q\alpha, k, k(n-1)) \sqrt{(Mse/n)}.$$

The method is easy to apply since it requires a single value for judging the significance of all differences, that is, it is a fixed range. It can also be used to compute a set of confidence intervals for differences and it takes into account the number of treatments in the experiment (Steel and Torrie). However, it is a more conservative procedure than the LSD

2.6 Scheffe's Method

Scheffe's method applies to the set of estimates of all possible contrasts among the factor level means, not just the pairwise differences considered by Tukey's methods (Engineering Statistics Handbook).

Two means $\bar{y}_i$ and $\bar{y}_j$ are significantly different if:

$|\bar{y}_i - \bar{y}_j| \geq \sqrt{[(k-1)F\alpha; k-1, \nu]}\sqrt{(2Mse/n)}$ or $|t_{ij}| \geq \sqrt{[(k-1)\, F\alpha; k-1, \nu]}$

where $F\alpha; k-1, \nu$ is the value obtained from F-table at k-1, ν degrees of freedom and α is the level of significance.

Confidence intervals can be constructed for all possible contrasts using the Scheffe's method. An arbitrary contrast is defined by:

$$C = \sum_{i=1}^{K} Ci\, \mu; \qquad \text{where} \quad \sum_{i=1}^{K} Ci = 0$$

We estimate C by: $\hat{C} = \sum_{i=1}^{K} C_i \bar{y}_i$ for which the estimated variance is

$$S^2_{\hat{c}} = \sigma^2_{\hat{c}} \sum_{i=1}^{K} C^2_i / n_i$$

The confidence limits for any contrast C are:

$\hat{c} \pm \sqrt{[(k-1)F\alpha; k-1, (N-K)\, S_{\hat{c}}]}$

Where $\hat{c}$ is an estimate for C.

The null hypothesis that there is no difference in the means is not rejected if 0 falls within the confidence interval.

The method is general, so that all possible contrasts can be tested for significance and it can be used to construct confidence intervals. It was once one of the most popular procedures but has now fallen in to disuse because it is very conservative (Dallal); it never declares a contrast significant if the overall F-test is not significant. Most other multiple comparison methods can find significant contrasts when the overall F-test is not significant.

2.7 Bonferroni method:

The method is simple and it allows many comparison statements to be made (or confidence intervals to be constructed) while still assuring an overall confidence coefficient is maintained.

The MCP applies to an ANOVA situation when the analyst has picked out a particular set of pairwise comparisons or contrasts or linear combinations in advance. It is valid for equal and unequal sample sizes.

The Bonferroni t-test with MEER $<\alpha$ declares two means to be significantly different if: $|t_{ij}| \geq t(2\alpha/k(k-1), \nu)$ or $|\bar{y}_i - \bar{y}_j| \geq t(2\alpha/k(k-1), \nu)\sqrt{(2Mse/n)}$

Where α is the significance level, ν is the number of error degrees of freedom.

The confidence limits for g linear combinations C_i are

$$C_i \pm t_{\alpha/2g;\ (N-K)} S_{\hat{c}i}$$

Where $S_{\hat{c}i} = \sigma_{\hat{c}i} \sqrt{(\Sigma\ C_i^2 / n_i)}$

The Bonferroni method makes an adjustment for the fact that multiple comparisons are being made. Consider the case of 4 means, where there are 6 possible pairwise comparisons, the Bonferroni adjustment basically multiplies each of the significant levels from LSD test by the number of tests performed, i.e. 6. So, for example, if the LSD test reports that the difference between groups 1 and 2 is significant at the 0.009574 level, the Bonferroni adjustment multiplies this by 6 (the number of pairwise comparisons when there are 4 groups) and reports a significance level of 6 x 0.009574 = 0.057442. As this is greater than 0.05, the difference between groups 1 and 2 is not considered significant.

The Bonferroni method is a very flexible multiple comparison procedure and it compensates for the fact that multiple comparisons are being made. The problem with this method is that it is not an exact procedure. The Bonferroni adjusted p value is larger than the true p value

(Dallal), and using smaller p values than necessary makes effects harder to detect.

2.8 Sidak's Method

The Sidak's method, like the Bonferroni method, also makes an adjustment for multiple comparisons. The adjustment computes the level of significance as: $1 - (1\text{- LSD significance})^{K(K-1)/2}$

So, for 6 comparisons, if LSD significance level is 0.009574; the Sidak's significance is: $1 - (1 - 0.009574)^6 = 0.056087$.

The adjustment is aimed at reducing our overall chance of falsely rejecting each hypothesis to α rather than letting it increase with each additional test.

Two means are significantly different if: $|t_{ij}| \geq t(\varepsilon ; \nu)$

where $\varepsilon = 1 - (1 - \alpha)^{k(k-1)/2}$ for comparison of k means

The Sidak's method makes adjustment for the comparison error rate as well as the level of significance and it is less conservative than the Bonferroni method. However, it is more conservative than the Fisher's LSD and Scheffe's methods.

2.9 **SMM or GT2 Method**

This method was devised by Hochberg (1974). It is similar to Tukey's method, but it uses the studentized maximum modulus instead of the studentized range. The method is proven to hold MEER at a level not exceeding α with unequal sample sizes.

Two means are declared significantly different if:

$$|t_{ij}| \geq m(\alpha ; C, \nu).$$

Where $m(\alpha, C, \nu)$ is the α -level critical value of the studentized maximum modulus distribution of c independent normal variables with ν degrees of freedom and $C = K(K-1)/2$.

This method holds the MEER at a level not exceeding α and it uses a single value for judging the significance of all differences.

Its disadvantage is that it is generally less powerful than the Tukey-kramer method and always less powerful than Tukey's test for equal cell sizes.

2.10 **Gabriel's method**

This method is also based on the studentized maximum modulus. It is applicable only to arithmetic means.

The null hypothesis is rejected if:

$$|\bar{y}_i - \bar{y}_j| / S[1/\sqrt{2n_i} + 1/\sqrt{2n_j}] \geq m(\alpha ; k, \nu)$$

For equal cell sizes, Gabriel's method is equal to Hochberg's GT^2 method. For unequal cell sizes Gabriel's method is more powerful than GT^2 but may become liberal with highly disparate cell sizes (Dunnett 1980).

Gabriel's test is the only method for unequal sample sizes that lends itself to a graphical representation as intervals around the means. Assuming $\bar{y}_i > \bar{y}_j$ you can rewrite the preceding inequality as:

$$\bar{y}_i - m(\alpha ; k, v)\frac{S}{\sqrt{2n_i}} \geq \bar{y}_j - m(\alpha ; k, v)\frac{S}{\sqrt{2n_j}}$$

The expression on the left does not depend on j, nor does the expression on the right depend on i. Hence you can form what Gabriel calls an (l,u) – interval around each sample mean and declare two means to be significantly different if their (l,u) – intervals do not overlap (HSu 1996).

The method is more powerful than GT2 for unequal cell sizes and it is the only method for unequal cell sizes that lends itself to a graphical representation as intervals around the means. But it is liberal with highly disparate cell sizes.

2.11 Studies on Evaluation of Multiple Comparisons Procedures

Carma and Swanson (1973) in their paper "An Evaluation of Ten Pairwise Multiple Comparison Procedures by Monte Carlo Methods" used computer simulation techniques to study the type I and type III error rates

and the correct decision rates for ten pairwise multiple comparison procedures. The three rates were evaluated for each of the ten MCPs under different amounts of replication, various numbers of treatment and different levels of homogeneity among the means.

The type I error rate is the probability of rejecting a true null hypothesis. The reverse decision or type III error rate is the probability of declaring one treatment superior to another when the reverse is actually true. The correct decision rate is the probability of declaring one treatment superior to another when it actually is.

The multiple comparison procedures considered under this study were:

1. Least Significance Difference (LSD).
2. Tukey Significant Difference (TSD).
3. Student-Newman-Keul's Procedure (SNK).
4. Duncan's Multiple Range Test (MRT).
5. Scheffe's Significant Difference (SSD).
6. Fisher's Significant Difference 1 (FSD 1) i.e. ($\alpha = 0.01$)
7. " " " 2 (FSD 2) i.e. ($\alpha = 0.05$)
8. " " " 3 (FSD 3) i.e. ($\alpha = 0.10$)
9. Baye's Significant Difference (BSD)

10. Baye's Exact Test (BET)

Discussing the results of the analysis, the authors observed that the SSD is not quite capable of detecting real differences when they exist. This statement, however applies only to the use of Scheffe's procedure as a pairwise multiple comparisons procedure and not to its use for testing unplanned linear contrasts among means. It was also observed that TSD and SNK are clearly inferior in ability to detect true differences especially when the true differences ranged from 0.56 to about 2.56. SSD, TSD and SNK provide excellent protection against type1 error but it is the authors' feeling that, in evaluation of various procedures, concern for ability to detect real differences should receive a high priority.

The LSD and the FSD3 can be eliminated from consideration due to their high lack of protection against type I errors. The outstanding procedures therefore were: FSD2, BSD, BET and MRT.

Unfortunately, while the MRT often produces a lower frequency of type I error, the other 3 are generally more sensitive in detecting real differences, especially as the number of treatments increases. Since the BET is an improved and more exact version than the BSD it seems reasonable to prefer the former. Removing the MRT and BSD from further consideration based on these comments, the choice is narrowed to two procedures, the FSD2 and

BET. In many, perhaps most, experimental situations, the choice of either the BET or the FSD2 appears to be reasonable.

Olorunju and Asiribo (2003) carried out a study titled:

"Evaluation of Methods used for Multiple Comparison of Means in Agricultural Experiments" in which they compared the effectiveness of some of the most frequently used methods for "Multiple Treatment comparisons" in Agriculture. The methods considered were Least Significance Difference t-test (LSD), Duncan's Multiple Range Test (DMRT), Tukey's t-test, Studentized-Newman-Keul's Multiple Range Test (SNK), Studentized Maximum Modulus test and Scheffe's test.

The important consideration was to find how the treatments could be partitioned into some homogeneous or near homogeneous groups that are very similar or not different from one another with respect to their performance.The study concludes that Scheffe provides a better method of performing Multiple Comparisons in Agriculture for a more conservative result. There are less problems of 'chaining' or overlap observed generally when compared with LSD and Duncan's procedures.

The Authors advised that multiple comparisons of means should not be considered once the F-test declares no significant treatment effects.

Also, based on the objectives of an experimenter or the treatment structure,

planned comparisons can be carried out rather than holding all possible pairs of means comparison. With planned or group comparisons, contrasts can be constructed and if necessary, confidence intervals can also be obtained; one of the advantages of this procedure is that the various comparisons are independent.

Our study is more elaborate than that of Olorunju and Asiribo in the sense that: we compared ten (10) MCPs while they compared five (5) and they used a few sets of data obtained from Agricultiral experiments while we used Computer Simulation to generate thousands of data for the evaluation of the Comparison Procedures.

Victor Chew (1976), despite his reservations for the use of MCPs, made the following recommendation:

"In the final analysis, the choice will hinge on a choice between an experimentwise error rate (for which Tukey's HSD is the recommended procedure) and a comparison wise error rate for which Duncan's MRT is recommended. We can remove or reduce reservations about Duncan's MRT (prone to type 1 error) by requiring an initial significant overall F-test or by taking Duncan's comparison wise error rate to be 0.01 or 0.001. Similarly, we can remove or reduce reservations about Tukey's HSD (some times unable to detect a difference) by taking Tukey's experimentwise to be 0.1 or

0.25."

2.12 Antagonists of the Multiple Comparisons Procedures

The debate on MCPs is not limited to the choice of an appropriate method, there are some statisticians that have serious reservations on the use of the comparison procedures; notable among them is Rupert G. Miller Jr. who is widely respected in the field of multiple comparisons procedures. He made the following comments on MCPs in his book "Simultaneous Statistical Inference" 2nd edition:

"This is the hardest part of the book because this is where Statistics takes leave of Mathematics and must be guided by subjective judgment….

Provided the non simultaneous statistician (one who never adjusts for multiple comparisons) and his client are well aware of their error rates for groups of statements, and feel the group rates are either satisfactory or unimportant, the author has no quarrel with them. Every man should get to pick his own error rates. Simultaneous techniques certainly do not apply, or should not be applied, to every problem".

Unhappy with the way MCPs are being used Godwin Aflakpal warned that the Multiple Comparison Tests developed to improve upon the inadequacies of the LSD are overused or abused."

Victor Chew in his paper "Comparing treatment means: a compendium" discussed the uses and abuses of multiple comparison procedures. He is of the opinion that glaring abuses are their use in comparing treatments that are factorial in nature or in comparing several levels of a quantitative factor. He said in the former case, the degrees of freedom or sum of squares for treatments should be partitioned to correspond to main effects and interactions; while regression analysis is the appropriate technique in the latter case. If the regression is significant, no multiple comparison procedure is necessary. All treatments (including intermediate ones not used in the experiment) are significantly different in their effects.

2.13 **SUMMARY**

From all the Literature reviewed, one cannot single out any MCP and consider it to be the "uniformly best" among all methods. However, various Authors made their recommendations on some of the MCPs, giving conditions under which such methods are ideal.

The author of the book 'Engineering Statistics' observed that if all pairwise comparisons are of interest, Tukey has the edge. If however, only a subset of pairwise comparisons is required, then Bonferroni is recommended. Also if many or all contrasts might be of interest, the Scheffe

method tends to give a narrower confidence interval and is therefore the preferred method.

Olorunju and Asiribo chose Scheffe as the best among some five MCPs for classification of treatment means in to homogeneous groups.

Swanson and Carmer recommended Baye's Exact Test (BET) and Fisher's LSD2 (α =0.05), even though BET is not a popular method.

Chew prefers Tukey if experimentwise error rate is to be controlled and Duncan's MRT if one is interested in controlling comparisonwise error rate.

Dallal says he uses both Fisher's LSD and Tukey's HSD. Differences that are significant according to HSD are judged significant. Differences that are not significant according to LSD are judged non significant. Differences that are judged significant by LSD but not significant by HSD are judged open to further investigation.

It can be seen that the opinions expressed by these authors about the choice of an ideal MCP are almost as many as the number of authors. This, and the fact that we also want to verify the claims made by some of the authors about the comparison procedures are the reasons why we feel that there is the need to carry out this study, albeit on a smaller scale.

CHAPTER III

METHODOLOGY

3.0 **Introduction**

In this chapter we discuss the details of how to conduct the research on the selected MCPs with a view to evaluating them.

The bases for evaluating the MCPs are:

1. Comparisonwise Error Rate;
2. Experimentwise Error Rate and
3. Correct Decision Rate

1. **Comparisonwise Error Rate (CER)**: This is the ratio of the number of comparisons in which a false significance (i.e. Type I error) is reported to the total number of non significant comparisons tested.
2. **Experimentwise Error Rate (EER):** This is the ratio, multiplied by 100, of the number of experiments in which at least one type I error is committed, to the total number of experiments in which at least one true difference equals zero.
3. **Correct Decision Rate (CDR):** This is the percentage of comparisons in which neither type I nor type II error is committed. It measures the ability of an MCP to avoid both type I and type II errors.

The Comparisonwise Error Rates are expected to be generally lower than the Experimentwise Error Rates because CER gives the probability that any one comparison will be found significant by chance (which is expected to be α); while the EER is the probability that at least one type 1 error will be made in a set of comparisons (or in an experiment). The later has a higher chance of occurrence, because if we make three independent non-significant comparisons in an experiment at $\alpha = 0.05$ each, for example, the probability of Experimentwise type 1 error is approximately 0.15.

CER and EER are based on type I error, while CDR is a measure of the ability of the MCP to avoid both type I and type II errors.

The multiple comparison procedures selected for comparison are:

1. Fisher's Least Significance Difference (LSD)
2. Tukey's Honestly Significant Difference (HSD)
3. Duncan's New Multiple Range Test (MRT)
4. Scheffe's Significant Difference (SSD)
5. Bonferroni's Significant Difference (BSD)
6. Sidak's Method
7. Gabriel's Method
8. Student Newman Keul's Method (SNK)
9. Hochberg's SMM or GT^2 Method (Hochberg)

3.1 Source of Data

The data used for this study were generated by means of computer simulation. We considered this option because we feel that it is the best way for evaluating the practical utilities of the various MCPs and their ability to control the error rate. Furthermore, the simulation method enables us to obtain experimental data under different conditions (different treatment numbers, replication numbers, homogeneity of the true treatment means etc). The Experiment (simulation) can also be repeated many times for every set of conditions, so that empirical estimates for the error rates can be computed. Repetition of the experiment involves the generation of a new set of normally distributed random errors (e_{ij}) and the computation of Y_{ij}'s.

3.2 Generation of the Experimental Data (Simulation Method)

The model used for the Experiment is the One-Way fixed-effect Analysis of Variance model viz:

$Y_{ij} = \mu + T_i + e_{ij}$

Where Y_{ij} is the simulated value of Y corresponding to the ith treatment and jth replication;

μ is the grand mean and it is set to be equal to 100;

T_i is the ith treatment effect, which is obtained as the treatment mean minus

the grand mean;

e_{ij} is the random error component. Numerical sample values of e_{ij} are obtained from a normal distribution with mean zero and standard deviation 20.

The values of 100 and 20 were chosen for the overall mean and error standard deviation so that the coefficient of variation can be in the order of 20% in any experiment. A coefficient of variation of 25% is a typical value in some Agricultural Experiments. Mead and Curnow (1993)

Data for 500 completely randomized design experiments were generated for each combination of five sets of treatment means and three different replication numbers (4, 6 and 12).These five groups of treatment means were chosen with some means within each group made to be equal or close (homogeneous) while others are relatively far apart. The number of means in the different groups also varies; five different numbers of means (3, 4, 5, 6, and 10) were used. It is our wish to see the effect of 'treatment number' and 'replication number' on the error rates and the CDR for the nine MCPs under study. The statistical package SPSS was used to generate the experimental data and also carry out the Analysis (both the ANOVA and the Post-Hoc tests). To do the Simulation, a variable was declared each for grand mean, treatment mean, treatment effect (calculated as treatment mean-

grand mean), error (generated from N(0, 20)), treatment and yield (Y_{ij}).

The yield is calculated as: Yield = grand mean + treatment effect +error.

For each experiment the random errors were generated afresh and the yield recalculated.

3.3 SYNTAX USED IN SPSS TO GENERATE AND ANALYSE THE DATA

- COMPUTE C = C+1 .
- EXECUTE .
- COMPUTE ERROR = RV.NORMAL(0,20) .
- EXECUTE .
- COMPUTE YIELD = grandmean + treateffect + error .
- EXECUTE .
- ONEWAY
- yield BY treat
- /STATISTICS DESCRIPTIVES HOMOGENEITY
- /MISSING ANALYSIS
- /POSTHOC = SNK TUKEY DUNCAN SCHEFFE LSD BONFERRONI SIDAK GABRIEL GT2
- ALPHA(.05).

3.4 A sample of simulation result and output for ANOVA/Post-hoc test

The tables below show a single simulation of the experiment with five treatments and 4 replications and also the output of the ANOVA and post-hoc tests.

Table 3.1 is the data obtained from a single simulation of an experiment with 5 treatments and 4 replications.

In **Table 3.2**, the mean yields and other descriptive statistics are displayed.

Table 3.3 is the Analysis of Variance (ANOVA) Table showing the result of test for equality of means. If the value in the last column is less than 0.05 (our chosen level of significance) we would conclude that not all the means are equal, and to find out which means are not equal a post hoc test is carried out to make a pairwise comparison of the means.

Table 3.4 is the result of the post hoc tests where multiple comparisons of the treatment means are carried out using the nine MCPS under study.

The entries in the first column are the MCPs; in the second and third columns are the treatments being compared (treatments I and J); the fourth column shows the difference between treatments I and J, the asterisks (*) on some of the entries in this column indicate that the two treatment means are significantly different. Where there is no asterisk, the means are not significantly different.

The standard error of the difference and the significance probability are the entries in the fifth and sixth columns, while the seventh and eighth columns show the lower and upper bounds of the 95% confidence interval of the difference. It can be seen that where ever the lower and upper bounds have the same signs, the pair of means being compared are significantly different.SNK and Duncan are not among the MCPs in this Table. This is because the two MCPs can not be used to construct confidence intervals. So the multiple comparisons are made using the Table of homogeneous subsets (Table 3.5).

Table 3.5 is the table of homogeneous subsets where the treatment means are arranged in ascending order and those that are homogeneous (not significantly different) are placed in the same column (subset).

TABLE 3.1

A SAMPLE OF SIMULATION RESULT

Reps	Treat	Grand mean	Treat mean	Treat effect	Error	Yield
Rep 1	1	100	110	10	-.03	109.7
Rep 1	2	100	115	15	10.58	125.58
Rep 1	3	100	85	-15	-13.85	71.2
Rep 1	4	100	83	-17	-2.81	80.19
Rep 1	5	100	68	-32	-7.8	60.2
Rep 2	1	100	110	10	-30.15	79.85
Rep 2	2	100	115	15	-11.39	103.61
Rep 2	3	100	85	-15	11.47	96.47
Rep 2	4	100	83	-17	13.55	96.55
Rep 2	5	100	68	-32	-12.22	55.78
Rep 3	1	100	110	10	-0.34	109.66
Rep 3	2	100	115	15	4.0	119
Rep 3	3	100	85	-15	0.26	85.26
Rep 3	4	100	83	-17	4.07	87.07
Rep 3	5	100	68	-32	1.27	69.27
Rep 4	1	100	110	10	-3.18	106.82
Rep 4	2	100	115	15	8.26	123.26
Rep 4	3	100	85	-15	0.66	85.66
Rep 4	4	100	83	-17	0.59	83.59
Rep 4	5	100	68	-32	3.08	71.08

TABLE 3.2

DESCRIPTIVE STATISTICS FOR THE OBSERVED RESULT

Descriptives								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	4	108.3260	1.72327	.86164	105.5839	111.0681	106.82	109.97
2.00	4	117.8623	9.88561	4.94280	102.1321	133.5925	103.61	125.58
3.00	4	84.6377	10.38294	5.19147	68.1161	101.1592	71.15	96.47
4.00	4	86.8506	7.04657	3.52329	75.6379	98.0633	80.19	96.55
5.00	4	64.0826	7.30012	3.65006	52.4665	75.6987	55.78	71.08
Total	20	92.3518	20.66507	4.62085	82.6803	102.0234	55.78	125.58

TABLE 3.3

ANALYSIS OF VARIANCE (ANOVA) TABLE

ANOVA YIELD					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7179.522	4	1794.880	28.815	.000
Within Groups	934.339	15	62.289		
Total	8113.861	19			

TABLE 3.4

POST HOC TESTS

Multiple Comparisons Dependent Variable: YIELD							
	(I) TREAT	**(J) TREAT**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
						Lower Bound	**Upper Bound**
Tukey HSD	**1.00**	**2.00**	-9.5363	5.58074	.458	-26.7692	7.6966
		3.00	23.6883(*)	5.58074	.005	6.4555	40.9212
		4.00	21.4754(*)	5.58074	.012	4.2425	38.7083
		5.00	44.2434(*)	5.58074	.000	27.0105	61.4763
	2.00	**1.00**	9.5363	5.58074	.458	-7.6966	26.7692
		3.00	33.2247(*)	5.58074	.000	15.9918	50.4576
		4.00	31.0117(*)	5.58074	.000	13.7788	48.2446
		5.00	53.7797(*)	5.58074	.000	36.5468	71.0126
	3.00	**1.00**	-23.6883(*)	5.58074	.005	-40.9212	-6.4555
		2.00	-33.2247(*)	5.58074	.000	-50.4576	-15.9918
		4.00	-2.2129	5.58074	.994	-19.4458	15.0200
		5.00	20.5550(*)	5.58074	.016	3.3222	37.7879
	4.00	**1.00**	-21.4754(*)	5.58074	.012	-38.7083	-4.2425
		2.00	-31.0117(*)	5.58074	.000	-48.2446	-13.7788
		3.00	2.2129	5.58074	.994	-15.0200	19.4458
		5.00	22.7680(*)	5.58074	.007	5.5351	40.0009
	5.00	**1.00**	-44.2434(*)	5.58074	.000	-61.4763	-27.0105
		2.00	-53.7797(*)	5.58074	.000	-71.0126	-36.5468
		3.00	-20.5550(*)	5.58074	.016	-37.7879	-3.3222
		4.00	-22.7680(*)	5.58074	.007	-40.0009	-5.5351

Scheffe	**1.00**	**2.00**	-9.5363	5.58074	.585	-29.0468	9.9741
		3.00	23.6883(*)	5.58074	.014	4.1779	43.1988
		4.00	21.4754(*)	5.58074	.027	1.9649	40.9859
		5.00	44.2434(*)	5.58074	.000	24.7329	63.7539
	2.00	**1.00**	9.5363	5.58074	.585	-9.9741	29.0468
		3.00	33.2247(*)	5.58074	.001	13.7142	52.7351
		4.00	31.0117(*)	5.58074	.001	11.5013	50.5222
		5.00	53.7797(*)	5.58074	.000	34.2692	73.2902
	3.00	**1.00**	-23.6883(*)	5.58074	.014	-43.1988	-4.1779
		2.00	-33.2247(*)	5.58074	.001	-52.7351	-13.7142
		4.00	-2.2129	5.58074	.997	-21.7234	17.2975
		5.00	20.5550(*)	5.58074	.036	1.0446	40.0655
	4.00	**1.00**	-21.4754(*)	5.58074	.027	-40.9859	-1.9649
		2.00	-31.0117(*)	5.58074	.001	-50.5222	-11.5013
		3.00	2.2129	5.58074	.997	-17.2975	21.7234
		5.00	22.7680(*)	5.58074	.018	3.2575	42.2785
	5.00	**1.00**	-44.2434(*)	5.58074	.000	-63.7539	-24.7329
		2.00	-53.7797(*)	5.58074	.000	-73.2902	-34.2692
		3.00	-20.5550(*)	5.58074	.036	-40.0655	-1.0446
		4.00	-22.7680(*)	5.58074	.018	-42.2785	-3.2575
LSD	**1.00**	**2.00**	-9.5363	5.58074	.108	-21.4314	2.3587
		3.00	23.6883(*)	5.58074	.001	11.7933	35.5834
		4.00	21.4754(*)	5.58074	.002	9.5803	33.3705
		5.00	44.2434(*)	5.58074	.000	32.3483	56.1385
	2.00	**1.00**	9.5363	5.58074	.108	-2.3587	21.4314
		3.00	33.2247(*)	5.58074	.000	21.3296	45.1197
		4.00	31.0117(*)	5.58074	.000	19.1167	42.9068
		5.00	53.7797(*)	5.58074	.000	41.8847	65.6748
	3.00	**1.00**	-23.6883(*)	5.58074	.001	-35.5834	-11.7933

		2.00	-33.2247(*)	5.58074	.000	-45.1197	-21.3296
		4.00	-2.2129	5.58074	.697	-14.1080	9.6821
		5.00	20.5550(*)	5.58074	.002	8.6600	32.4501
	4.00	**1.00**	-21.4754(*)	5.58074	.002	-33.3705	-9.5803
		2.00	-31.0117(*)	5.58074	.000	-42.9068	-19.1167
		3.00	2.2129	5.58074	.697	-9.6821	14.1080
		5.00	22.7680(*)	5.58074	.001	10.8729	34.6630
	5.00	**1.00**	-44.2434(*)	5.58074	.000	-56.1385	-32.3483
		2.00	-53.7797(*)	5.58074	.000	-65.6748	-41.8847
		3.00	-20.5550(*)	5.58074	.002	-32.4501	-8.6600
		4.00	-22.7680(*)	5.58074	.001	-34.6630	-10.8729
Bonferroni	**1.00**	**2.00**	-9.5363	5.58074	1.000	-27.8748	8.8022
		3.00	23.6883(*)	5.58074	.007	5.3498	42.0269
		4.00	21.4754(*)	5.58074	.016	3.1369	39.8139
		5.00	44.2434(*)	5.58074	.000	25.9049	62.5819
	2.00	**1.00**	9.5363	5.58074	1.000	-8.8022	27.8748
		3.00	33.2247(*)	5.58074	.000	14.8861	51.5632
		4.00	31.0117(*)	5.58074	.001	12.6732	49.3502
		5.00	53.7797(*)	5.58074	.000	35.4412	72.1182
	3.00	**1.00**	-23.6883(*)	5.58074	.007	-42.0269	-5.3498
		2.00	-33.2247(*)	5.58074	.000	-51.5632	-14.8861
		4.00	-2.2129	5.58074	1.000	-20.5515	16.1256
		5.00	20.5550(*)	5.58074	.022	2.2165	38.8936
	4.00	**1.00**	-21.4754(*)	5.58074	.016	-39.8139	-3.1369
		2.00	-31.0117(*)	5.58074	.001	-49.3502	-12.6732
		3.00	2.2129	5.58074	1.000	-16.1256	20.5515
		5.00	22.7680(*)	5.58074	.010	4.4295	41.1065
	5.00	**1.00**	-44.2434(*)	5.58074	.000	-62.5819	-25.9049
		2.00	-53.7797(*)	5.58074	.000	-72.1182	-35.4412

		3.00	-20.5550(*)	5.58074	.022	-38.8936	-2.2165
		4.00	-22.7680(*)	5.58074	.010	-41.1065	-4.4295
Sidak	**1.00**	**2.00**	-9.5363	5.58074	.681	-27.8123	8.7397
		3.00	23.6883(*)	5.58074	.007	5.4124	41.9643
		4.00	21.4754(*)	5.58074	.016	3.1994	39.7514
		5.00	44.2434(*)	5.58074	.000	25.9674	62.5194
	2.00	**1.00**	9.5363	5.58074	.681	-8.7397	27.8123
		3.00	33.2247(*)	5.58074	.000	14.9487	51.5006
		4.00	31.0117(*)	5.58074	.001	12.7358	49.2877
		5.00	53.7797(*)	5.58074	.000	35.5037	72.0557
	3.00	**1.00**	-23.6883(*)	5.58074	.007	-41.9643	-5.4124
		2.00	-33.2247(*)	5.58074	.000	-51.5006	-14.9487
		4.00	-2.2129	5.58074	1.000	-20.4889	16.0630
		5.00	20.5550(*)	5.58074	.022	2.2791	38.8310
	4.00	**1.00**	-21.4754(*)	5.58074	.016	-39.7514	-3.1994
		2.00	-31.0117(*)	5.58074	.001	-49.2877	-12.7358
		3.00	2.2129	5.58074	1.000	-16.0630	20.4889
		5.00	22.7680(*)	5.58074	.010	4.4920	41.0440
	5.00	**1.00**	-44.2434(*)	5.58074	.000	-62.5194	-25.9674
		2.00	-53.7797(*)	5.58074	.000	-72.0557	-35.5037
		3.00	-20.5550(*)	5.58074	.022	-38.8310	-2.2791
		4.00	-22.7680(*)	5.58074	.010	-41.0440	-4.4920
Gabriel	**1.00**	**2.00**	-9.5363	5.58074	.614	-27.5469	8.4743
		3.00	23.6883(*)	5.58074	.007	5.6777	41.6990
		4.00	21.4754(*)	5.58074	.015	3.4648	39.4860
		5.00	44.2434(*)	5.58074	.000	26.2328	62.2540
	2.00	**1.00**	9.5363	5.58074	.614	-8.4743	27.5469
		3.00	33.2247(*)	5.58074	.000	15.2141	51.2353
		4.00	31.0117(*)	5.58074	.001	13.0011	49.0223

		5.00	53.7797(*)	5.58074	.000	35.7691	71.7903
	3.00	**1.00**	-23.6883(*)	5.58074	.007	-41.6990	-5.6777
		2.00	-33.2247(*)	5.58074	.000	-51.2353	-15.2141
		4.00	-2.2129	5.58074	1.000	-20.2235	15.7977
		5.00	20.5550(*)	5.58074	.020	2.5444	38.5657
	4.00	**1.00**	-21.4754(*)	5.58074	.015	-39.4860	-3.4648
		2.00	-31.0117(*)	5.58074	.001	-49.0223	-13.0011
		3.00	2.2129	5.58074	1.000	-15.7977	20.2235
		5.00	22.7680(*)	5.58074	.009	4.7574	40.7786
	5.00	**1.00**	-44.2434(*)	5.58074	.000	-62.2540	-26.2328
		2.00	-53.7797(*)	5.58074	.000	-71.7903	-35.7691
		3.00	-20.5550(*)	5.58074	.020	-38.5657	-2.5444
		4.00	-22.7680(*)	5.58074	.009	-40.7786	-4.7574
Hochberg	**1.00**	**2.00**	-9.5363	5.58074	.614	-27.5469	8.4743
		3.00	23.6883(*)	5.58074	.007	5.6777	41.6990
		4.00	21.4754(*)	5.58074	.015	3.4648	39.4860
		5.00	44.2434(*)	5.58074	.000	26.2328	62.2540
	2.00	**1.00**	9.5363	5.58074	.614	-8.4743	27.5469
		3.00	33.2247(*)	5.58074	.000	15.2141	51.2353
		4.00	31.0117(*)	5.58074	.001	13.0011	49.0223
		5.00	53.7797(*)	5.58074	.000	35.7691	71.7903
	3.00	**1.00**	-23.6883(*)	5.58074	.007	-41.6990	-5.6777
		2.00	-33.2247(*)	5.58074	.000	-51.2353	-15.2141
		4.00	-2.2129	5.58074	1.000	-20.2235	15.7977
		5.00	20.5550(*)	5.58074	.020	2.5444	38.5657
	4.00	**1.00**	-21.4754(*)	5.58074	.015	-39.4860	-3.4648
		2.00	-31.0117(*)	5.58074	.001	-49.0223	-13.0011
		3.00	2.2129	5.58074	1.000	-15.7977	20.2235
		5.00	22.7680(*)	5.58074	.009	4.7574	40.7786

	5.00	**1.00**	-44.2434(*)	5.58074	.000	-62.2540	-26.2328
		2.00	-53.7797(*)	5.58074	.000	-71.7903	-35.7691
		3.00	-20.5550(*)	5.58074	.020	-38.5657	-2.5444
		4.00	-22.7680(*)	5.58074	.009	-40.7786	-4.7574
* The mean difference is significant at the .05 level.							

TABLE 3.5

HOMOGENEOUS SUBSETS

YIELD					
	TREAT	**N**	**Subset for alpha = .05**		
			1	**2**	**3**
Student-Newman-Keuls	**5.00**	4	64.0826		
	3.00	4		84.6377	
	4.00	4		86.8506	
	1.00	4			108.3260
	2.00	4			117.8623
Tukey HSD	**5.00**	4	64.0826		
	3.00	4		84.6377	
	4.00	4		86.8506	
	1.00	4			108.3260
	2.00	4			117.8623
Duncan	**5.00**	4	64.0826		
	3.00	4		84.6377	
	4.00	4		86.8506	
	1.00	4			108.3260
	2.00	4			117.8623
Scheffe	**5.00**	4	64.0826		

	3.00	4		84.6377	
	4.00	4		86.8506	
	1.00	4			108.3260
	2.00	4			117.8623
Gabriel	**5.00**	4	64.0826		
	3.00	4		84.6377	
	4.00	4		86.8506	
	1.00	4			108.3260
	2.00	4			117.8623
Hochberg	**5.00**	4	64.0826		
	3.00	4		84.6377	
	4.00	4		86.8506	
	1.00	4			108.3260
	2.00	4			117.8623

3.5 Data Analysis

The SPSS was used to analyze each experimental result, that is, to carry out the analysis of variance and post-hoc tests (multiple comparison tests) using the 9 MCPs under study.

The result of the ANOVA and Post-hoc test of the simulated experimental data was so voluminous that extracting information manually for the purpose of computing the error rates (EER and CER) and the CDR was time consuming and prone to human error , more so because this process had to be repeated 500 times for each set of treatment and replication numbers; and

since 5 different treatment numbers (3,4,5,6 and 10) and 3 replication numbers (4,6 and 12) were used , it means a total of 7500 (5*3*500) simulations and coding were done. As a result of this we had to make use of the Microsoft Excel Spread sheet for the purpose of coding the results and computing the three rates mentioned above

3.6 Coding procedure

The result of the ANOVA and Post hoc test is pasted on the Microsoft Excel Spread Sheet. Part of the result of the post hoc test, showing coding for Tukey, is given in table 3.6.

Step 1: In column C we write 0 for the lower bound if it is positive and 1 if it is negative; we also do the same thing for the upper bound in column D.

Step 2: The number in column D minus the corresponding number in column C is computed and written in column E as the code. It can be seen that where both the lower bound and the upper bound have the same sign, the code is 0; this means the treatment means compared are significantly different. And where the signs are different the means are not significantly different. The coding results are summarized in Table3.6 A. In column F we have the MCPs, column G shows the means being compared and the codes in column H are specially copied and pasted from column D.

TABLE 3.6

CODING TABLE

		A	B	C	D	E
MCP	**treatments**	**95% Confidence Interval for Mean Difference**				
	I,j	**Lower Bound**	**Upper Bound**			Code
TUKEY	1,2	-26.7692	7.6966	1	0	1
	1,3	6.4555	40.9212	0	0	0
	1,4	4.2425	38.7083	0	0	0
	1,5	27.0105	61.4763	0	0	0
	2,1	-7.6966	26.7692	1	0	1
	2,3	15.9918	50.4576	0	0	0
	2,4	16.1306	96.3466	0	0	0
	2,5	8.7556	88.9716	0	0	0
	3,1	-78.2407	1.9753	1	0	1
	3,2	-97.654	-17.438	1	1	0
	3,4	-41.4154	38.8006	1	0	1
	3,5	-48.7904	31.4256	1	0	1
	4,1	-76.9333	3.2827	1	0	1
	4,2	-96.3466	-16.1306	1	1	0
	4,3	-38.8006	41.4154	1	0	1
	4,5	-47.483	32.733	1	0	1

	5,1	-69.5583	10.6577	1	0	1
	5,2	-88.9716	-8.7556	1	1	0
	5,3	-31.4256	48.7904	1	0	1
	5,4	-32.733	47.483	1	0	1

Table 3.6 A

F	G	H
MCP	MEANS COMPARED	CODE
TUKEY HSD	1,2	1
	1,3	0
	1,4	0
	1,5	0
	2,3	0
	2,4	0
	2,5	0
	3,4	1
	3,5	1
	4,5	1

For the MCPs that cannot make confidence intervals (SNK and Duncan), we used the homogeneous subsets and the procedure is as follows:

Step 1: paste link was used to paste the post hoc test results of SNK and Duncan in a new table;

Step 2: Rows are rearranged in the new table so that the treatments are sorted in ascending order;

TABLE 3.7

HOMOGENEOUS SUBSETS (SNK)

TREATMENTS		GRP1	GRP2	GRP3	GRP4	GRP5
1	4		109.47			
2	4		128.88			
3	4	71.33				
4	4	72.64				
5	4	80.02				

TABLE 3.8

HOMOGENEOUS SUBSETS (DUNCAN)

TREATMENTS		GRP1	GRP2	GRP3	GRP4	GRP5
1	4		109.47			
2	4		128.88			
3	4	71.33				
4	4	72.64				
5	4	80.02				

Step 3: If the treatment means for a pair of treatments appear together in any of the subsets (Groups) in tables 3.7 and 3.8, the pair is coded 1 in table 3.9, otherwise it is coded 0. The same procedure was repeated until all the possible pairs of treatments were coded for both SNK and Duncan.

TABLE 3.9

CODING RESULT FOR SNK AND DUNCAN

MPC	MEANS COMPARED	CODE
SNK	1,2	1
	1,3	0
	1,4	0
	1,5	0
	2,3	0
	2,4	0
	2,5	0
	3,4	1
	3,5	1
	4,5	1
DUNCAN	1,2	1
	1,3	0
	1,4	0
	1,5	0
	2,3	0
	2,4	0
	2,5	0
	3,4	1
	3,5	1
	4,5	1

Microsoft Excel Functions were used to carry out the coding procedures. The Spread Sheet was prepared to take 10 results for coding at the same time. The codes for the 10 results were then pasted on another Spread Sheet where the error rates and CDR were computed, this was repeated until codes for 500 results were obtained for a given set of treatment and replication numbers.

3.7 Evaluation of the error rates

We have explained in section 3.2 that means that are equal or very close in value are considered to be homogeneous. Therefore any MCP that declares that means within a homogeneous group are significantly different has committed a type I error. Also if any pair of means that do not belong to the same homogeneous group are declared equal, a type II error has been committed. There are two kinds of type I error rates based on the experiment and comparison as the basic units. These rates, which have been explained at the beginning of this chapter, are computed as follows:

The Experimentwise Error Rate: **EER =** $\frac{n_{e\alpha}}{n_e} \times 100$

Where $n_{e\alpha}$ is the number of experiments with at least one type 1 error and n_e is the total number of experiments with at least two homogeneous

means.

Comparisonwise Error Rate: **CER** = $\frac{n_{c\alpha}}{n_c} \times 100$

Where $n_{c\alpha}$ is number of comparisons with type 1 error and n_c is the total number of non significant (homogeneous) comparisons tested.

Correct Decision Rate: We defined and computed the Correct Decision Rate as 100 minus the percentage of comparisons in which type I or type II error is committed.

$$\mathbf{CDR} = \left[1 - \frac{n_{c\alpha} + n_{c\beta}}{n_c}\right] \times 100$$

Where $n_{c\beta}$ is the number of comparisons with type 2 error, $n_{c\alpha}$ and n_c are as defined above.

The computation of the error rates was done on a spread sheet different from the one used for coding. And the results of 100 simulations were used at a time to compute the error rates and average of the five error rates was computed to get the error rate for 500 simulations.

The codes are presented on the spread sheet as follows:

TALE 3.10

Abridged table of coded results

A	B	C	D	E	F	G	H	I	J	K	L
	TUK HSD			SCHEFFE			LSD			BONF	
TREATS	1,2	1,3	3,4	1,2	1,3	3,4	1,2	3,4	3,5	1,2	1,3
SIM 1	1	0	1	1	0	1	0	1	0	1	0
SIM 2	1	0	1	1	0	1	1	1	0	1	0
SIM 3	1	0	1	1	1	1	1	0	0	1	0
SIM 4	1	1	1	1	0	1	1	1	0	1	0
SIM 5	1	0	1	1	1	1	1	1	0	1	1
SIM 6	1	1	1	1	1	1	1	1	1	1	0
SIM 7	1	1	1	1	0	1	1	1	0	1	1
SIM 8	1	0	0	1	0	1	0	1	1	1	0
SIM 9	1	0	1	1	0	1	0	0	0	1	0

Key: 0: Significant difference

1: No Significant Difference

Since we know the treatments that are homogeneous, we can tell when an error is committed by an MCP. If treatments 1 and 2 are homogeneous, the correct code in column B will be 1. Where ever we see 0 in column B a false significance has been declared, therefore a type I error has been committed by Tukey. If treatments 3 and 4 are also homogeneous, then any code of 0 in column D is also a type I error. Type II error is committed where a code of 1 appears in column C if treatments 1 and 3 are not homogeneous.

CHAPTER IV

PRESENTATION AND DISCUSSION OF RESULT

4.0 Introduction

After computing the rates (EER, CER and CDR) as presented in Table 4.1, we used SPSS to plot Charts so that we can see the general levels of the rates in the MCPs and also see how the rates are affected by increasing treatment and replication numbers. The Charts were drawn under the following titles:

1 General (Overall Mean) EER and CER for all the MCPs;

2 General Mean CDR for all the MCPs;

3 The Charts in 1 and 2 above were drawn separately for each treatment and replication number.

4 EER by treatment number for all the MCPs

5 EER "replication " " " " "

6 CER " treatment " " " " " "

7 CER " replication " " " " " "

8 CDR " treatment " " " " " "

9 CDR " replication " " " " " "

10 Charts numbers 4 to 9 were plotted again for each of the MCPs to show clearly how the rates are affected by increase in treatment and replication numbers under the various Comparison Procedures.

4.1 Error Rates and CDR computed from Simulated Experiments

The rates for the various MCPs as computed from the 500 simulations for each of the 15 sets of conditions are given in Table 4.1.

Table 4.2 is a summary of the rates showing the mean, maximum and minimum values of EER, CER and CDR for the various MCPs.

TABLE 4.1

ERROR RATES AND CDR FOR NINE MCP'S COMPUTED FROM 500 SIMULATIONS OF EXPERIMENTS
FOR EACH OF 15 COMBINATIONS OF TREATMENT AND REPLICATION NUMBERS.

CASE 1 **3 TREATMENTS, 12 REPLICATIONS, (TREATMENTS 2 AND 3 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2.8**	**2.8**	**98.46666667**
SCHEFFE	**2**	**2**	**98.53333333**
LSD	**6**	**6**	**97.8**
BONFERRONI	**2.4**	**2.4**	**98.46666667**
SIDAK	**2.4**	**2.4**	**98.53333333**
GABRIEL	**2.4**	**2.4**	**98.53333333**
HOCHBERG	**2.4**	**2.4**	**98.53333333**
SNK	**6**	**6**	**97.8**
DUNCAN	**6**	**6**	**97.8**

CASE 2 **3 TREATMENTS, 6 REPLICATIONS, (TREATMENTS 2 AND 3 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2.2**	**2.2**	**86.06666667**
SCHEFFE	**1.6**	**1.6**	**84**
LSD	**5.8**	**5.8**	**91.06666667**
BONFERRONI	**1.6**	**1.6**	**84.6**
SIDAK	**1.6**	**1.6**	**84.8**
GABRIEL	**1.6**	**1.6**	**84.93333333**
HOCHBERG	**1.6**	**1.6**	**84.93333333**
SNK	**5.8**	**5.8**	**88.86666667**
DUNCAN	**5.8**	**5.8**	**90.86666667**

CASE 3 **3 TREATMENTS, 4 REPLICATIONS, (TREATMENTS 2AND 3 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2.4**	**2.4**	**66.46666667**
SCHEFFE	**2.2**	**2.2**	**64.26666667**
LSD	**4.8**	**4.8**	**77.4**
BONFERRONI	**2.2**	**2.2**	**64.06666667**
SIDAK	**2.2**	**2.2**	**64.2**
GABRIEL	**2.2**	**2.2**	**64.8**
HOCHBERG	**2.2**	**2.2**	**64.8**
SNK	**4.8**	**4.8**	**70.46666667**
DUNCAN	**4.8**	**4.8**	**76.73333333**

CASE 4 **4 TREATMENTS, 12 REPLICATIONS. (TREATMENTS 1,2 AND 3 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**3**	**1.066666667**	**99.7**
SCHEFFE	**1.2**	**0.466666667**	**99.88**
LSD	**13.2**	**5.866666667**	**98.68**
BONFERRONI	**1.8**	**0.666666667**	**99.82**
SIDAK	**1.8**	**0.666666667**	**99.82**
GABRIEL	**1.8**	**0.666666667**	**99.82**
HOCHBERG	**1.8**	**0.666666667**	**99.82**
SNK	**5.6**	**2.933333333**	**99.44**
DUNCAN	**11**	**5.066666667**	**98.9**

CASE 5 **4 TREATMENTS, 6 REPLICATIONS. (TREATMENTS 1,2 AND 3 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2.6**	**0.866666667**	**99.02**
SCHEFFE	**1.6**	**0.533333333**	**98.82**
LSD	**7.8**	**3.2**	**98.98**
BONFERRONI	**2**	**0.666666667**	**98.96**
SIDAK	**2**	**0.666666667**	**98.96**
GABRIEL	**2**	**0.666666667**	**98.96**
HOCHBERG	**2**	**0.666666667**	**98.96**
SNK	**3.8**	**1.866666667**	**99.44**
DUNCAN	**7.2**	**3**	**99.22**

CASE 6 **4 TREATMENTS, 4 REPLICATIONS. (TREATMENTS 1,2 AND 3 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2.4**	**1.066666667**	**96.52**
SCHEFFE	**1.8**	**0.8**	**95.08**
LSD	**11.6**	**5.133333333**	**98.64**
BONFERRONI	**1.8**	**0.8**	**95.74**
SIDAK	**2**	**0.866666667**	**95.76**
GABRIEL	**2**	**0.866666667**	**96.04**
HOCHBERG	**2**	**0.866666667**	**96.04**
SNK	**4.6**	**2.4**	**98.38**
DUNCAN	**10**	**4.533333333**	**98.48**

CASE 7 **5TREATS, 12REPS, (TREAT 1,2 AND 3,4 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2**	**1**	**74.22**
SCHEFFE	**0.8**	**0.4**	**68.56**
LSD	**8.6**	**4.8**	**86.62**
BONFERRONI	**1.8**	**0.9**	**72.76**
SIDAK	**2**	**0.9**	**72.9**
GABRIEL	**2**	**1**	**72.92**
HOCHBERG	**2**	**1**	**72.92**
SNK	**9**	**5.2**	**82.3**
DUNCAN	**11.2**	**6.1**	**85.54**

CASE 8 **5TREATS, 6 REPS, (TREAT 1,2 AND 3,4 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**1.4**	**0.7**	**47.24**
SCHEFFE	**0.6**	**0.3**	**39.46**
LSD	**12.4**	**6.2**	**65.46**
BONFERRONI	**1.4**	**0.7**	**44.58**
SIDAK	**1.4**	**0.7**	**44.7**
GABRIEL	**1.4**	**0.7**	**45.06**
HOCHBERG	**1.4**	**0.7**	**45.06**
SNK	**8.2**	**4.1**	**54.08**
DUNCAN	**12.2**	**6.2**	**63.12**

CASE 9 **5TREATS, 4 REPS, (TREAT 1,2 AND 3,4 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**1.8**	**0.8**	**35.34**
SCHEFFE	**0.8**	**0.4**	**30.32**
LSD	**10.2**	**5.1**	**53.6**
BONFERRONI	**1.2**	**0.5**	**32.78**
SIDAK	**1.2**	**0.5**	**33.02**
GABRIEL	**1.4**	**0.6**	**33.62**
HOCHBERG	**1.4**	**0.6**	**33.62**
SNK	**6**	**2.8**	**39.54**
DUNCAN	**9.6**	**4.8**	**50.44**

CASE10 **6 TREATS, 12 REPS, (TREAT 1,2 ; 3,4 AND 5,6 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**0.8**	**0.266666667**	**80.13333333**
SCHEFFE	**0.2**	**0.066666667**	**75.98666667**
LSD	**15.8**	**5.533333333**	**88.73333333**
BONFERRONI	**0.6**	**0.2**	**79.2**
SIDAK	**0.6**	**0.2**	**79.22666667**
GABRIEL	**0.6**	**0.2**	**79.25333333**
HOCHBERG	**0.6**	**0.2**	**79.25333333**
SNK	**14**	**4.933333333**	**84.44**
DUNCAN	**15.2**	**5.533333333**	**87.84**

CASE11 **6 TREATS, 6 REPS, (TREAT 1,2 ; 3,4 AND 5,6 ARE HOMOGENEOUS)**

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**1.6**	**0.6**	**67.52**
SCHEFFE	**0.2**	**0.133333333**	**60.33333333**
LSD	**15.2**	**5.733333333**	**79.69333333**
BONFERRONI	**0.6**	**0.266666667**	**65.66666667**
SIDAK	**0.6**	**0.266666667**	**65.76**
GABRIEL	**0.8**	**0.333333333**	**66.02666667**
HOCHBERG	**0.8**	**0.333333333**	**66.02666667**
SNK	**11**	**4**	**74.96**
DUNCAN	**14.6**	**5.333333333**	**78.57333333**

CASE12

6 TREATS, 4 REPS, (TREAT 1,2 ; 3,4 AND 5,6 ARE HOMOGENEOUS)

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2.2**	**0.8**	**55.93333333**
SCHEFFE	**0.6**	**0.2**	**46.96**
LSD	**11.8**	**4.533333333**	**73.93333333**
BONFERRONI	**1.8**	**0.666666667**	**52.48**
SIDAK	**1.8**	**0.666666667**	**52.6**
GABRIEL	**1.8**	**0.666666667**	**53.29333333**
HOCHBERG	**1.8**	**0.666666667**	**53.29333333**
SNK	**9.2**	**3.333333333**	**63.92**
DUNCAN	**11.4**	**4.4**	**70.98666667**

10 TREATMENTS, 12 REPLICATIONS (HOMOGENEOUS TREATS:(1,2,3,4,5) AND (7,8)

CASE13

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2**	**0.2**	**83.21777778**
SCHEFFE	**0**	**0**	**75.56444444**
LSD	**33**	**5.363636364**	**89.36888889**
BONFERRONI	**1**	**0.109090909**	**82.46222222**
SIDAK	**1**	**0.109090909**	**82.49333333**
GABRIEL	**1**	**0.109090909**	**82.54666667**
HOCHBERG	**1**	**0.109090909**	**82.54666667**
SNK	**25.8**	**8.054545455**	**85.05777778**
DUNCAN	**38.6**	**11.83636364**	**86.98222222**

10 TREATMENTS, 6 REPLICATIONS (HOMOGENEOUS TREATS:(1,2,3,4,5) AND (7,8)

CASE14

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2.8**	**0.345454545**	**68.76888889**
SCHEFFE	**0.2**	**0.018181818**	**53.58222222**
LSD	**34.8**	**5.272727273**	**83.94666667**
BONFERRONI	**1.8**	**0.236363636**	**66.68444444**
SIDAK	**1.8**	**0.236363636**	**66.79555556**
GABRIEL	**2**	**0.254545455**	**67.01333333**
HOCHBERG	**2**	**0.254545455**	**67.01333333**
SNK	**26.4**	**8.2**	**76.66666667**
DUNCAN	**37.4**	**11.8**	**81.86666667**

10 TREATMENTS, 4 REPLICATIONS (HOMOGENEOUS TREATS:(1,2,3,4,5) AND (7,8)

CASE15

	EER (%)	CER (%)	CDR (%)
TUKEY HSD	**2.8**	**0.290909091**	**55.10666667**
SCHEFFE	**0**	**0**	**39.73777778**
LSD	**28.8**	**5.072727273**	**77.82222222**
BONFERRONI	**1.6**	**0.145454545**	**51.85777778**
SIDAK	**1.6**	**0.145454545**	**52.00888889**
GABRIEL	**1.6**	**0.145454545**	**52.58222222**
HOCHBERG	**1.6**	**0.145454545**	**52.58222222**
SNK	**26.4**	**8.036363636**	**66.95111111**
DUNCAN	**38**	**12.49090909**	**77.48888889**

TABLE 4.2

SUMMARY OF ERROR RATES (TYPE 1) AND CDR

MCP		EER	CER	CDR
TUKEY HSD	Mean	2.1867	1.0269	74.2480
	Minimum	.80	.20	35.34
	Maximum	3.00	2.80	99.70
SCHEFFE	Mean	.9200	.6079	68.7390
	Minimum	.00	.00	30.32
	Maximum	2.20	2.20	99.88
LSD	Mean	14.6533	5.2273	84.1163
	Minimum	4.80	3.20	53.60
	Maximum	34.80	6.20	98.98
BONFERRONI	Mean	1.5733	.8038	72.6750
	Minimum	.60	.11	32.78
	Maximum	2.40	2.40	99.82
SIDAK	Mean	1.6000	.8083	72.7719
	Minimum	.60	.11	33.02
	Maximum	2.40	2.40	99.82
GABRIEL	Mean	1.6400	.8273	73.0268
	Minimum	.60	.11	33.62
	Maximum	2.40	2.40	99.82
HOCHBERG	Mean	1.6400	.8273	73.0268
	Minimum	.60	.11	33.62
	Maximum	2.40	2.40	99.82
SNK	Mean	11.1067	4.8305	78.8206
	Minimum	3.80	1.87	39.54
	Maximum	26.40	8.20	99.44
DUNCAN	Mean	15.5333	6.5129	82.9892
	Minimum	4.80	3.00	50.44
	Maximum	38.60	12.49	99.22
Total	Mean	5.6504	2.3858	75.6015
	Minimum	.00	.00	30.32
	Maximum	38.60	12.49	99.88

4.2 Summary of the Results

The large number of conditions under which we have studied the MCPs makes it difficult to comprehend the results (the Charts) which are so numerous. We have therefore used tables to summarize the observable features of the descriptive charts for easy perusal and comprehension. Tables 4.3 and 4.4 are summaries of trends observed from the Charts. The Charts are presented in the appendices.

TABLE 4.3

SUMMARY TABLE SHOWING OBSERVABLE TRENDS FROM THE GRAPHS OF EER, CER AND CDR AGAINST THE MCPs FOR DIFFERENT TREATMENT AND REPLICATION NUMBERS

Category	**EER**	**CER**	**CDR**	
	Order	Order	Order	Location of Result
General (All Treatment & Replication Numbers Considered)	LSD, SNK & Duncan have relatively higher rates than the remaining MCPs	LSD, SNK & Duncan have relatively higher rates than the remaining MCPs	All the MCPs have high rates but those of LSD, SNK and Duncan are higher.	Appendix 1
3 Treatments	"	"	"	Appendix 2
4 Treatments	"	"	"	Appendix 3
5 Treatments	"	"	"	Appendix 4
6 Treatments	"	"	"	Appendix 5
10 Treatments	"	"	"	Appendix 6
4 Replications	"	"	"	Appendix 7
6 Replications	"	"	"	Appendix 8
12 Replications	"	"	"	Appendix 9

COMMENTS: Results presented in Table 4.3 show that the MCPs under study can be classified in to two: the first class is that of LSD, SNK and Duncan, this class, which differ significantly from the MCPs in the second class are characterized by high levels of EER and CER; the second class is that of Tukey's HSD, Scheffe, Bonferroni, Sidak, Gabriel and Hochberg, with relatively low type I error rates (see Fig.1). This classification remained so even under the different treatment and replication numbers.

Another important thing to note is that the MCPs do not differ significantly in their Correct Decision Rate. In fact going by Fig.2, MCPs in the first class have higher levels of CDR.

FIGURE 1

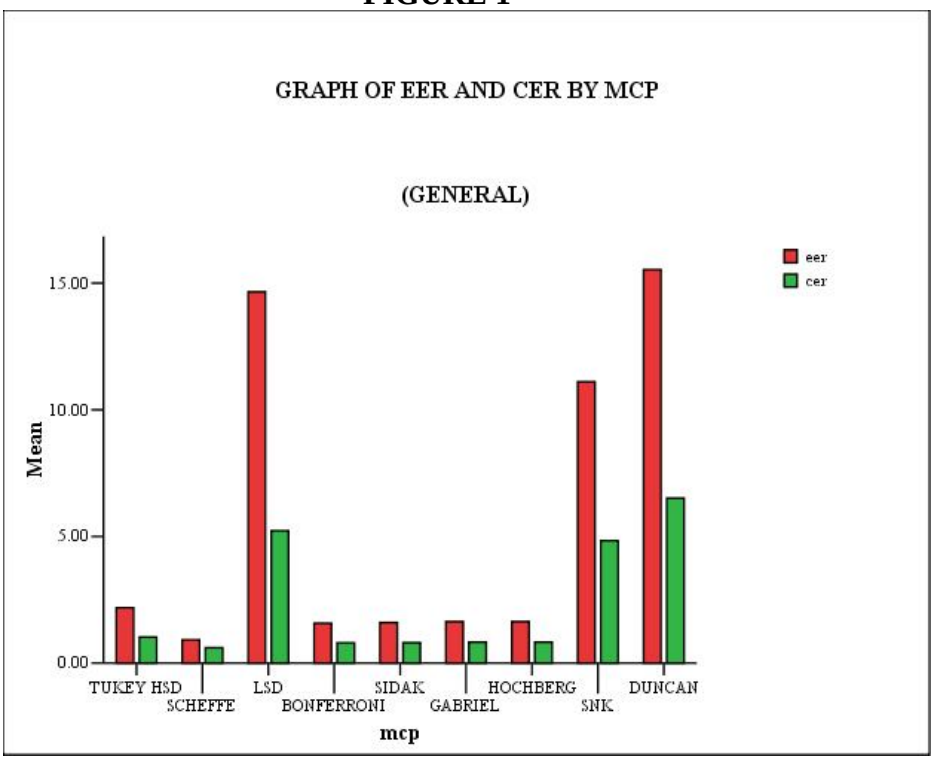


FIGURE 2

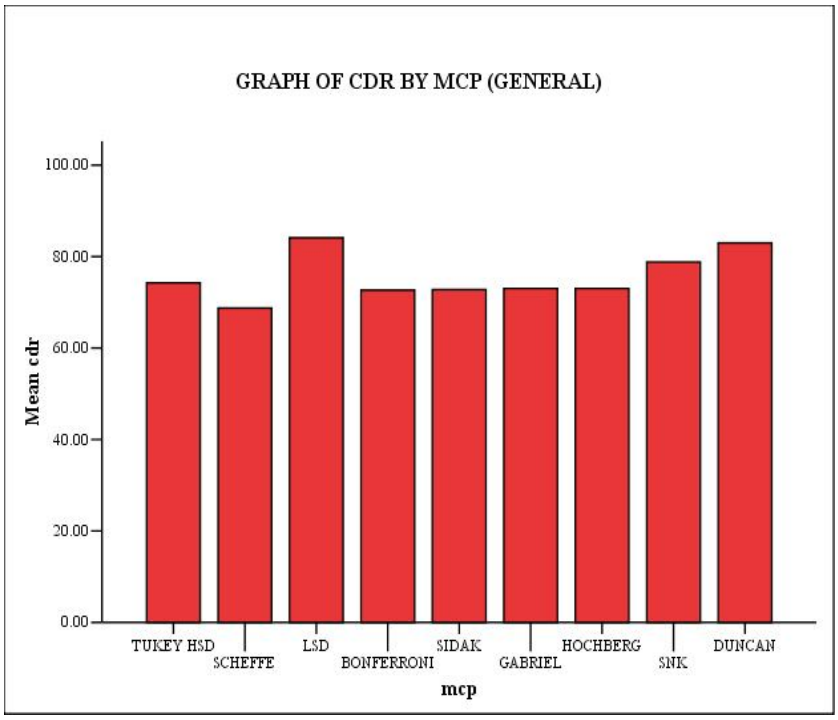


TABLE 4.4

SUMMARY TABLE SHOWING THE EFFECT OF INCREASING TREATMENT AND REPLICATION NUMBERS ON EER, CER AND CDR FOR DIFFERENT MCPs								
	MCP	EER		CER		CDR		
S/No		Effect of increasing Treatment Number	Effect of increasing Replication Number	Effect of increasing Treatment Number	Effect of increasing Replication Number	Effect of increasing Treatment Number	Effect of increasing Replication Number	Location of Result and Chart
1	Tukey	↓	↓	↓	↓	↓	↑	App. 10
2	Scheffe	↓	↓	↓	↓	↓	↑	App. 11
3	LSD	↑	↑	↑	↑	↓	↑	App. 12
4	Bonferro	↓	↓	↓	↓	↓	↑	App. 13
5	Sidak	↓	↓	↓	↓	↓	↑	App. 14
6	Gabriel	↓	↓	↓	↓	↓	↑	App. 15
7	Hochberg	↓	↓	↓	↓	↓	↑	App. 16
8	SNK	↑	↑	↑	↑	↓	↑	App. 17
9	Duncan	↑	↑	↑	↑	↓	↑	App. 18

KEY

↓ = Downwards slope

↑ = Upwards slope

4.3 COMMENTS ON SUMMARY OF THE RESULTS

EER: Increase in treatment number caused a fall in EER for Scheffe, Tukey, Bonferroni, Sidak, Gabriel and Hochberg; while the error rate increased for SNK, Duncan and LSD. For increasing the replication number, an upwards slope was observed for LSD, SNK and Duncan; while the remaining six Comparison Procedures had a reduction in EER; this was, however, not as sharp as the one caused by the treatment number.

CER: The effects of increasing treatment number and that of replication number are the same with those of EER.

CDR: A sharp fall was observed in all the MCPs for increase in number of treatments. The effect of increasing replication number on the Comparison Procedures was uniform, a general upwards trend was observed. This shows that increase in replication number leads to the reduction of either type I error or type II error in a Comparison Procedure.

4.4 Some Trends Observed from Multiple Bar Charts of the MCPs

4.4.1 Multiple Bar Charts of EER by Numbers of Treatments and Replications for the MCPs:

It was observed that when the number of treatments was 6 or 10, the difference between the LSD, SNK and Duncan; and the other group made up of Tukey, Scheffe, Bonferroni, Sidak, Gabriel and Hochberg, was more pronounced than for 3, 4 or 5 treatments (Fig.3). This is because EER increases as the number of treatment increases in the first group, while reverse is the case in the second group. So the gap between the two groups expands as the number of treatment increases. This result suggests that the variation in Experimentwise Error Rate between the two groups of Multiple Comparison Procedures is low when the number of treatments is small and relatively high when the number of treatments is high. The effect of increase in replication number on the MCPs was such that EER was increasing for

LSD, SNK and Duncan while it was decreasing for the remaining MCPs (Fig.4). The resulting effect is like that of increasing treatment number; the gap between the two groups is exacerbated.

FIGURE 3

GRAPH OF EER BY TREATMENT NUMBER FOR THE MCPs

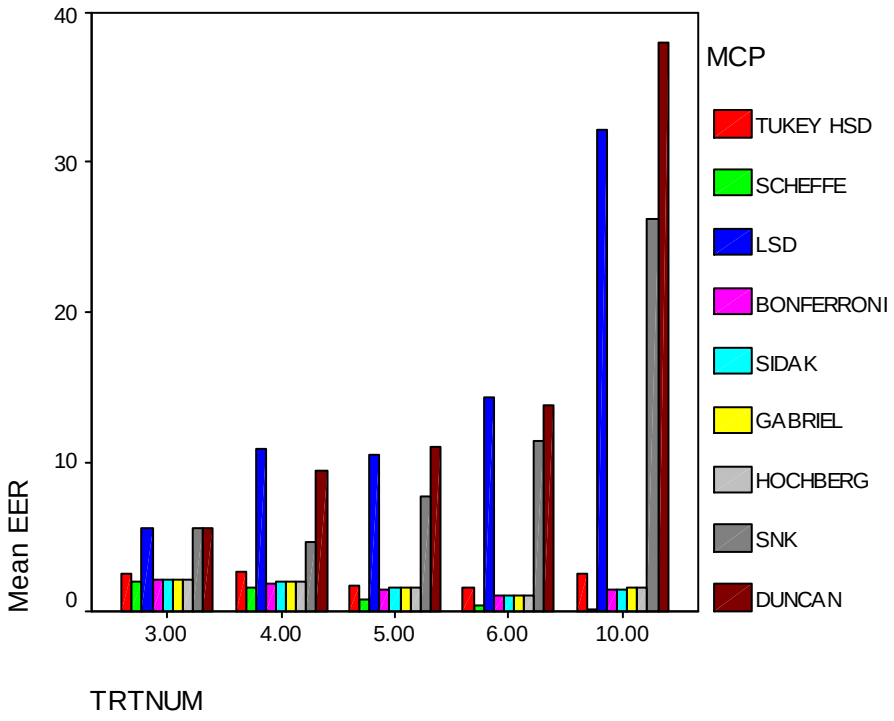
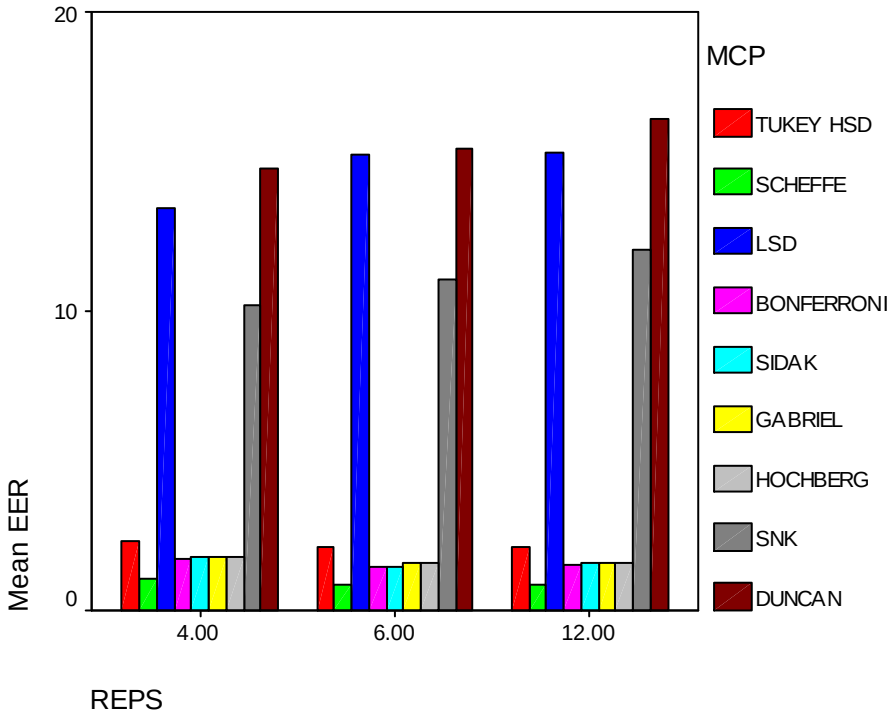


FIGURE 4

GRAPH OF EER BY REPLICATION NUMBER FOR THE MCPs



4.4.2 Multiple Bar Charts of CER by Numbers of Treatments and Replications for the MCPs

The effect of increase in treatment number on the CER is the same with that of EER as described in Section 4.4.1 above (Fig.5). However, as the replication number increased CER sloped downwards only slightly in Tukey, Scheffe, Bonferroni, Sidak, Gabriel and Hochberg; an upwards slope was observed for LSD, SNK and Duncan (Fig.6).

FIGURE 5

GRAPH OF CER BY TREATMENT NUMBER FOR THE MCPs

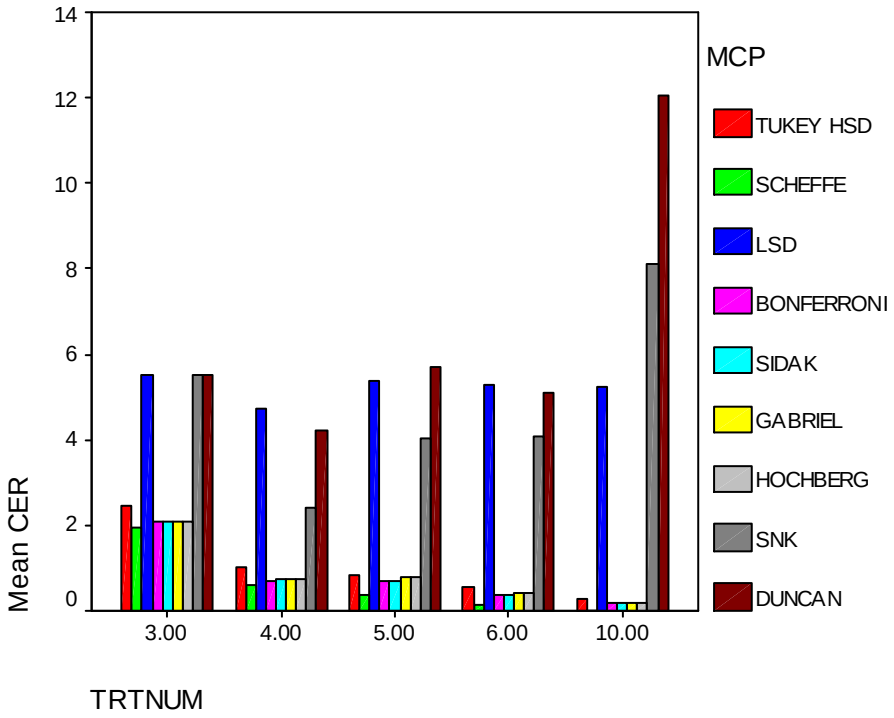
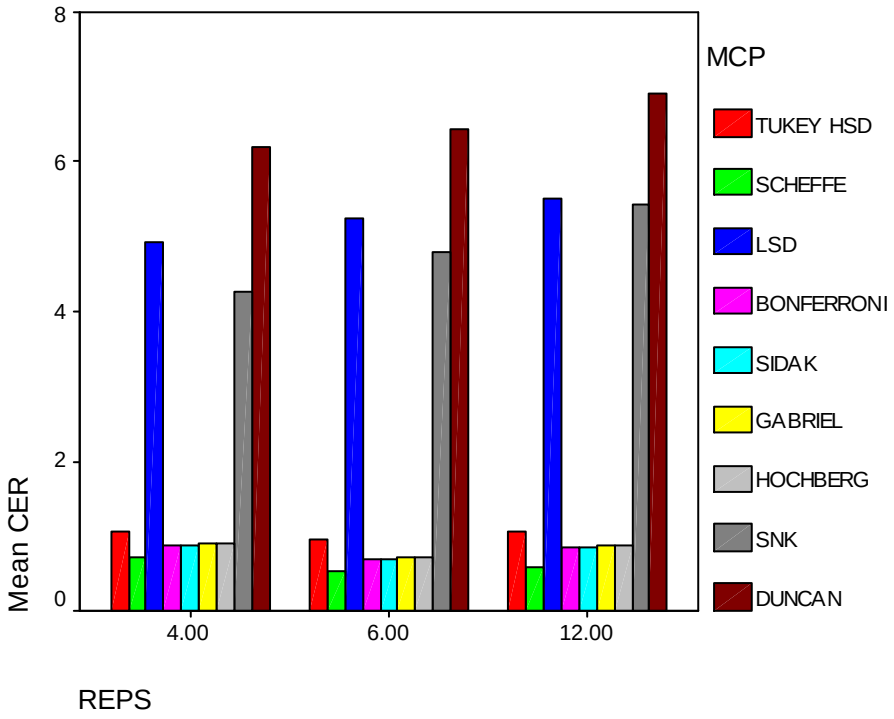


FIGURE 6

GRAPH OF CER BY NUMBER OF REPLICATIONS FOR MCPs



4.4.3 **Multiple Bar Charts of CDR by Numbers of Treatments and Replications for the MCPs**

Increasing the number of treatments led to a decrease in the CDR (Fig.7), while as the number of replications increased, the CDR increased for all the MCPs (Fig.8). This implies that when the number of treatments is 5 or more, the replication number should be at least 6 for a more accurate decision.

FIGURE 7

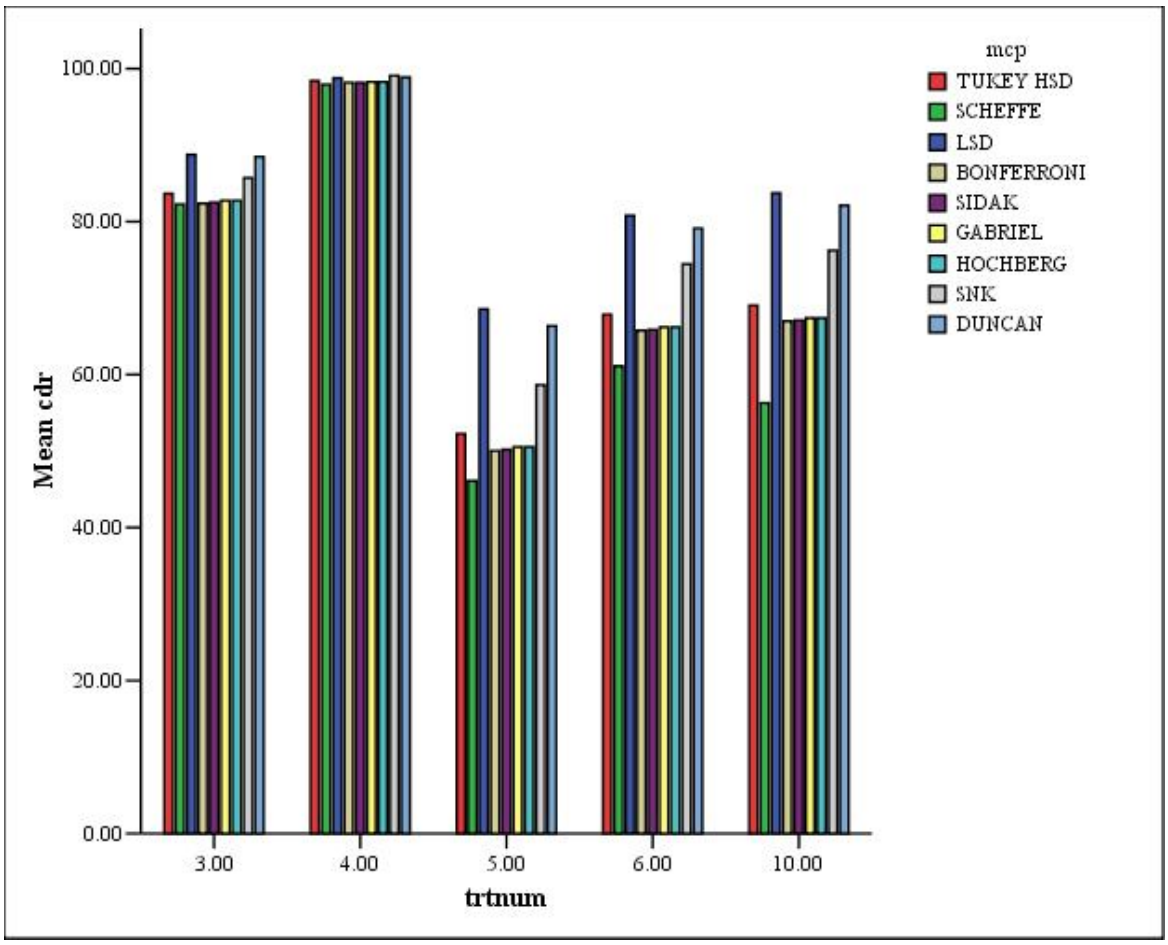
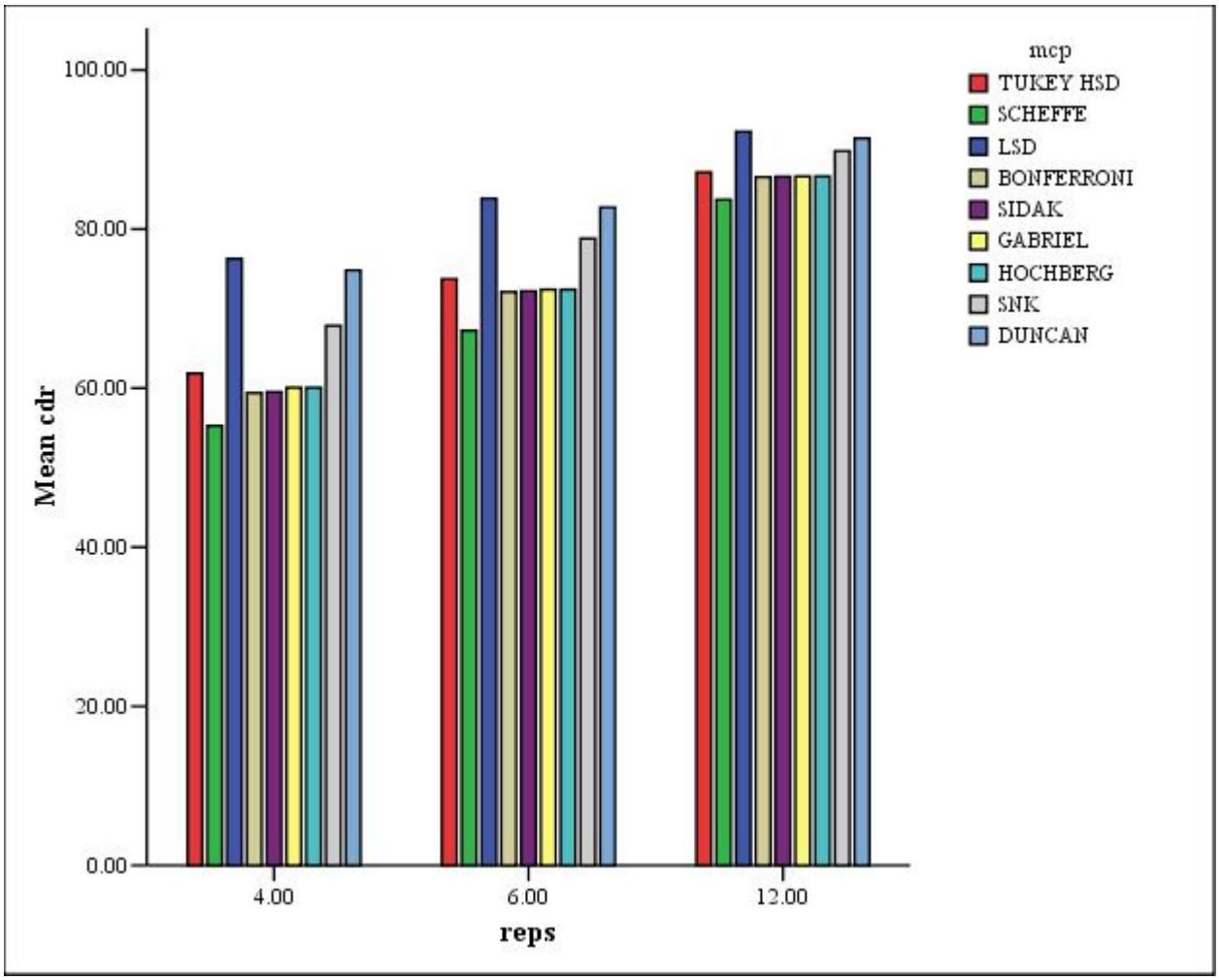

mcp
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
3.00
4.00
5.00
6.00
10.00
trtnum

FIGURE 8


mcp
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
4.00
6.00
12.00
reps

CHAPTER V

SUMMARY AND CONCLUSION

5.0 Introduction

We have said in chapter three that the basis for evaluating the MCPs were EER, CER and CDR. Results from our analysis (Appendices 1-9) have shown that there is no significant difference in CDR among the Comparison Procedures as all have high levels of the rate. We therefore lay emphasis on EER and CER in comparing the efficiencies of the Procedures. We have also discussed how the rates were affected in each of the nine MCPs under study by increase in treatment and replication numbers.

We would like to state that this study differs in approach from similar studies discussed in this thesis in the following ways:

i. greater scope in terms of the number and types of multiple comparison procedures;
ii. method of evaluation of the MCP's and
iii. evaluation under different treatment and replication numbers.

5.1 Experimentwise Error Rate

There was a highly significant difference in EER among the MCPs. Scheffe had the smallest EER value and this is in agreement with the result of the study made by Olorunju and Asiribo (2003). Other MCPs that had low

EER values (Mean EER<5%) were Tukey HSD, Bonferroni, Sidak, Gabriel and Hochberg. MCPs in this group have been shown at various times by scientists like Steel and Torrie (1980), Chew (1976), Dallal; to control the EER. The second group of Comparison Procedures with high values of EER (Mean EER>10%) is made up of LSD, SNK and Duncan. As for LSD, this is not surprising since it is known to be weak in protection against Experimentwise type1 error. In fact some of the MCPs have been formed to check this particular set back. But SNK and Duncan are widely believed to protect against type1 error (Carma and Swanson (1975) and Chew (1976)), so the high rates of EER observed here is contrary to popular belief. This has brought to bare, the fear expressed by Einot and Gabriel (1975) that Duncan has a "high type 1 error rate"; and the rebuke by Dallal who calls Duncan's MRT "a wolf in goat's skin".

5.2 Comparisonwise Error Rate

The Comparisonwise Error Rates were generally lower than the Experimentwise Error Rates. This is expected, as explained in section 3.6; because CER gives the probability that any one comparison will be found significant by chance (which is expected to be α); while the EER is the probability that at least one type 1 error will be made in a set of comparisons (or in an experiment). Scheffe has the lowest average CER value (0.61%)

while Duncan has the highest with a rate of 6.5%. Tukey, Bonferroni, Sidak, Gabriel and Hochberg have kept the error rate below 1%. SNK and LSD, like Duncan, have mean CER that is approximately 6%.

5.3 Correct Decision Rate

There was no significant difference among the MCPs in their mean CDR this shows that the comparison procedures (SNK, LSD and Duncan) that have proved to be weak in protection against type 1 error are actually good in protecting against type 2 error and the other set of MCPs made up of Tukey, Scheffe, Bonferroni, Sidak, Gabriel and Hochberg have high rates of type 2 error, hence the relatively low CDR values.

5.4 Effect of increasing Treatment or Replication Number on EER and CER for the individual MCPs

The fall in both EER and CER observed for increasing the numbers of treatments and replications in Scheffe, Tukey, Bonferroni, Sidak, Gabriel and Hochberg (sharp fall in Scheffe) can be attributed to the fact that the treatment means are estimated more accurately when the replication number is large, thereby making the difference between any two homogeneous treatment means very small, hence reducing the chances of declaring a false

significance. The significant increase in the error rates observed for the other group of Comparison Procedures may be due to the use of multiple ranges (in Duncan and SNK) or due to reduction in the size of confidence interval also caused by increase in treatment or replication number. So the need to choose from the first group of six MCPs is even greater when the number of treatments is large and we want to control the type 1 error. However if the risk of type 1 error is not great and the number of treatments is small, we can use LSD, SNK or Duncan.

Increase in the replication number has led to an increase in Correct Decision Rate in all the MCPs.

5.5 Conclusion

From the foregoing discussion, we can make the following conclusions:

a. There is clear difference among the nine Multiple Comparison Procedures studied in their protection against type I Comparisonwise Error Rate and Experimentwise Error Rate. Scheffe, Tukey, Bonferroni, Sidak, Gabriel and Hochberg have kept mean CER and EER below 1% and 3% respectively, But LSD, SNK and Duncan have mean CER of 4% to 6% and mean EER of 11% to 16% (Table 4.2).

b. Ranking the MCPs in order of their protection against type I error, we have: Scheffe, Bonferroni, Sidak, Gabriel, Hochberg, Tukey, SNK, LSD and Duncan.

c. Using high treatment or replication number reduces the chances of committing type I error in Scheffe, Bonferroni, Sidak, Gabriel, Hochberg and Tukey.

d. MCPs that have high protection against type I error are prone to type II error, leading to a relatively low Correct Decision Rate, and those with high type 1 error rate have high CDR due to low type II error rate.

e. The variation among the MCPs in their protection against type I error is more pronounced when the number of treatments is large.

f. The relative efficiencies (or rank) of the MCPs in terms of their protection against EER and CER remain the same under different treatment and replication numbers.

g. Increase in the replication number causes an increase in the Correct Decision Rate in all the MCPs.

5.6 Recommendations

I. If the risk of type I error is so great, use Scheffe.

II. If the risk of type I error is great and you are also concerned about type II error, use any of the following: Bonferroni, Sidak, Hochberg Gabriel or Tukey.

III. If the number of treatments is small and the risk of type I error is not great, use LSD, SNK or Duncan.

IV. Use a high number of replications to get a more accurate result.

5.7 Areas for further Research

Due to time and resources constrain this research was carried out using a limited set of conditions, like numbers of treatments (5), numbers of replications (3) etc. The scope can be broadened for further research to include:

a. a higher range of number of treatments (e.g. 3,4,...,20 treatments);
b. different set of treatment means within each level of treatment number (e.g. For 6 treatments we can have 1, 2, 3 etc homogeneous sets of treatment means);

c. different levels of standard deviation for the normally distributed random error component (e_{ij}) used in the simulation model;
d. unequal sample sizes and
e. Planned comparisons (i.e. Contrasts).

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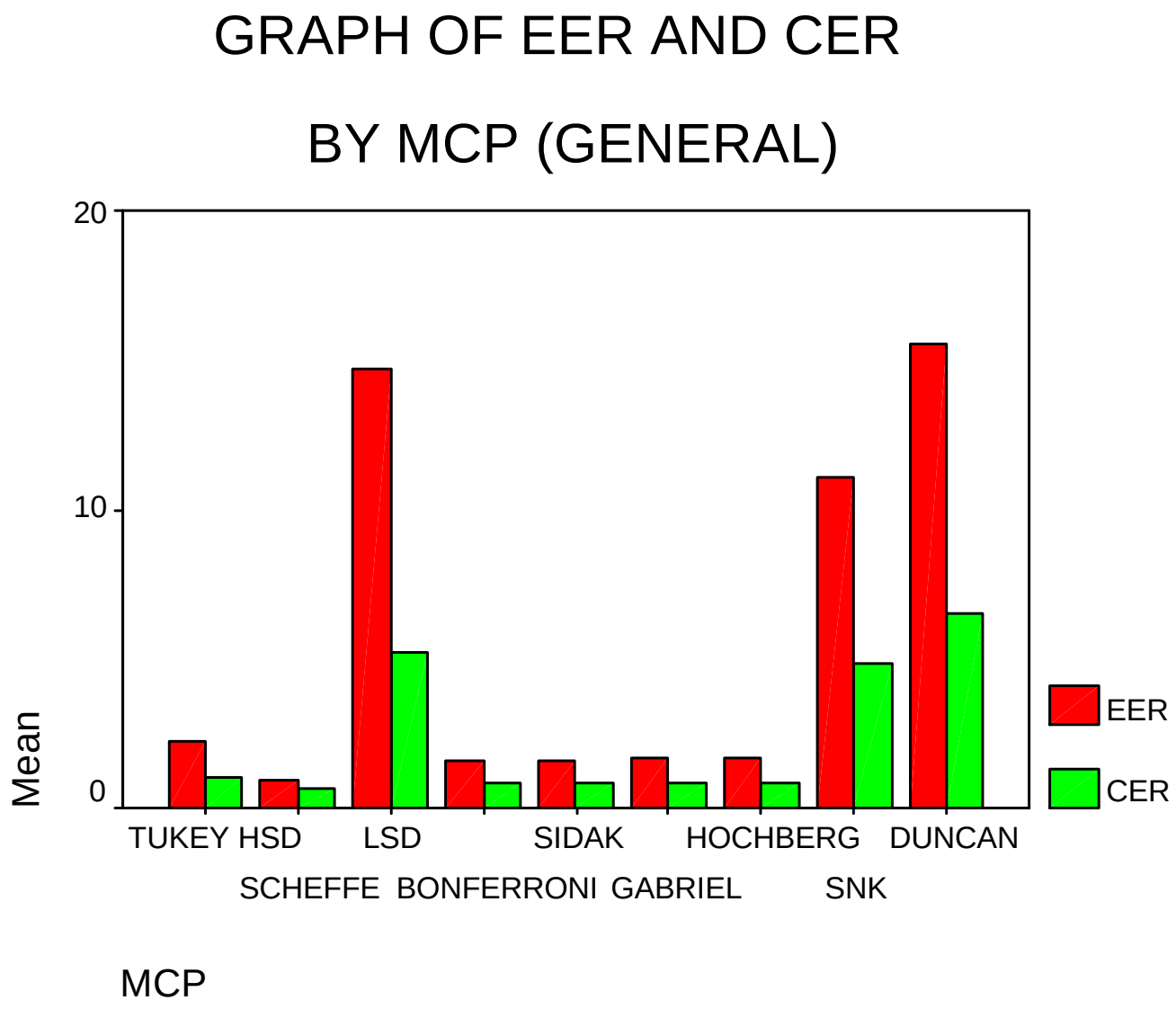
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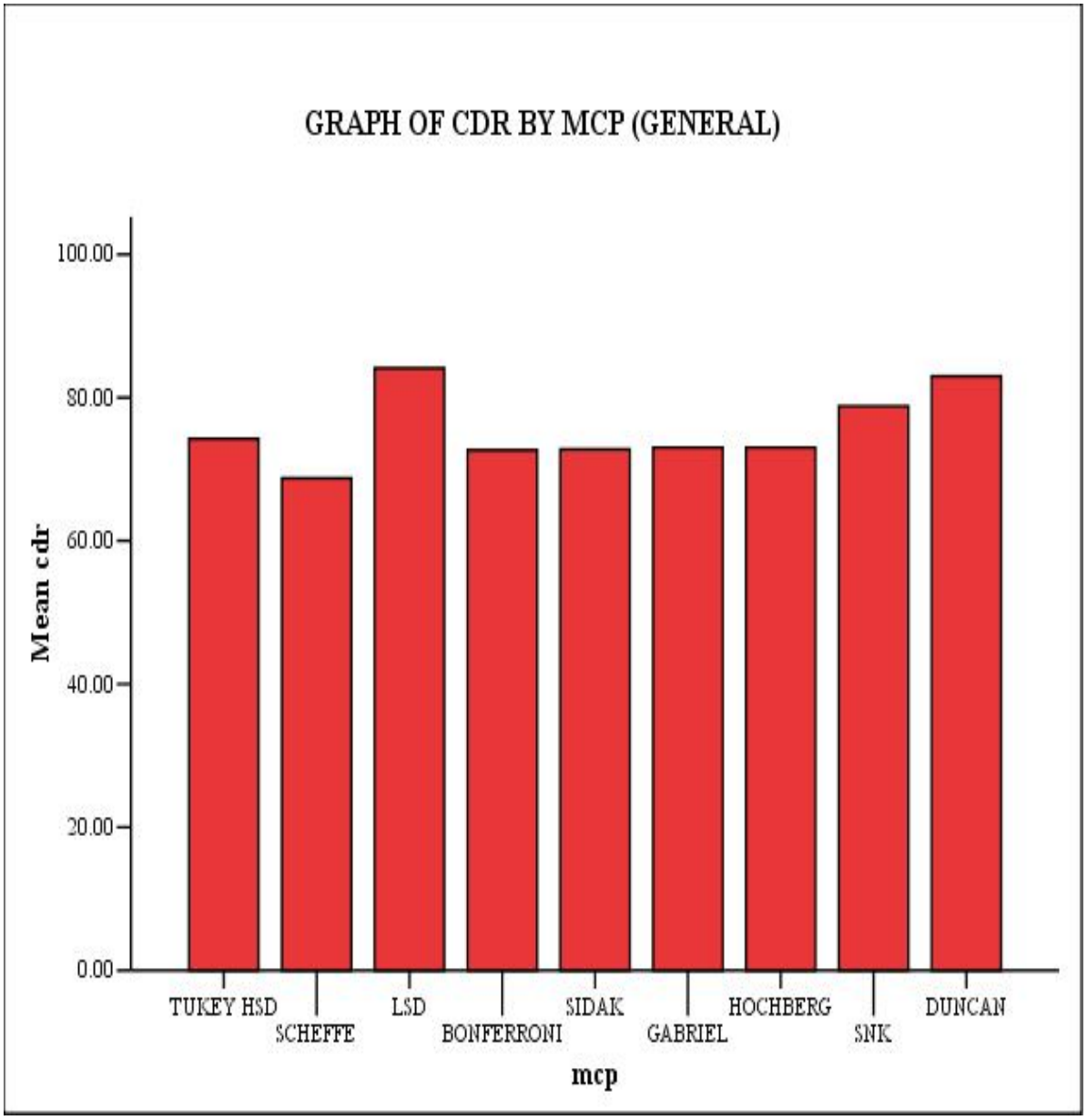
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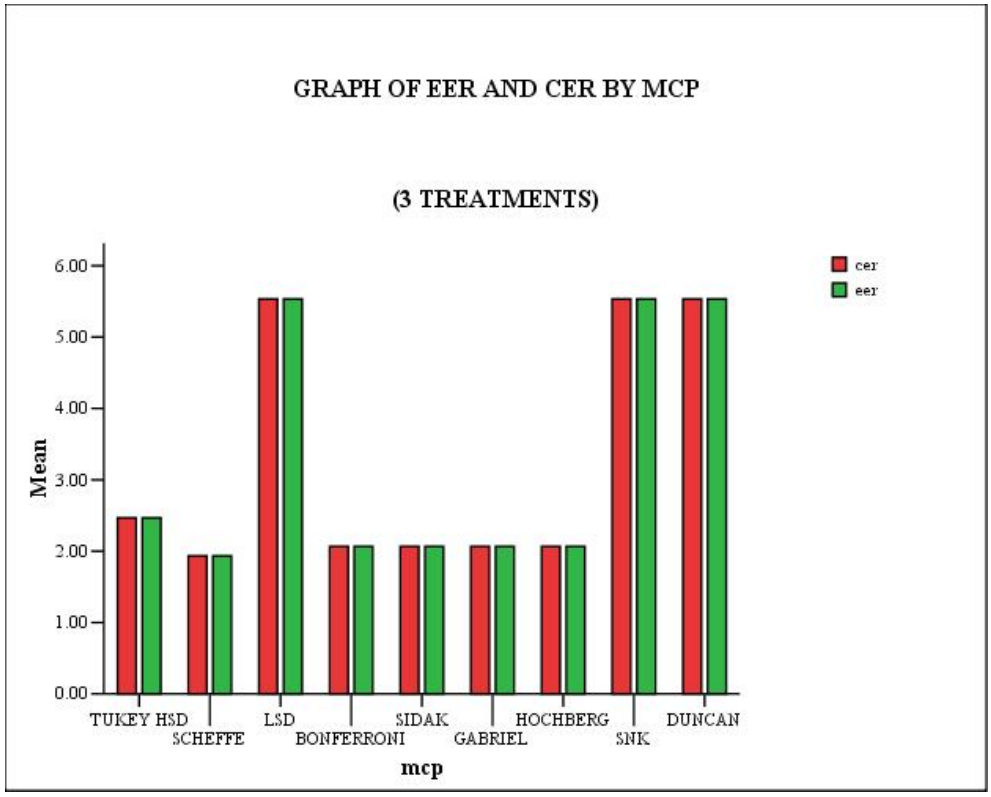
www./t). nist.gov/div/898/handbook/prc/ (Engineering statistic handbook).

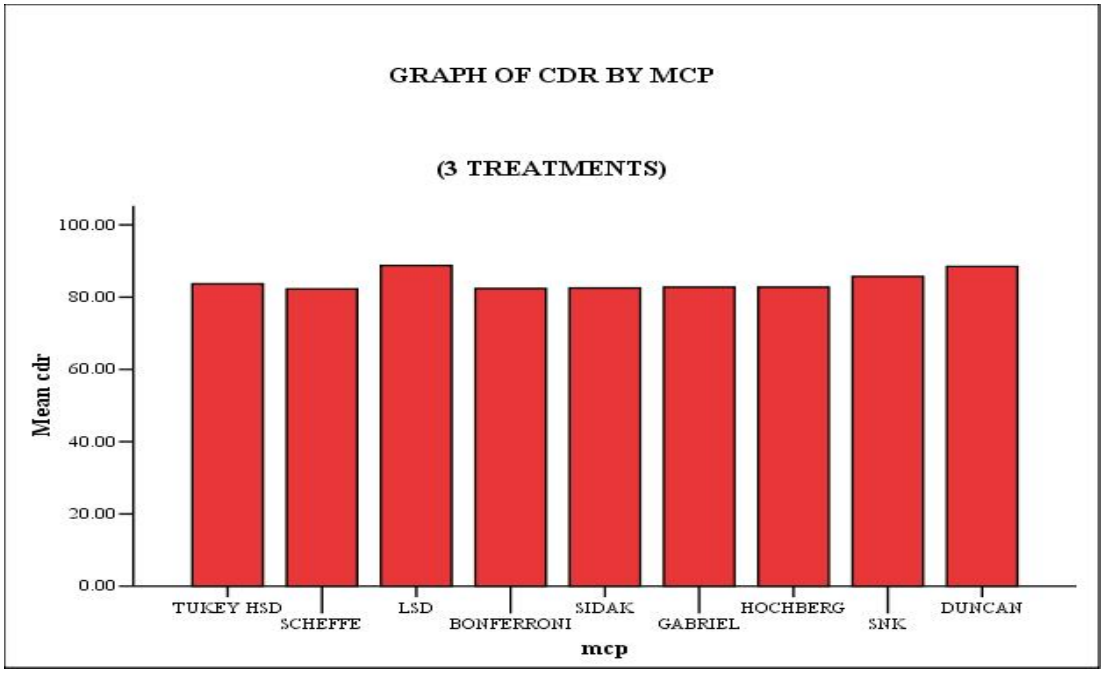
APPENDIX 1


GRAPH OF EER AND CER
BY MCP (GENERAL)
20
10
0
Mean
TUKEY HSD
LSD
SIDAK
HOCHBERG
DUNCAN
SCHEFFE
BONFERRONI
GABRIEL
SNK
MCP
EER
CER

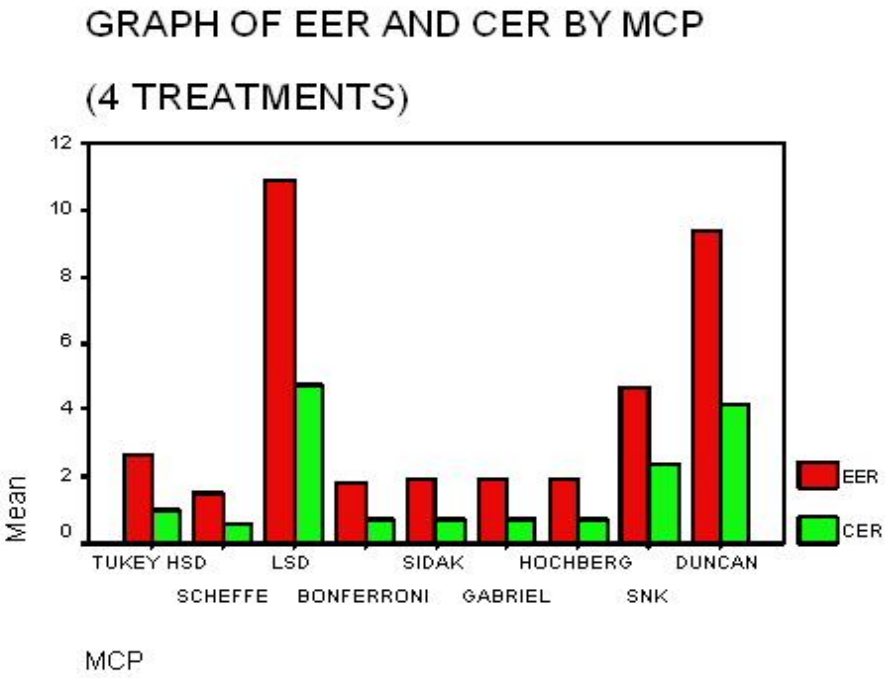

GRAPH OF CDR BY MCP (GENERAL)
100.00
80.00
60.00
40.00
20.00
0.00
Mean cdr
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
mcp

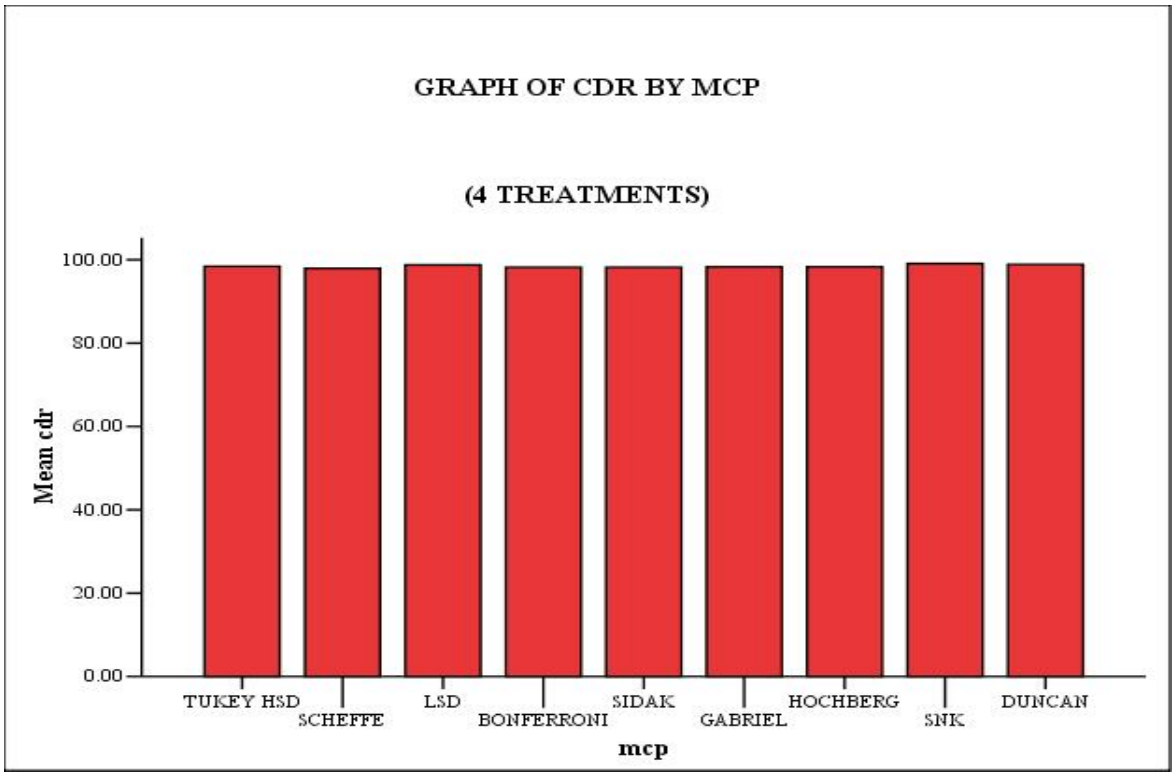
APPENDIX 2


GRAPH OF EER AND CER BY MCP
(3 TREATMENTS)
cer
eer
Mean
6.00
5.00
4.00
3.00
2.00
1.00
0.00
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
mcp

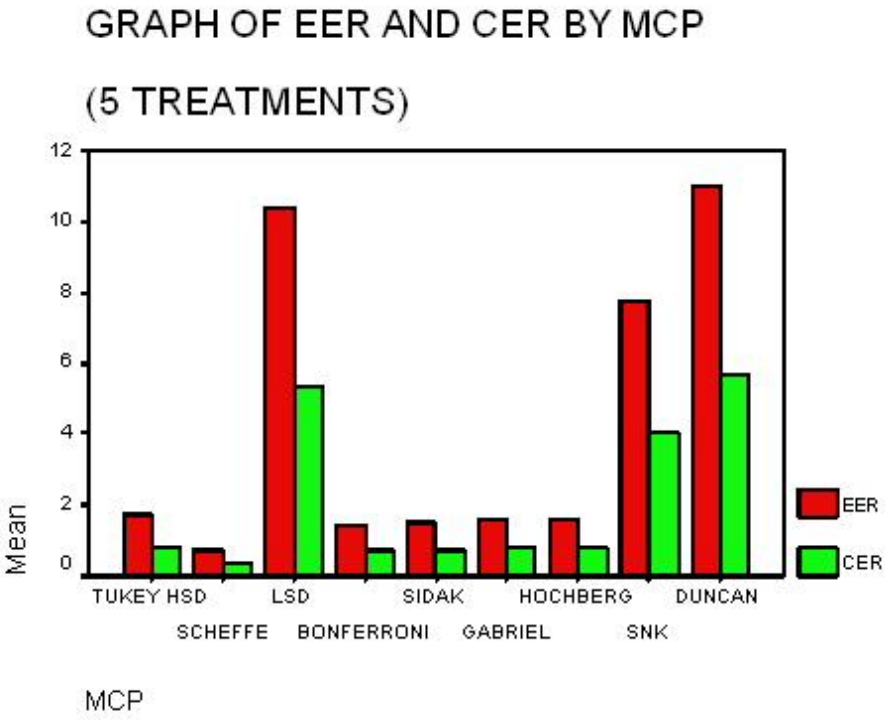

GRAPH OF CDR BY MCP
(3 TREATMENTS)
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
mcp

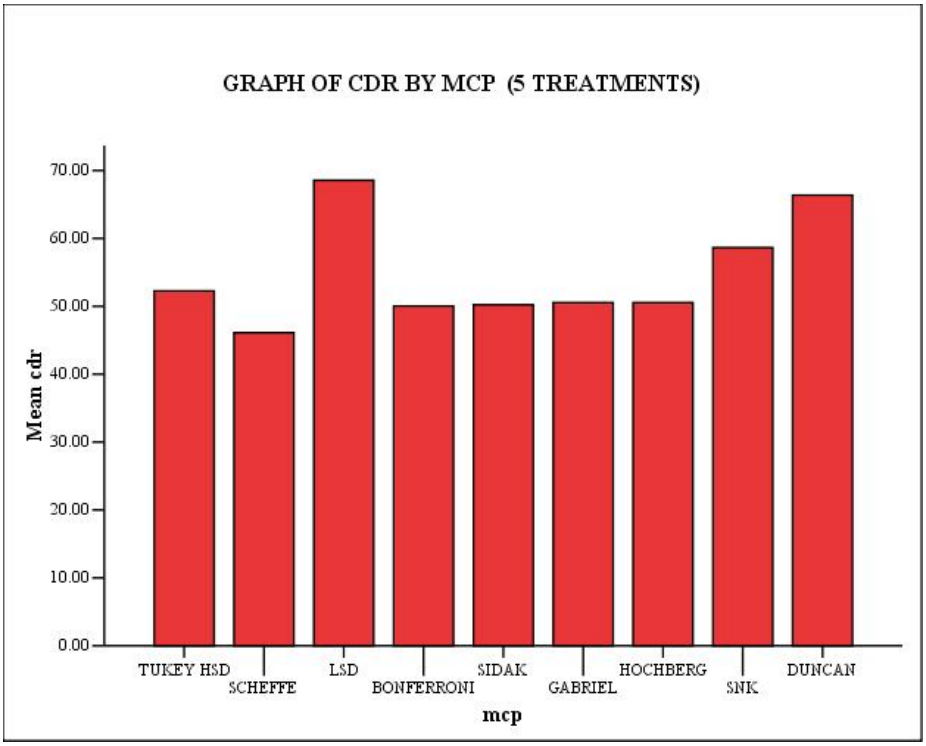
APPENDIX 3


GRAPH OF EER AND CER BY MCP
(4 TREATMENTS)
12
10
8
6
4
2
0
Mean
EER
CER
TUKEY HSD
LSD
SIDAK
HOCHBERG
DUNCAN
SCHEFFE
BONFERRONI
GABRIEL
SNK
MCP

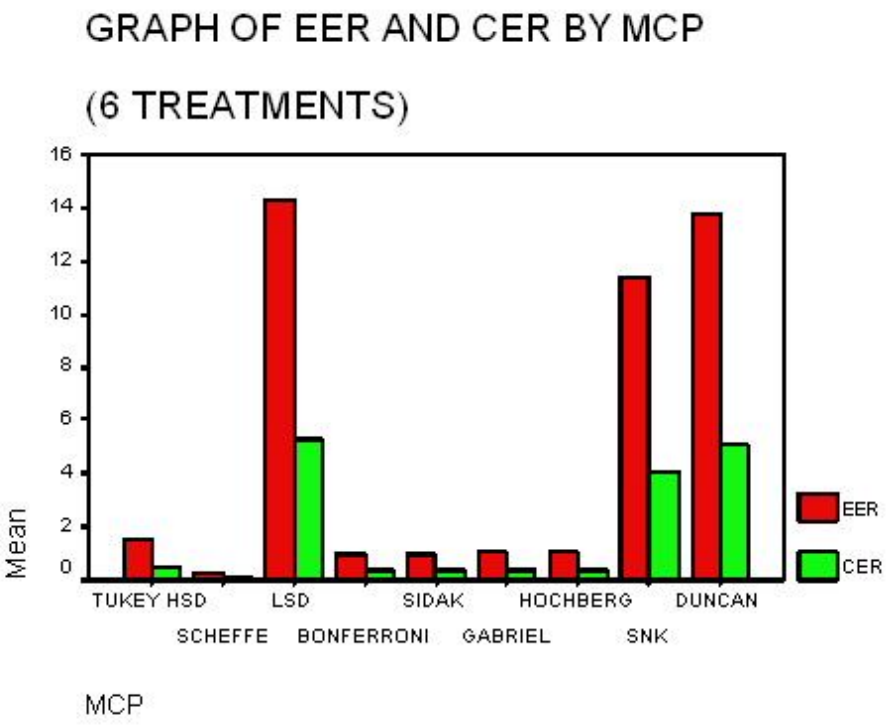

GRAPH OF CDR BY MCP
(4 TREATMENTS)
100.00
80.00
60.00
40.00
20.00
0.00
Mean cdr
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
mcp

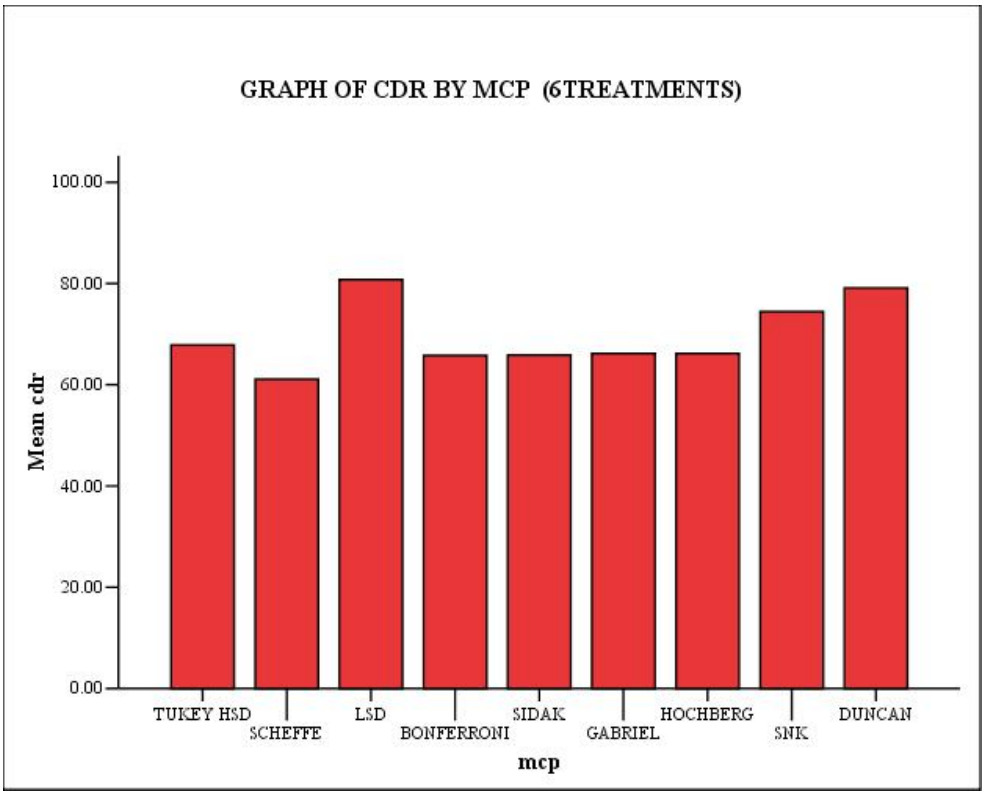
APPENDIX 4


GRAPH OF EER AND CER BY MCP
(5 TREATMENTS)
Mean
12
10
8
6
4
2
0
EER
CER
TUKEY HSD
LSD
SIDAK
HOCHBERG
DUNCAN
SCHEFFE
BONFERRONI
GABRIEL
SNK
MCP

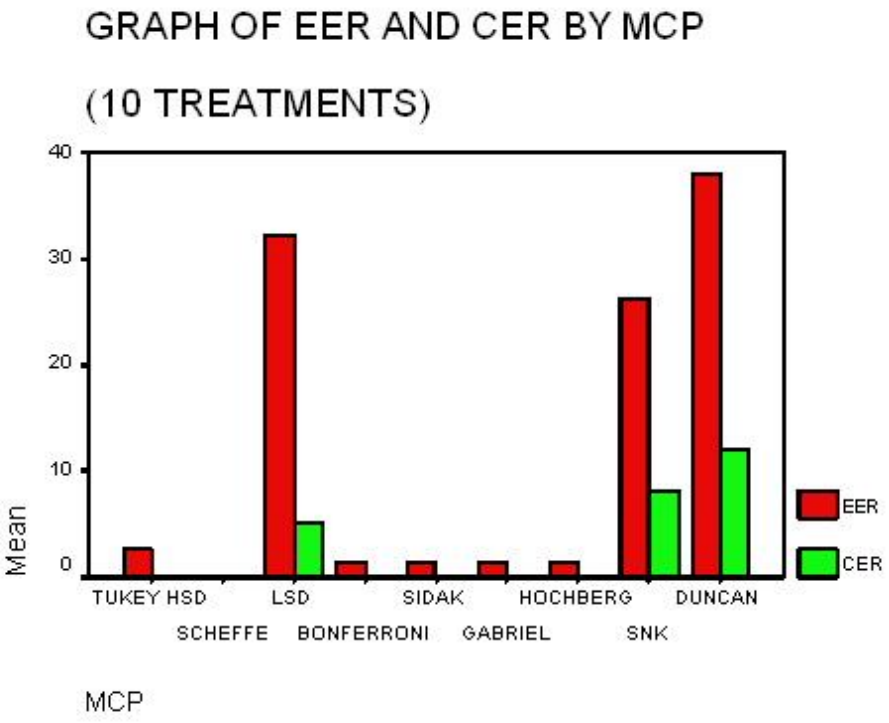

GRAPH OF CDR BY MCP (5 TREATMENTS)
Mean cdr
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
mcp

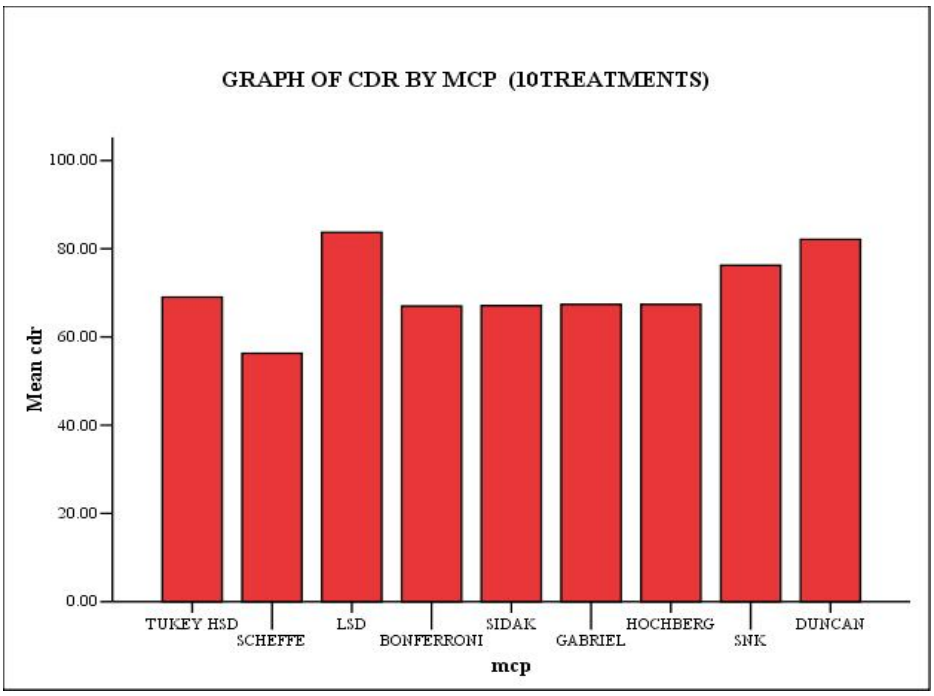
APPENDIX 5


GRAPH OF EER AND CER BY MCP
(6 TREATMENTS)
16
14
12
10
8
6
4
2
0
Mean
EER
CER
TUKEY HSD
LSD
SIDAK
HOCHBERG
DUNCAN
SCHEFFE
BONFERRONI
GABRIEL
SNK
MCP


GRAPH OF CDR BY MCP (6TREATMENTS)
100.00
80.00
60.00
40.00
20.00
0.00
Mean cdr
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
mcp

APPENDIX 6

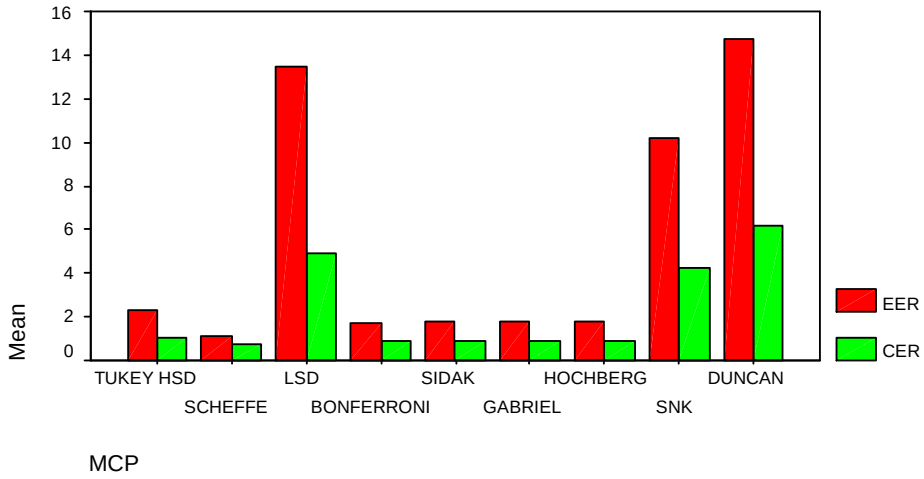

GRAPH OF EER AND CER BY MCP
(10 TREATMENTS)
40
30
20
10
0
Mean
EER
CER
TUKEY HSD
LSD
SIDAK
HOCHBERG
DUNCAN
SCHEFFE
BONFERRONI
GABRIEL
SNK
MCP

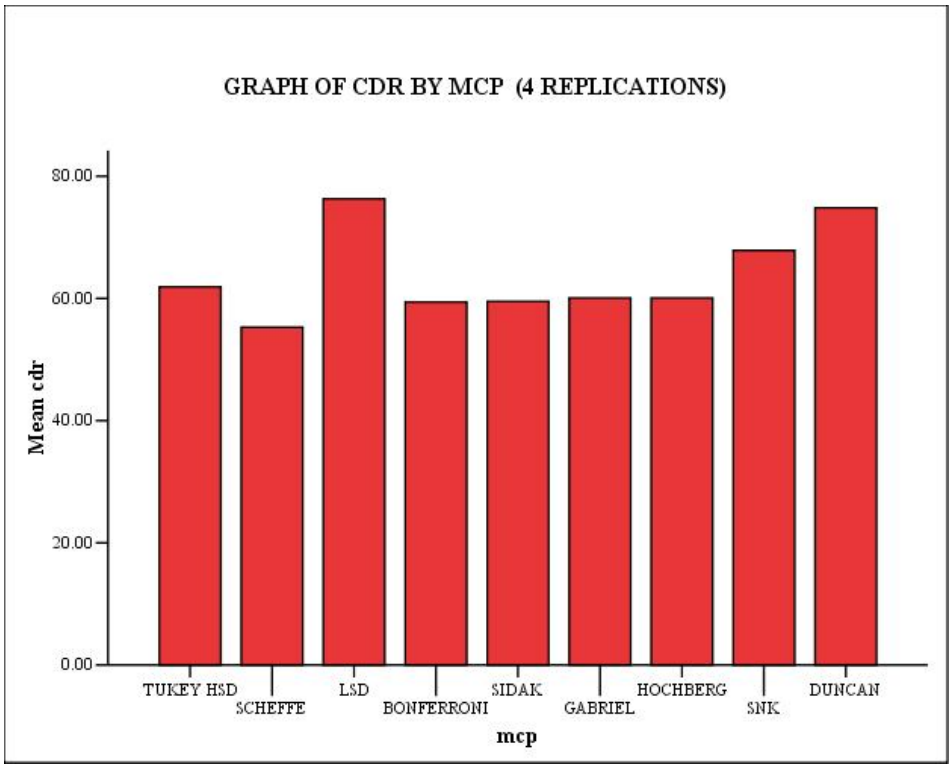

GRAPH OF CDR BY MCP (10TREATMENTS)
100.00
80.00
60.00
40.00
20.00
0.00
Mean cdr
TUKEY HSD
SCHEFFE
LSD
BONFERRONI
SIDAK
GABRIEL
HOCHBERG
SNK
DUNCAN
mcp

APPENDIX 7

GRAPH OF EER AND CER

BY MCP (4 REPLICATIONS)

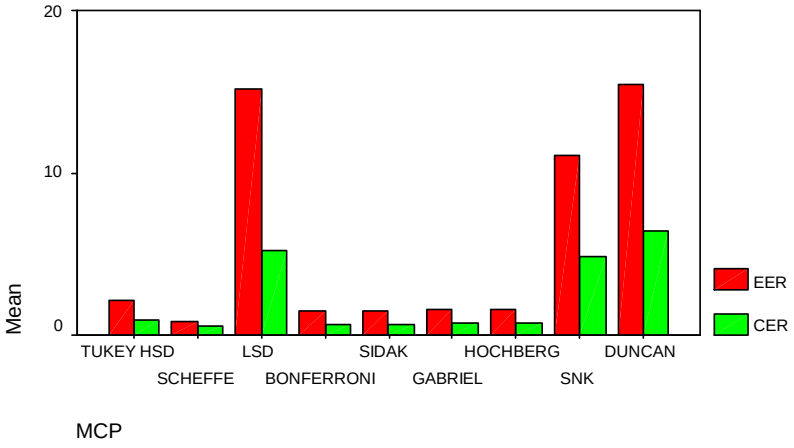


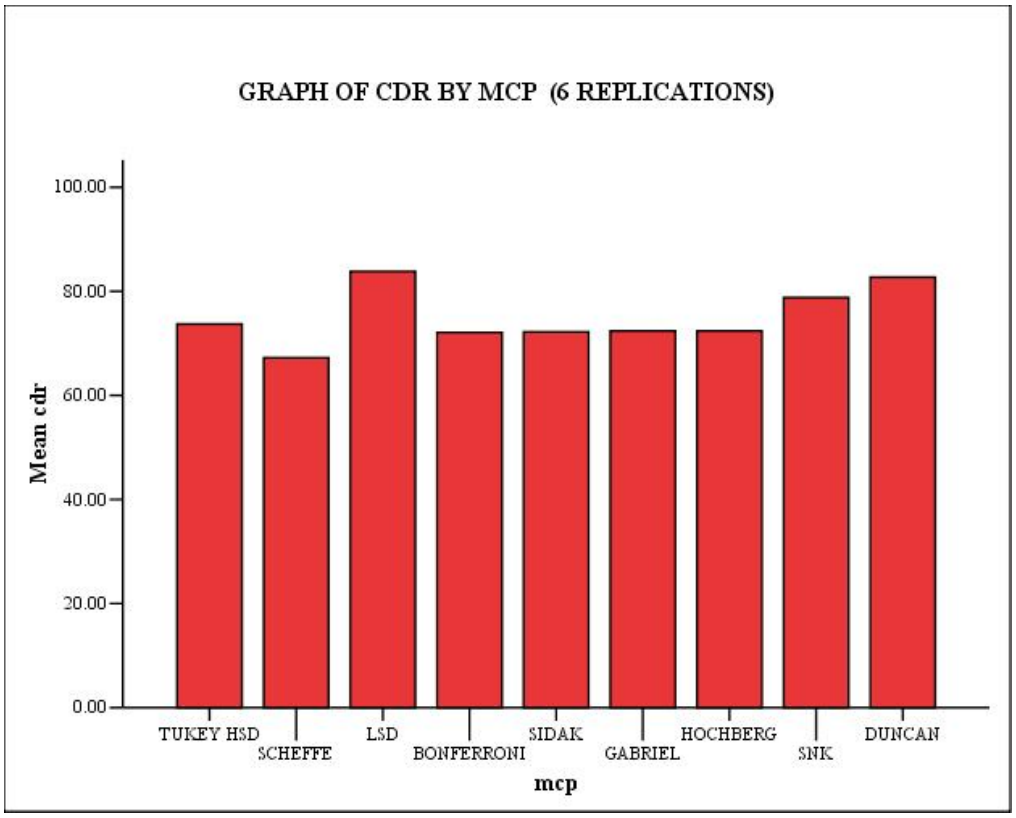


APPENDIX 8

GRAPH OF EER AND CER

BY MCP (6 REPLICATIONS)

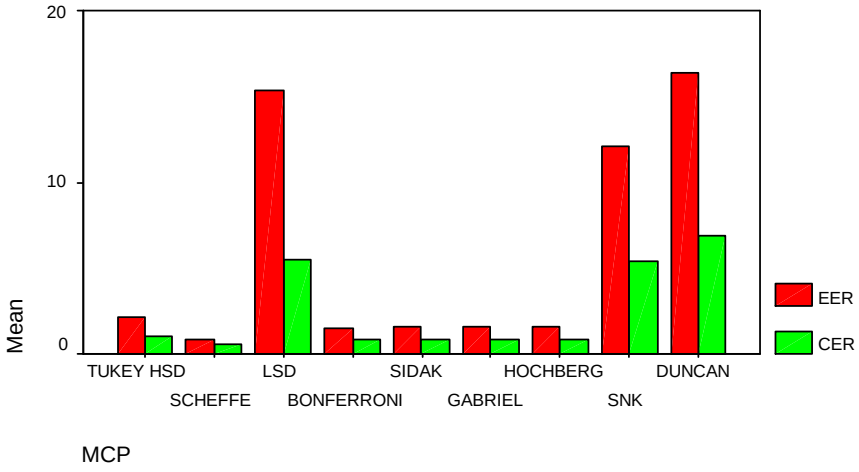


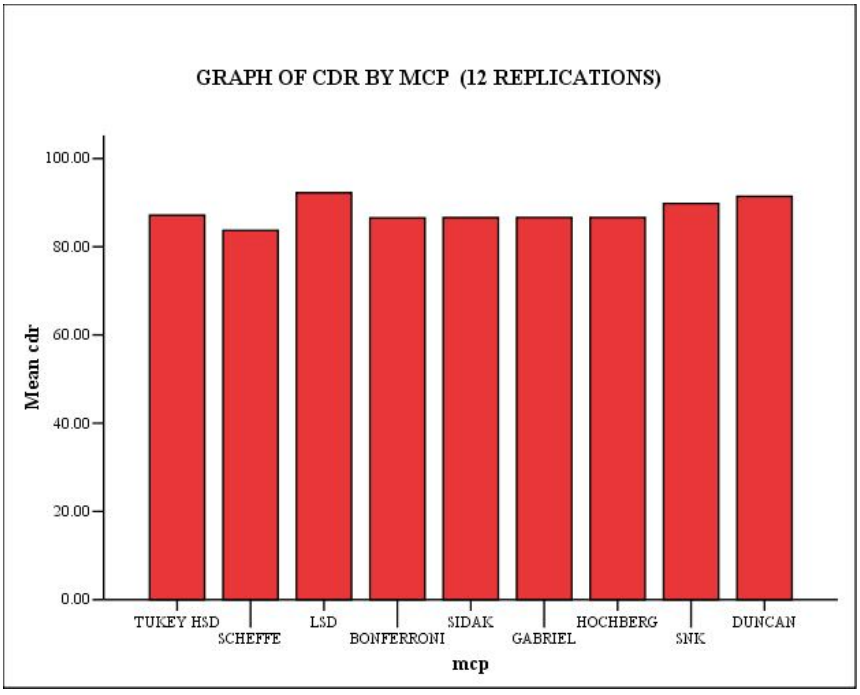


APPENDIX 9

GRAPH OF EER AND CER

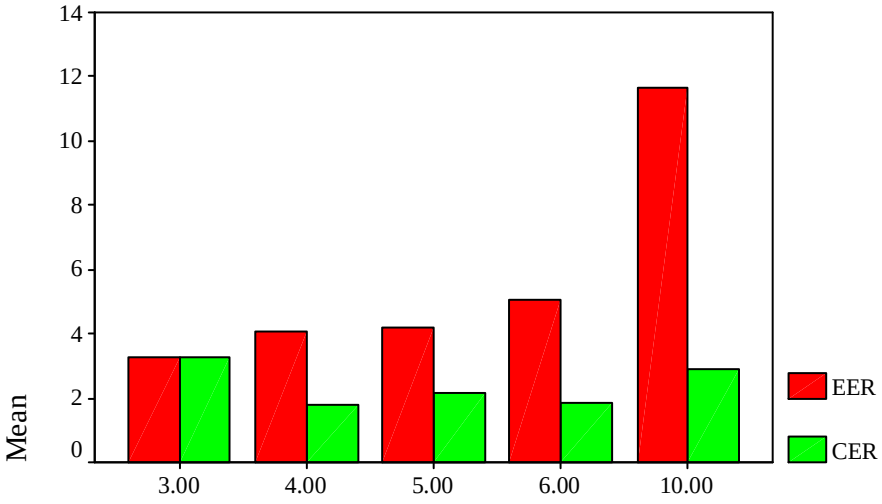
BY MCP (12 REPLICATIONS)

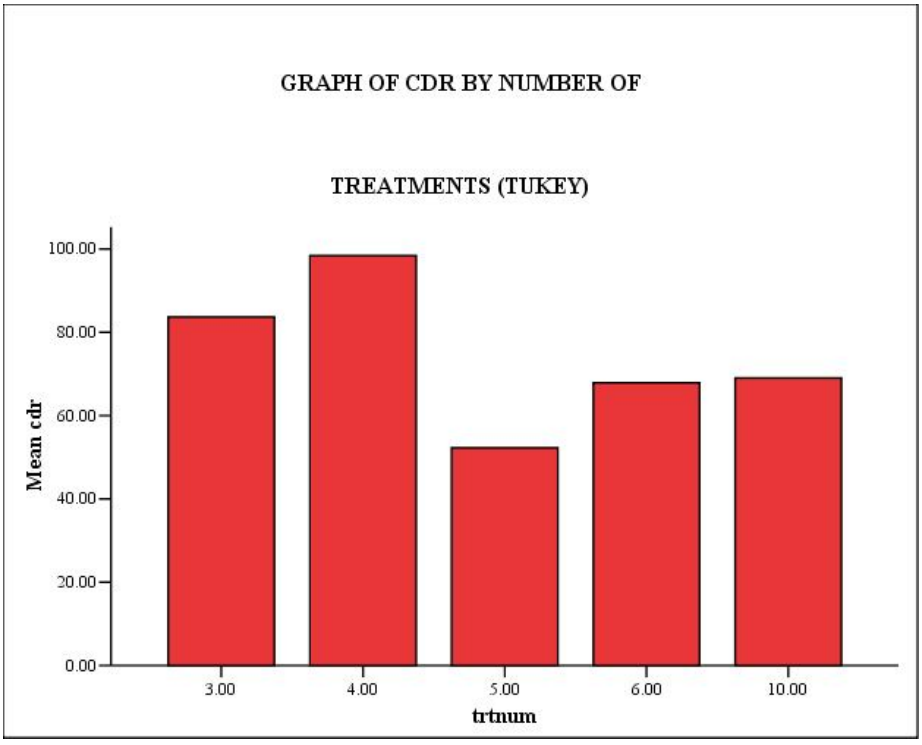


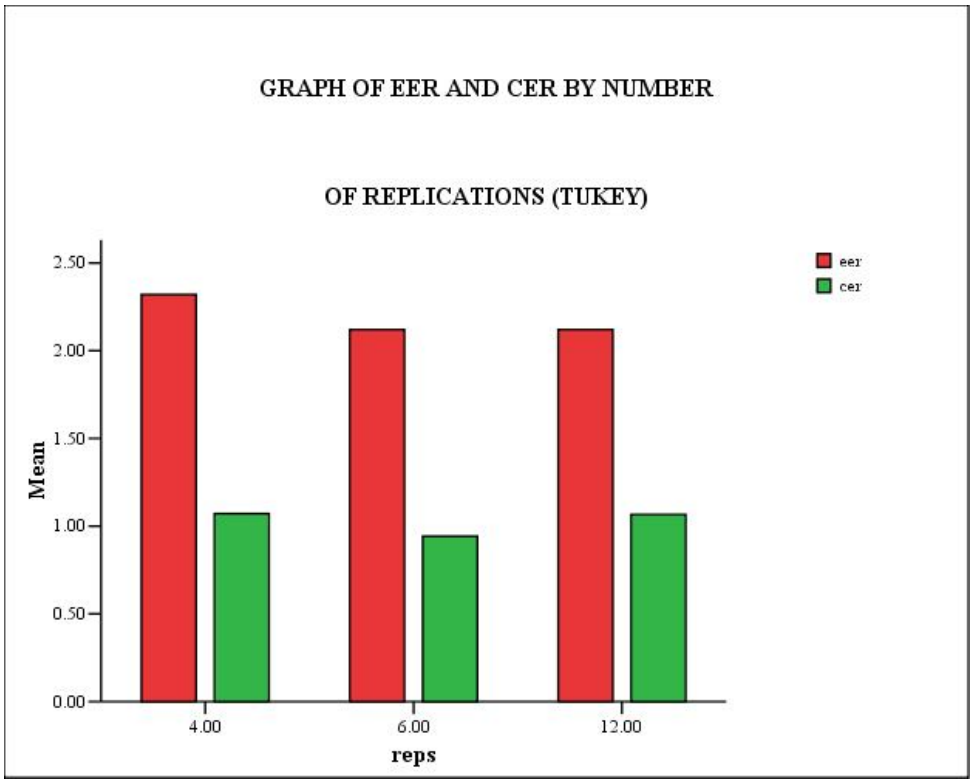


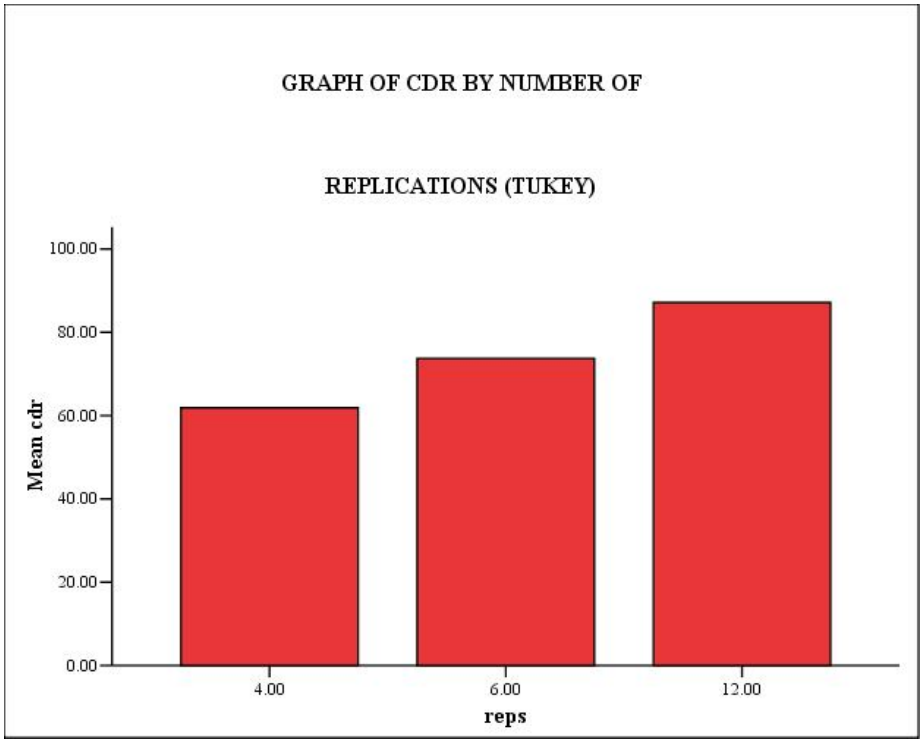
APPENDIX 10 (TUKEY)

GRAPH OF EER CER BY NUMBER OF TREATMENTS (TUKEY)



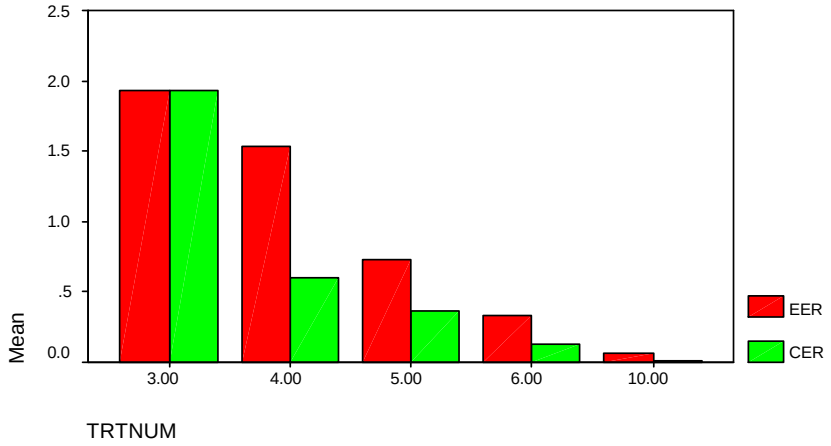


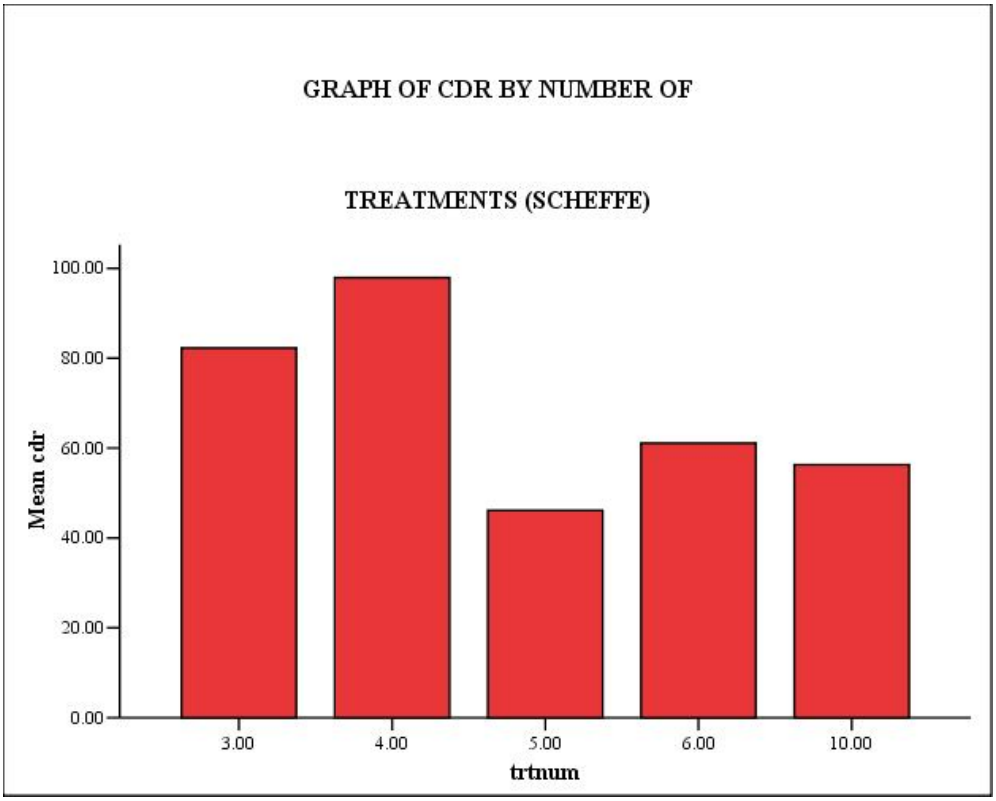

GRAPH OF EER AND CER BY NUMBER
OF REPLICATIONS (TUKEY)
eer
cer
Mean
2.50
2.00
1.50
1.00
0.50
0.00
4.00
6.00
12.00
reps

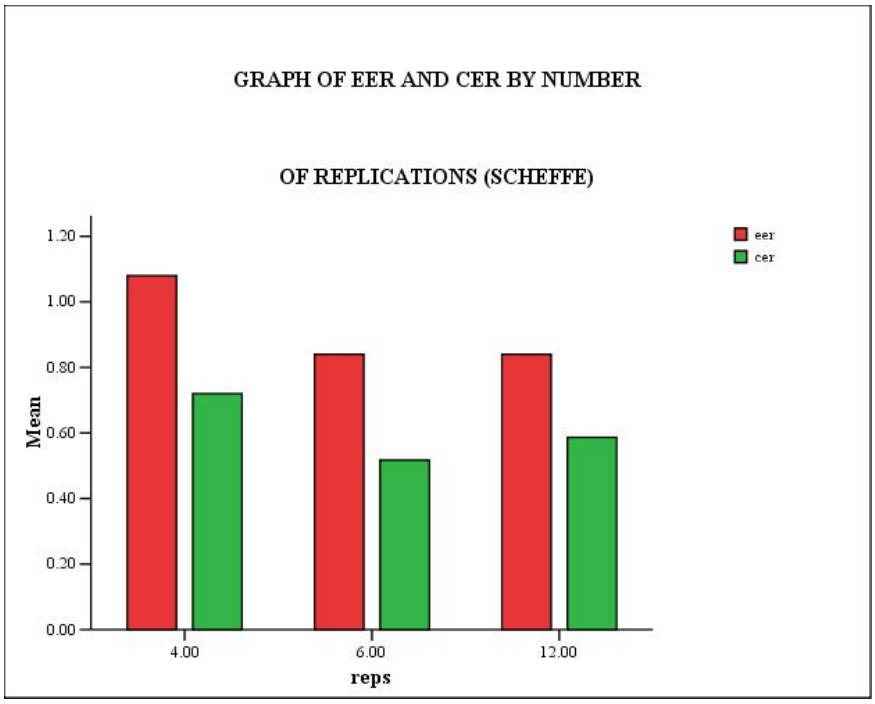

GRAPH OF CDR BY NUMBER OF
REPLICATIONS (TUKEY)
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
4.00
6.00
12.00
reps

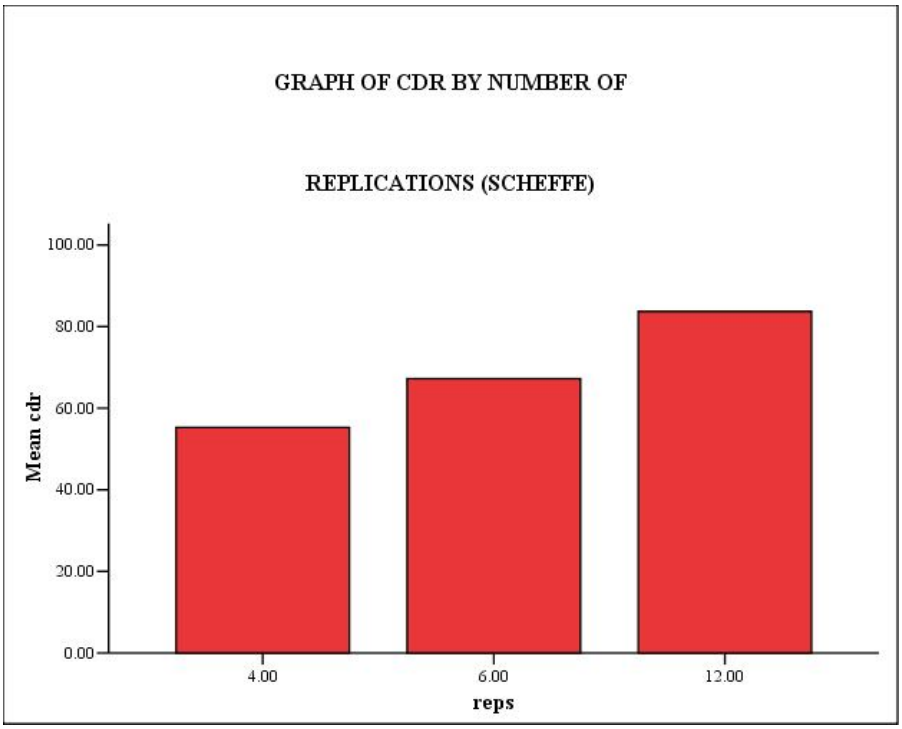
APPENDIX 11 (SCHEFFE)

GRAPH OF EER AND CER BY NUMBER OF TREATMENTS (SCHEFFE)



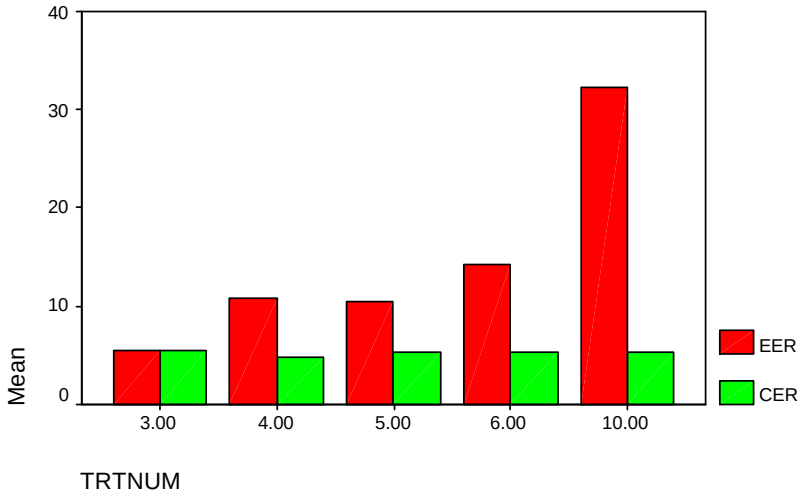


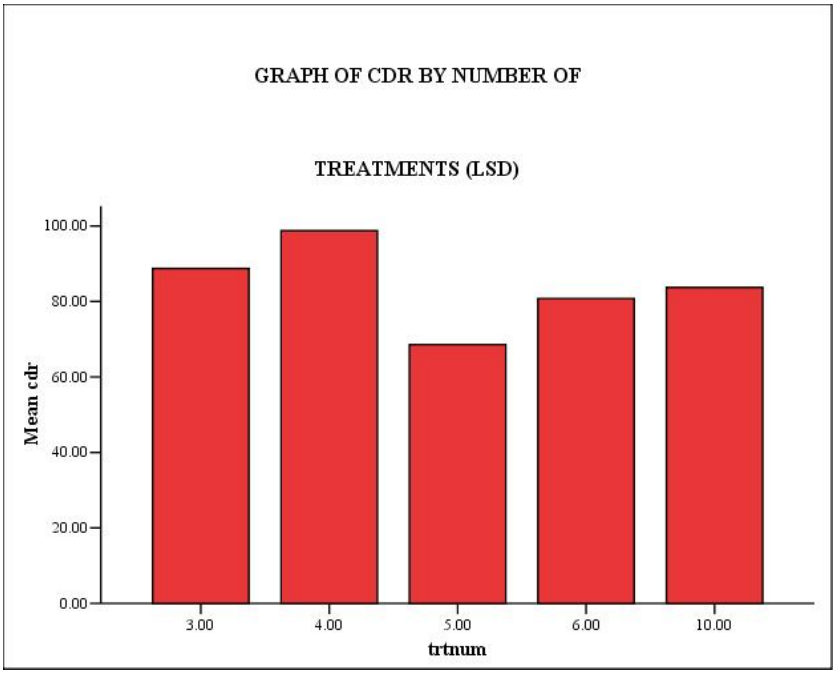

GRAPH OF EER AND CER BY NUMBER
OF REPLICATIONS (SCHEFFE)
eer
cer
Mean
1.20
1.00
0.80
0.60
0.40
0.20
0.00
4.00
6.00
12.00
reps


GRAPH OF CDR BY NUMBER OF
REPLICATIONS (SCHEFFE)
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
4.00
6.00
12.00
reps

APPENDIX 12 (LSD)

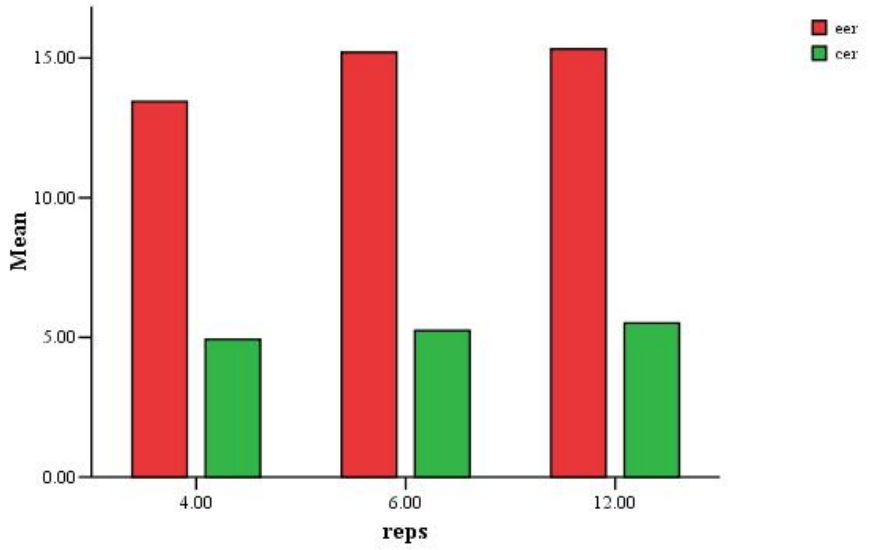
GRAPH OF EER AND CER BY NUMBER OF TREATMENTS (LSD)





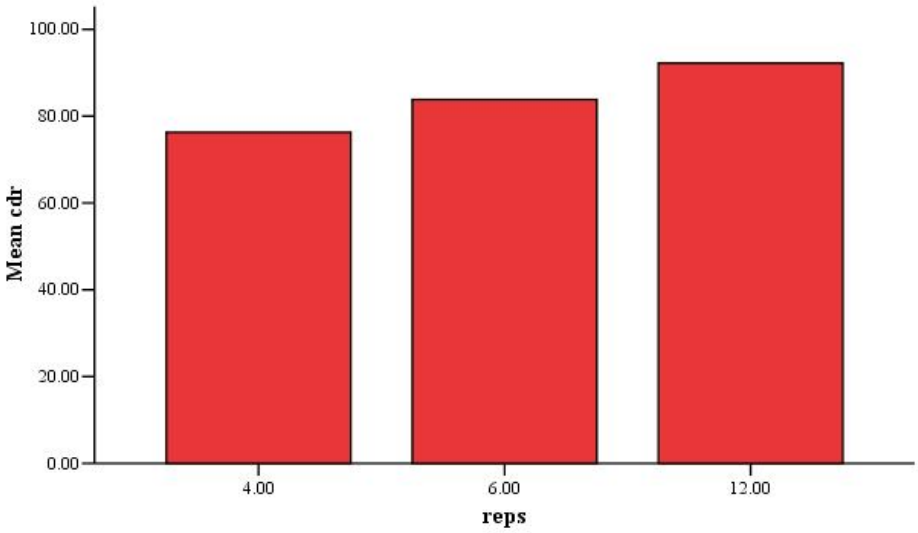
GRAPH OF EER AND CER BY NUMBER

OF REPLICATIONS (LSD)



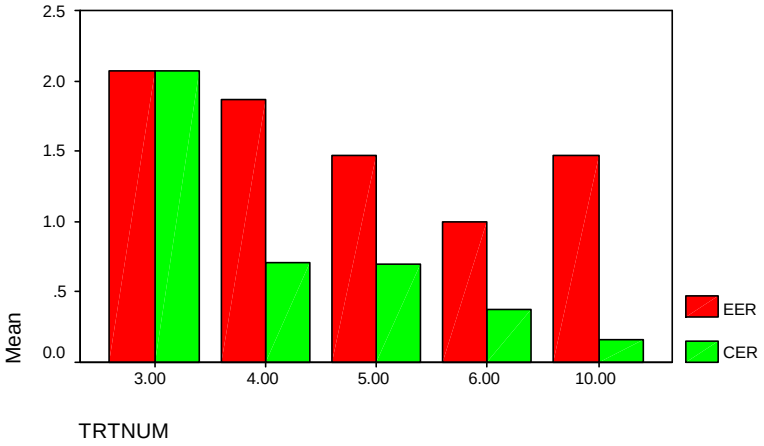
GRAPH OF CDR BY NUMBER OF

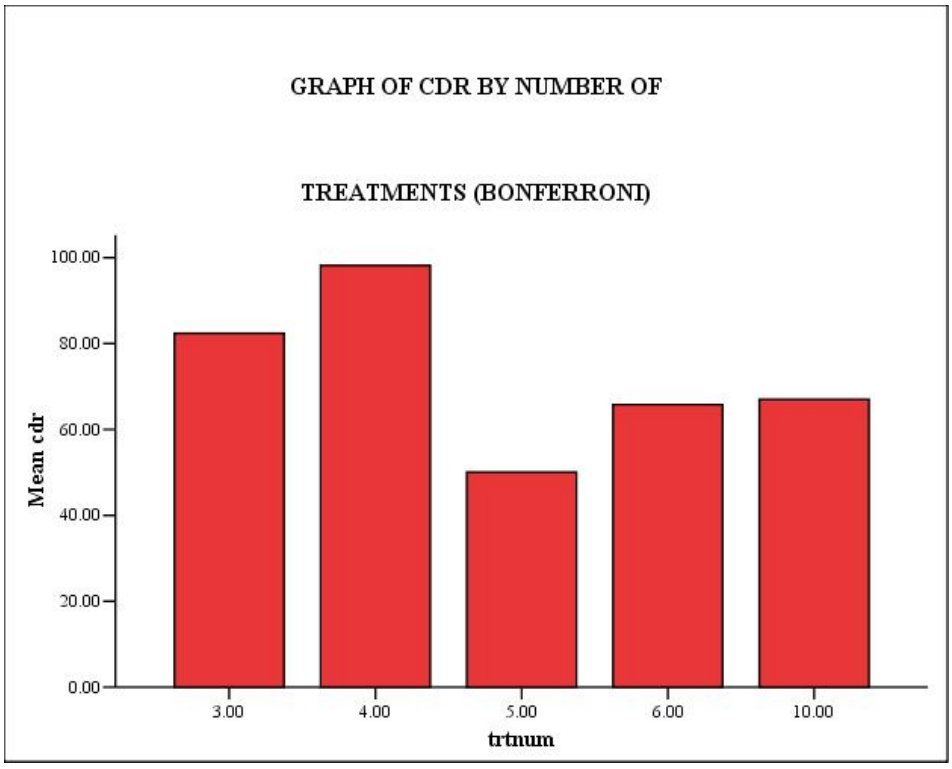
REPLICATIONS (LSD)



APPENDIX 13 (BONFERRONI)

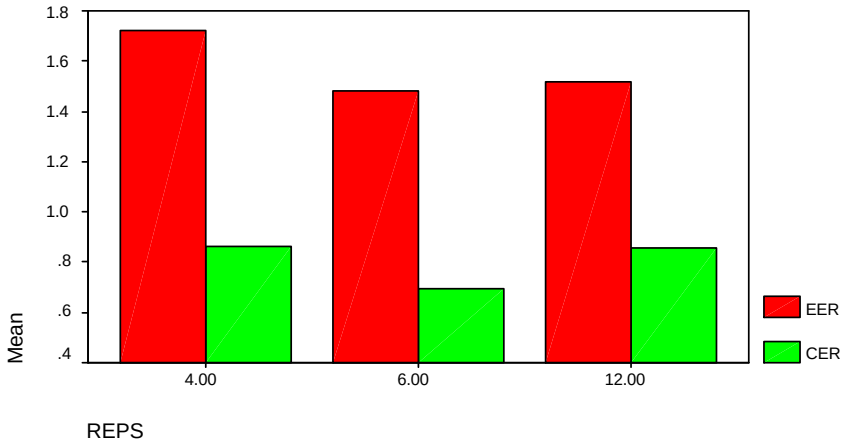
GRAPH OF EER AND CER BY NUMBER OF TREATMENTS (BONFERRONI)

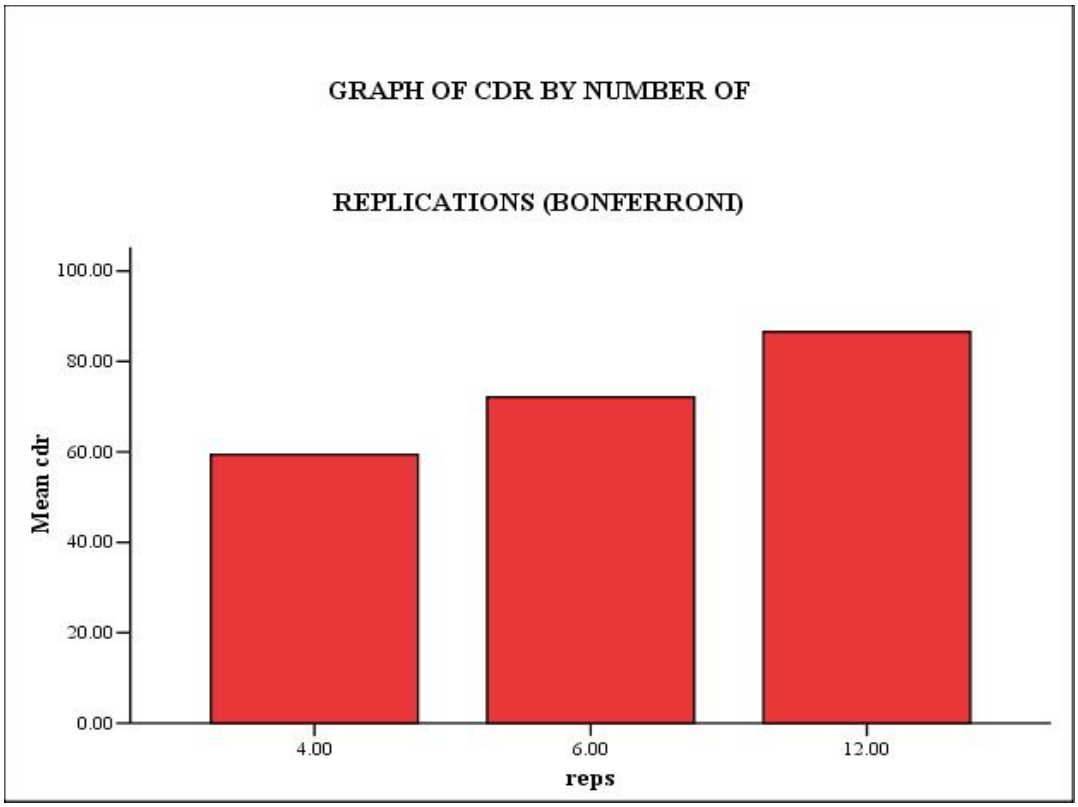




GRAPH OF EER AND CER BY NUMBER

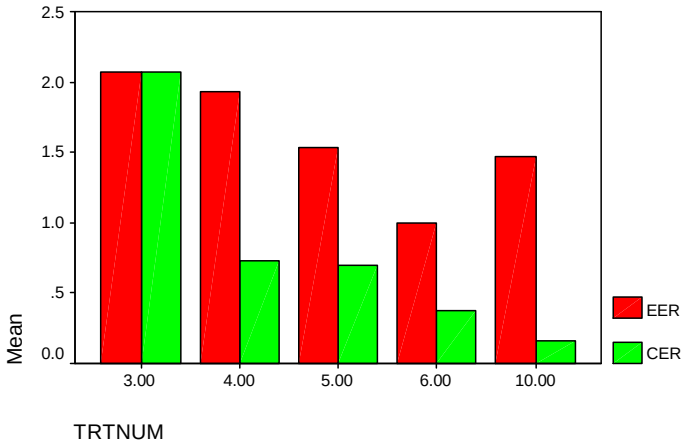
OF REPLICATIONS (BONFERRONI)

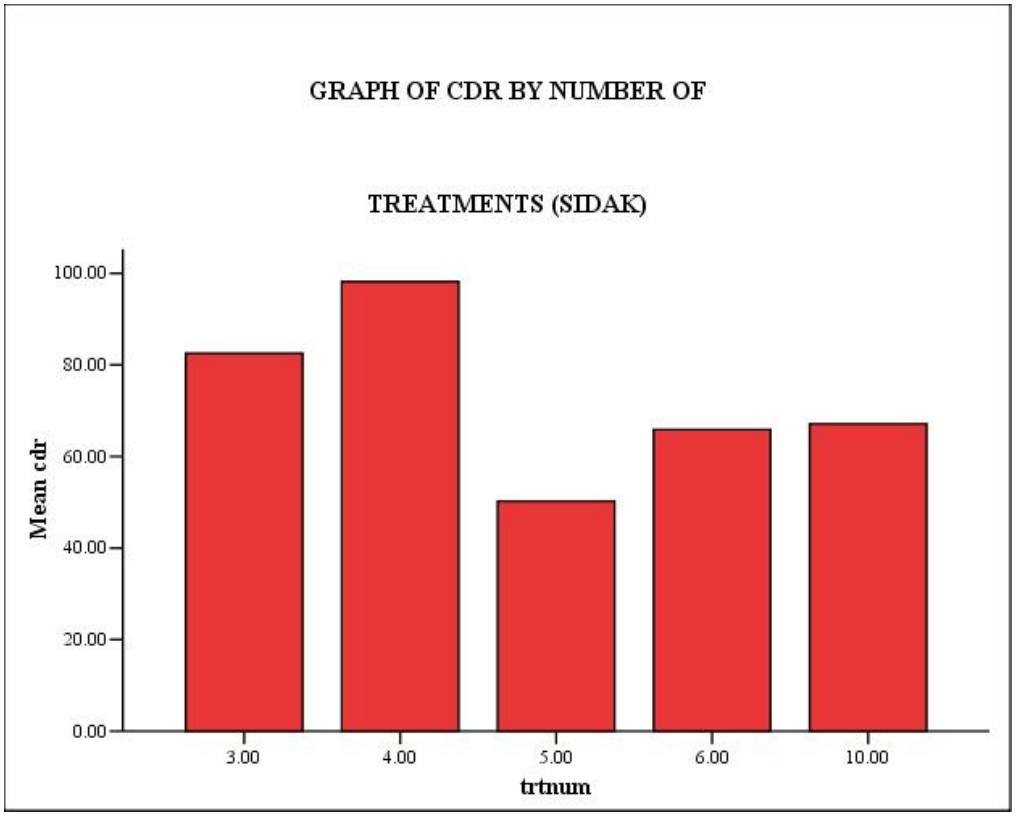


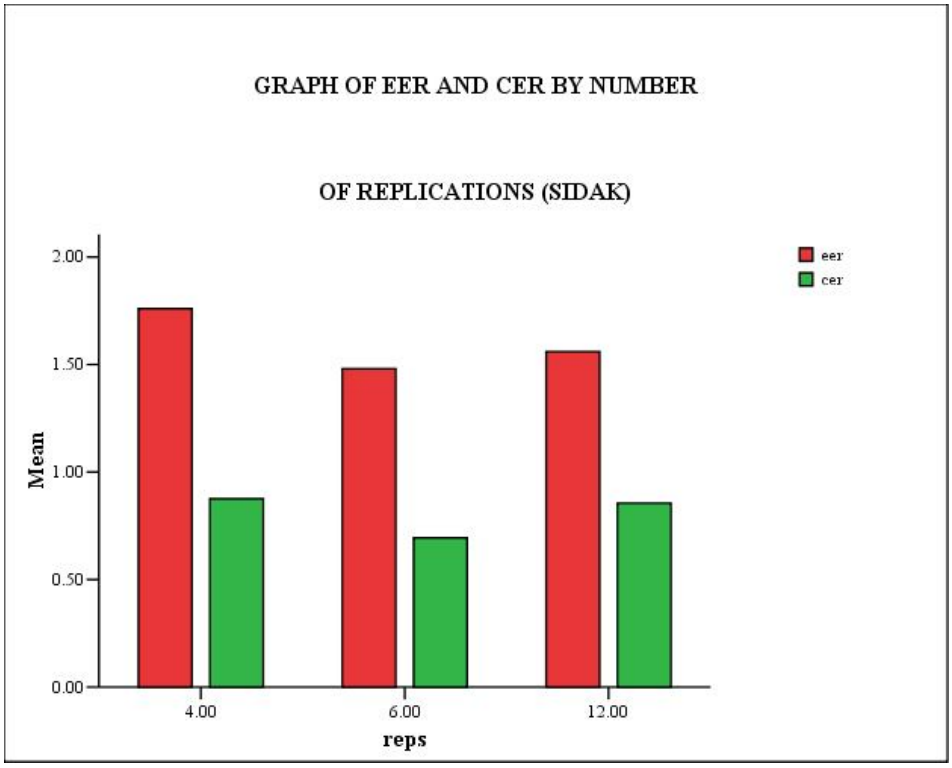


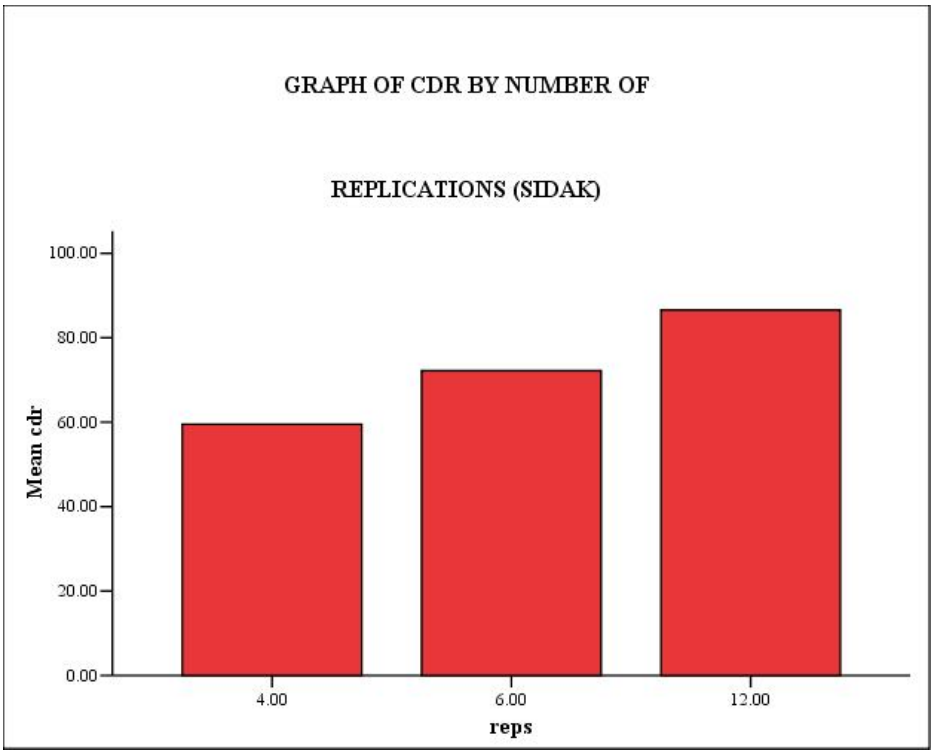
APPENDIX 14 (SIDAK)

GRAPH OF EER AND CER BY NUMBER OF TREATMENTS (SIDAK)



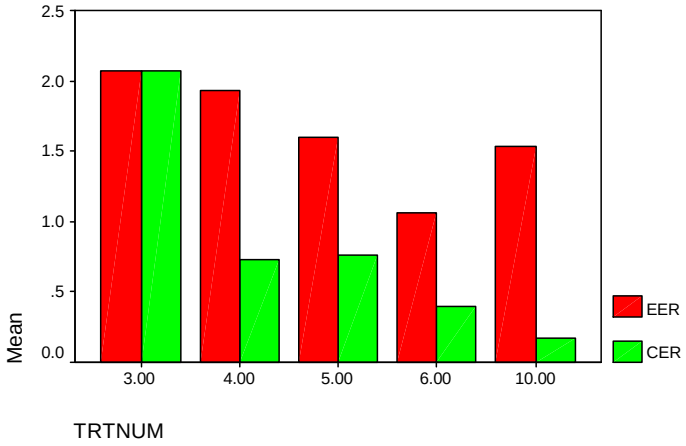


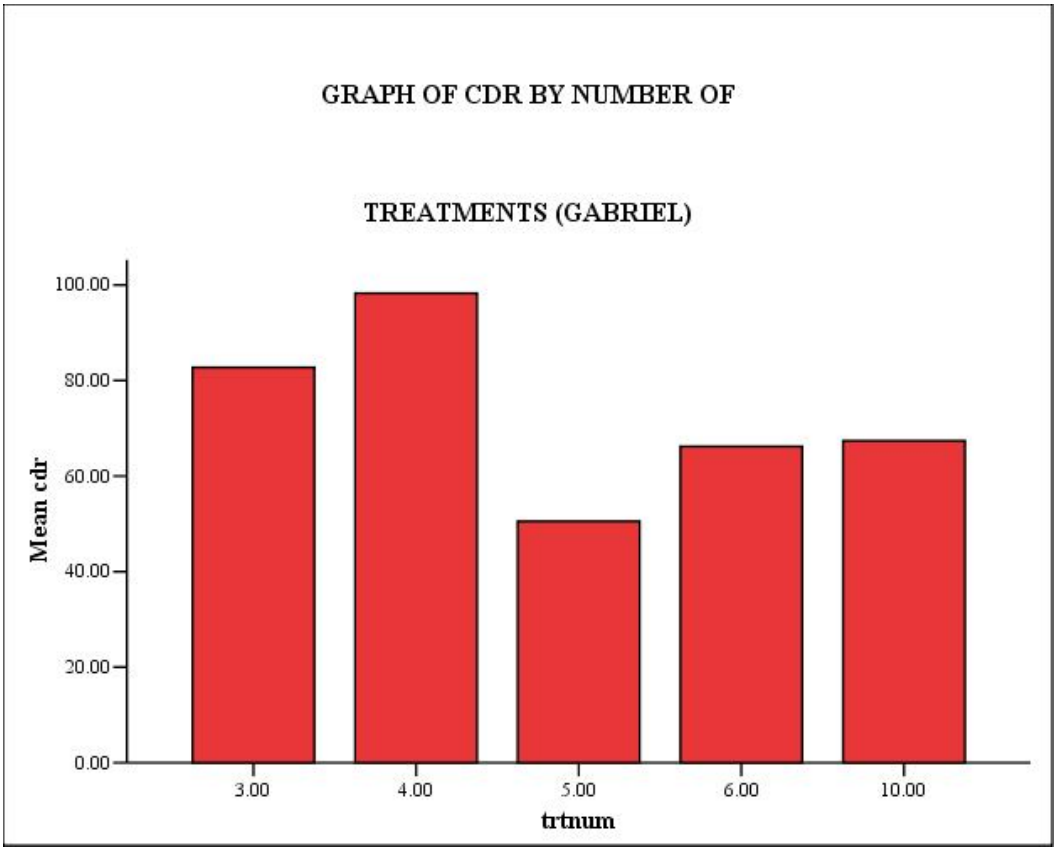

GRAPH OF EER AND CER BY NUMBER
OF REPLICATIONS (SIDAK)
eer
cer
Mean
2.00
1.50
1.00
0.50
0.00
4.00
6.00
12.00
reps

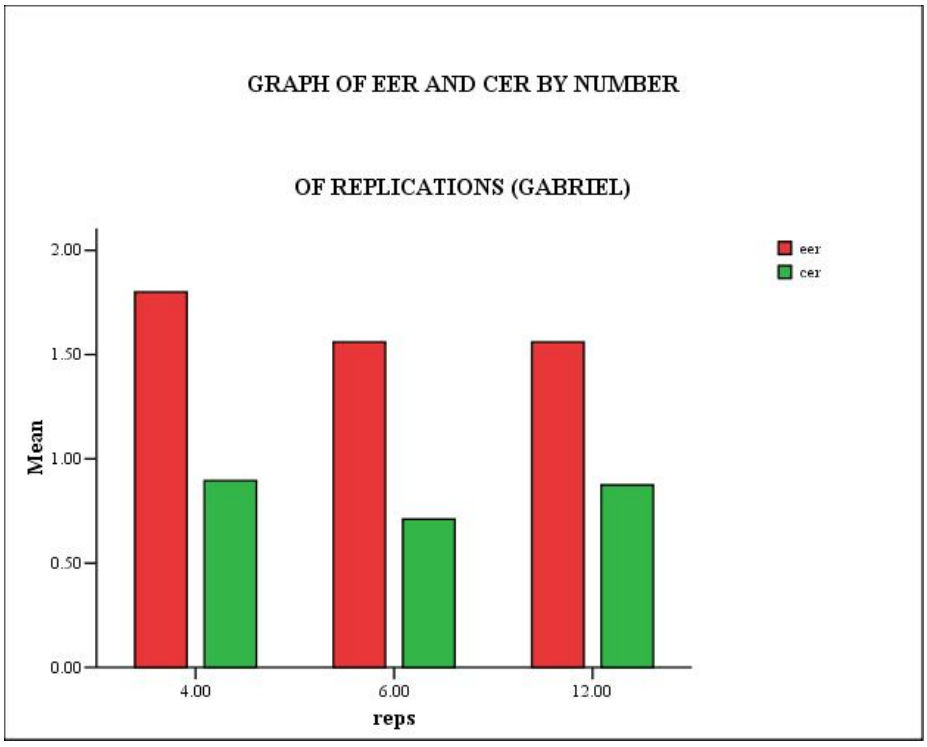

GRAPH OF CDR BY NUMBER OF
REPLICATIONS (SIDAK)
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
4.00
6.00
12.00
reps

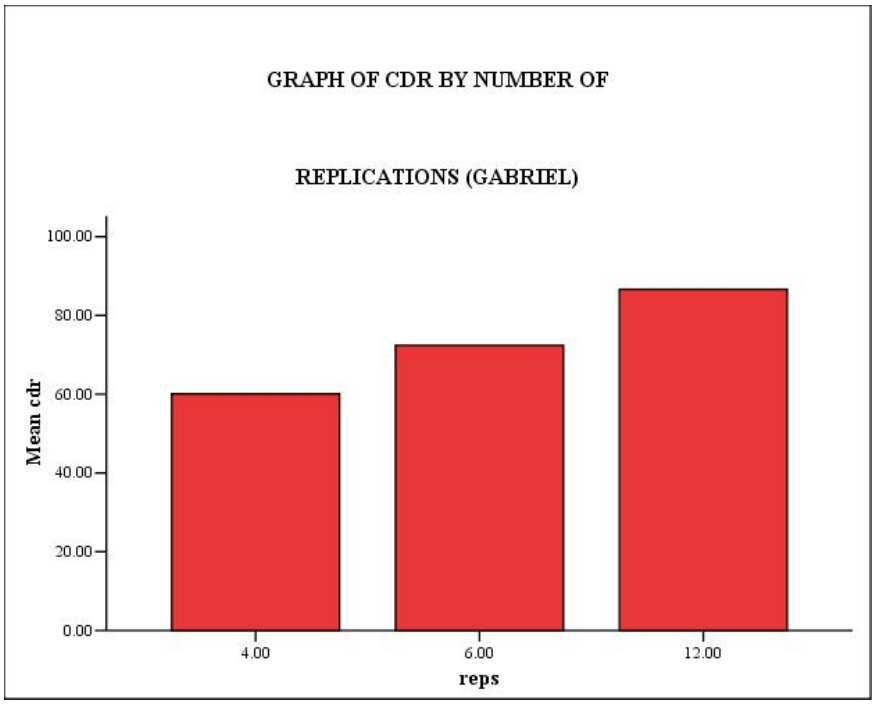
APPENDIX 15 (GABRIEL)

GRAPH OF EER AND CER BY NUMBER OF TREATMENTS (GABRIEL)



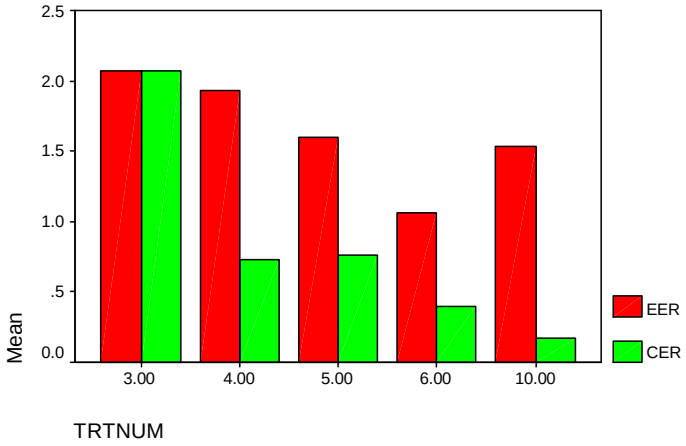


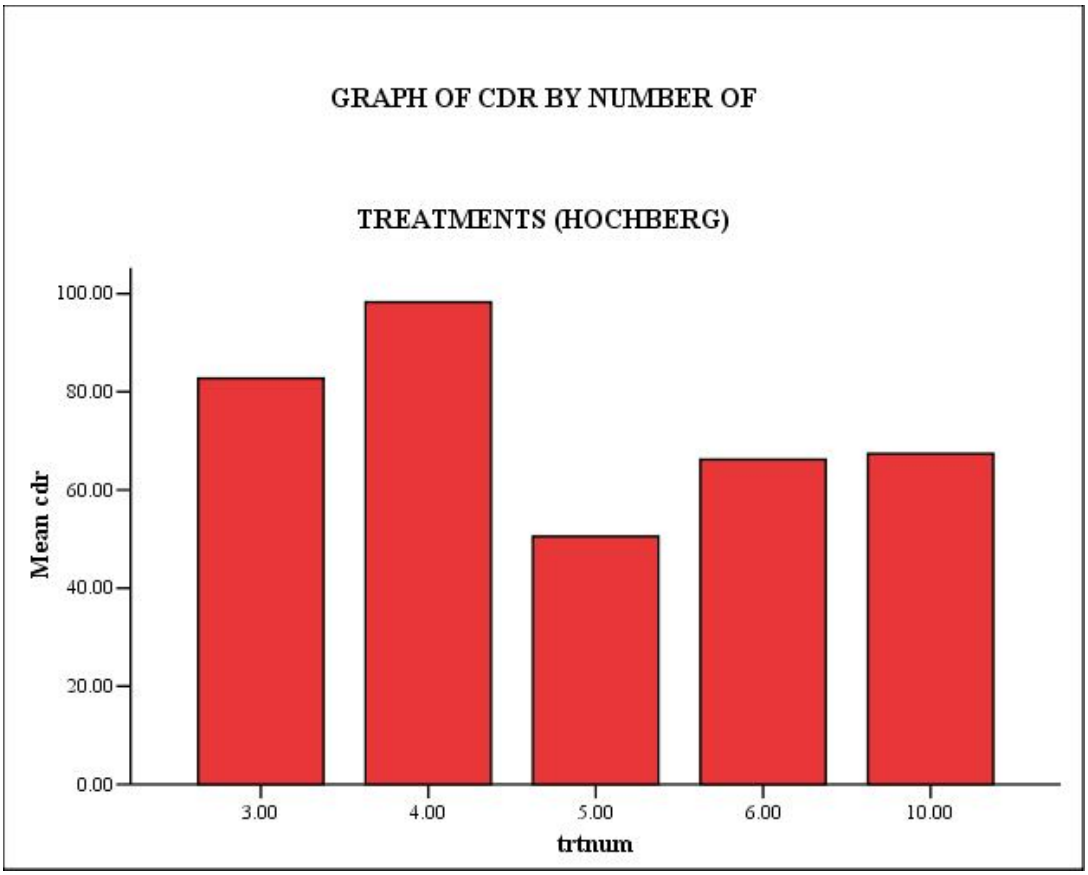

GRAPH OF EER AND CER BY NUMBER
OF REPLICATIONS (GABRIEL)
eer
cer
Mean
2.00
1.50
1.00
0.50
0.00
4.00
6.00
12.00
reps

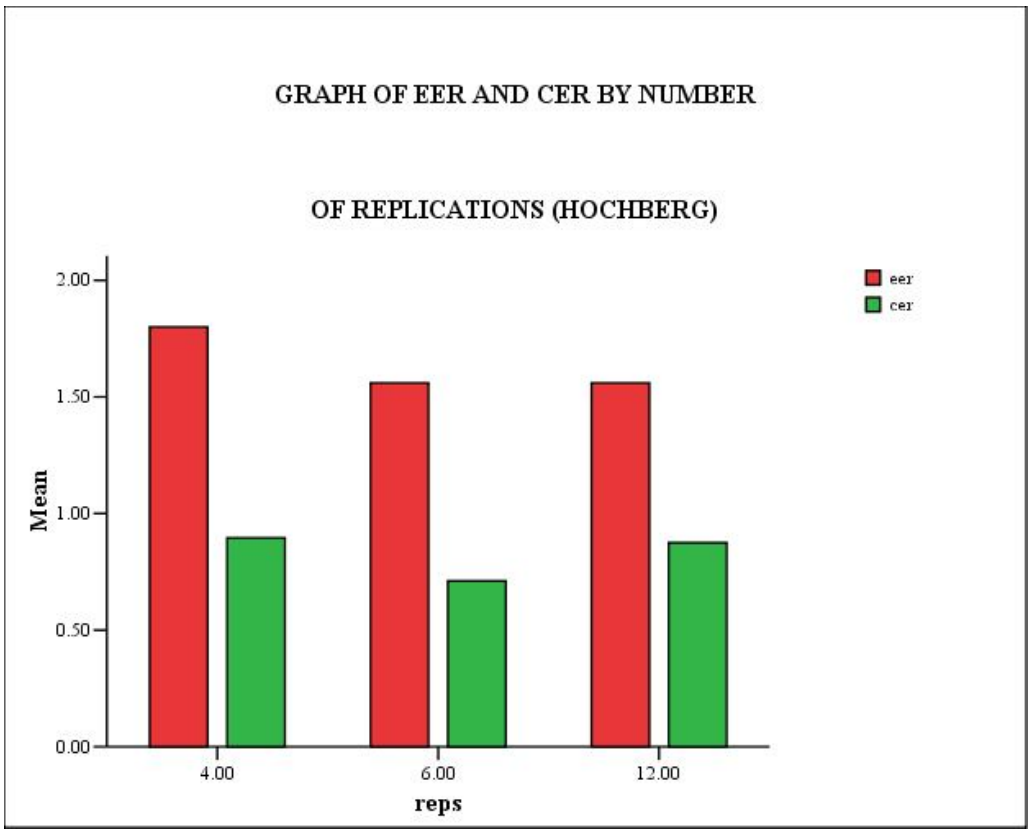

GRAPH OF CDR BY NUMBER OF
REPLICATIONS (GABRIEL)
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
4.00
6.00
12.00
reps

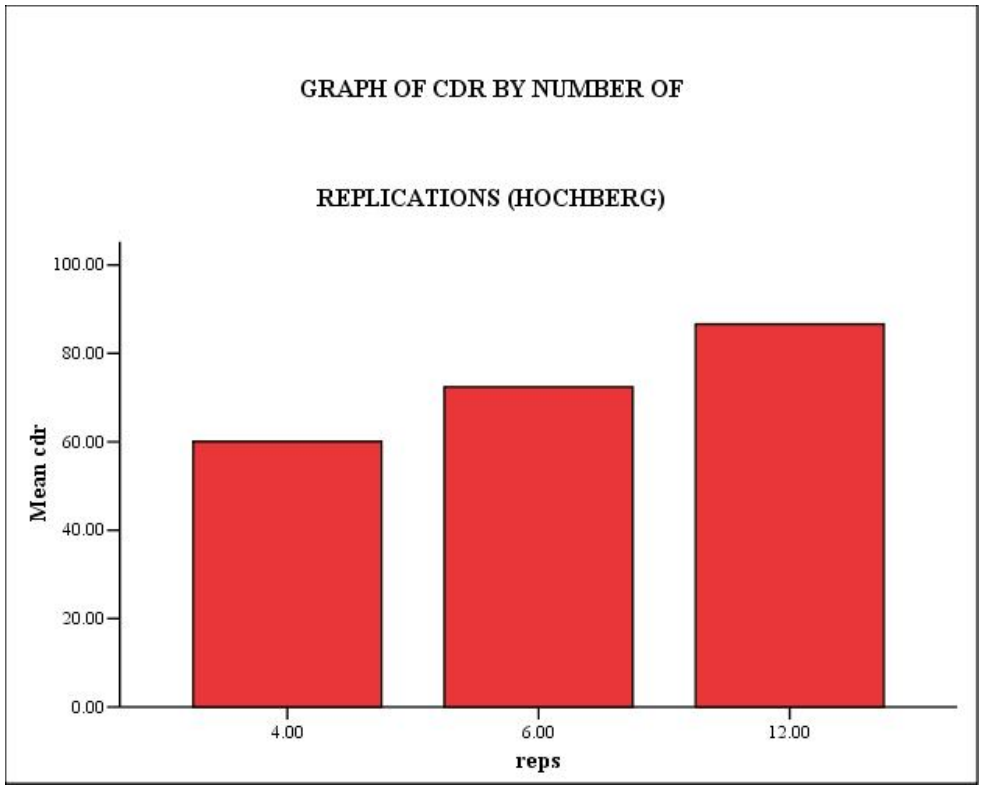
APPENDIX 16 (HOCHBERG)

GRAPH OF EER AND CER BY NUMBER OF TREATMENTS (HOCHBERG)



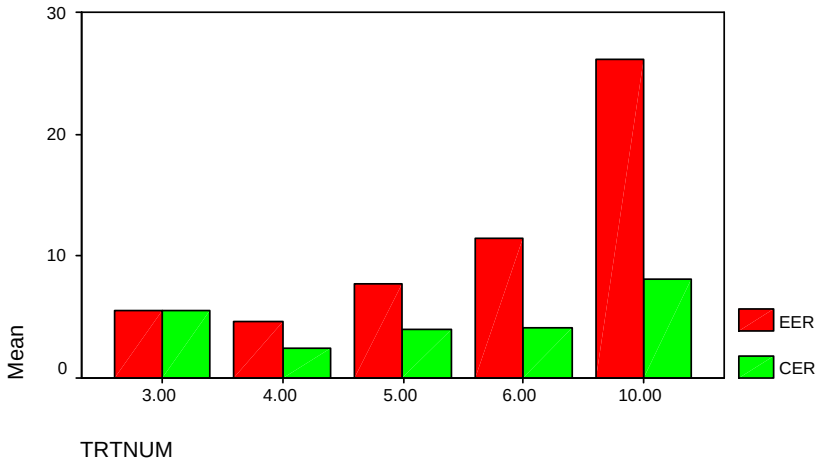


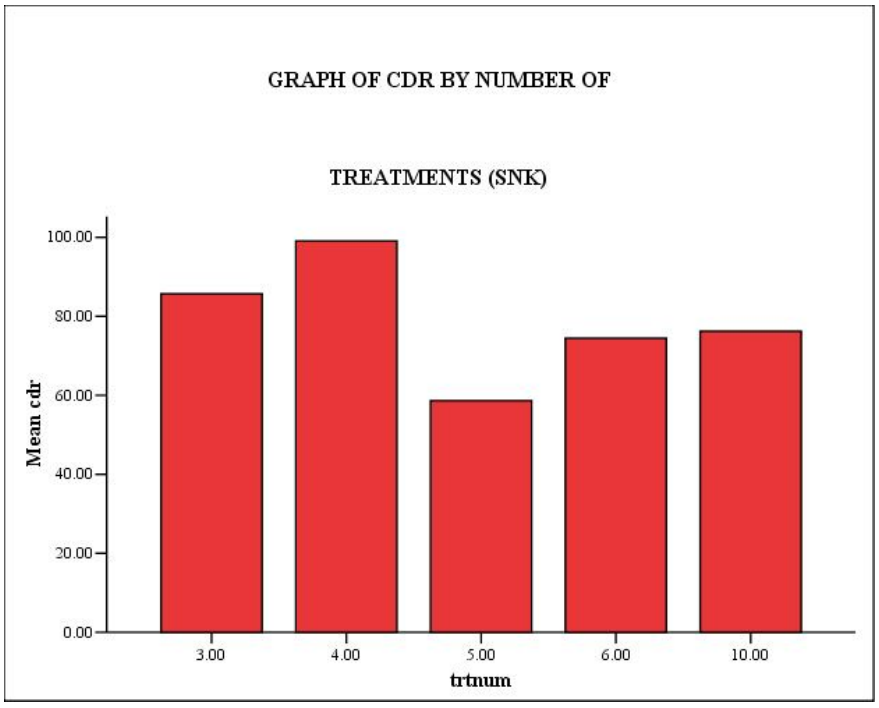

GRAPH OF EER AND CER BY NUMBER
OF REPLICATIONS (HOCHBERG)
eer
cer
Mean
2.00
1.50
1.00
0.50
0.00
4.00
6.00
12.00
reps

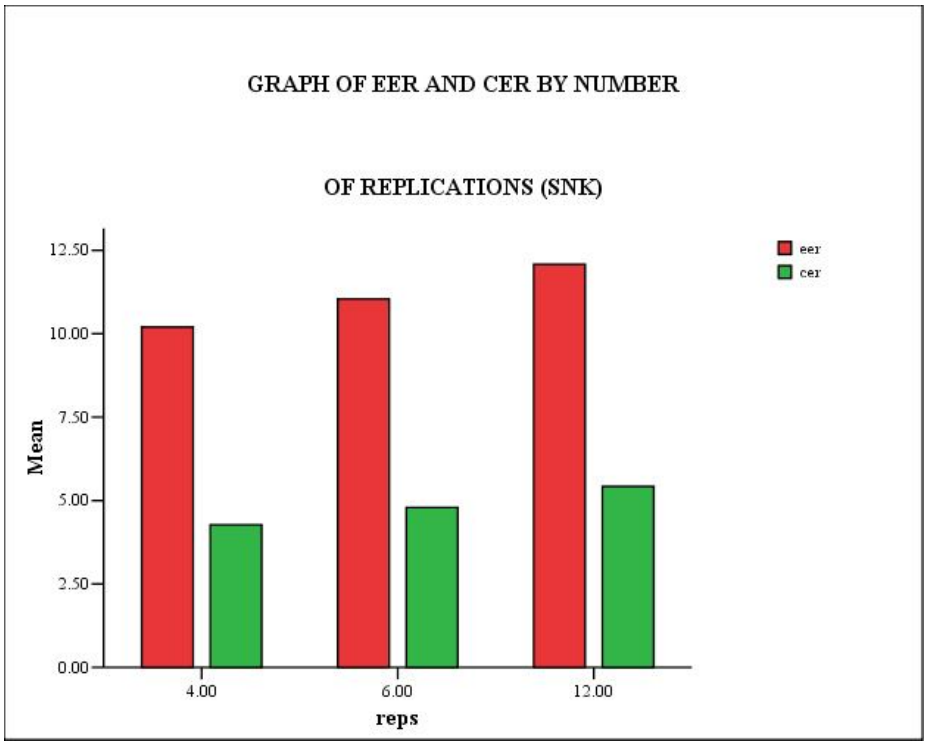

GRAPH OF CDR BY NUMBER OF
REPLICATIONS (HOCHBERG)
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
4.00
6.00
12.00
reps

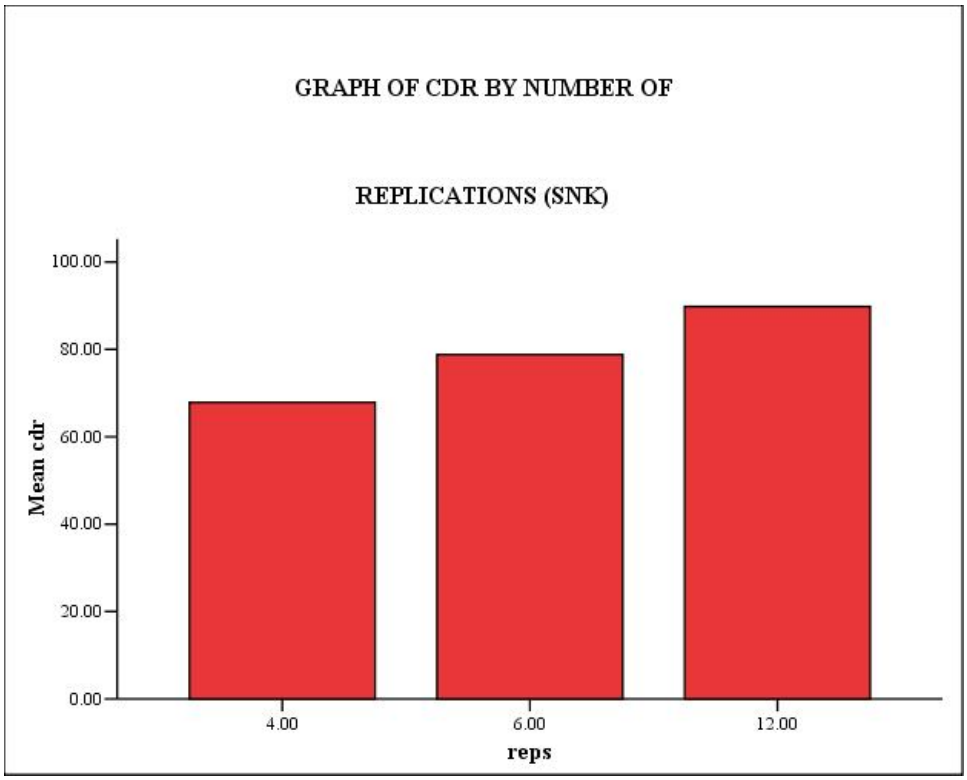
APPENDIX 17 (SNK)

GRAPH OF EER AND CER BY NUMBER OF TREATMENTS (SNK)



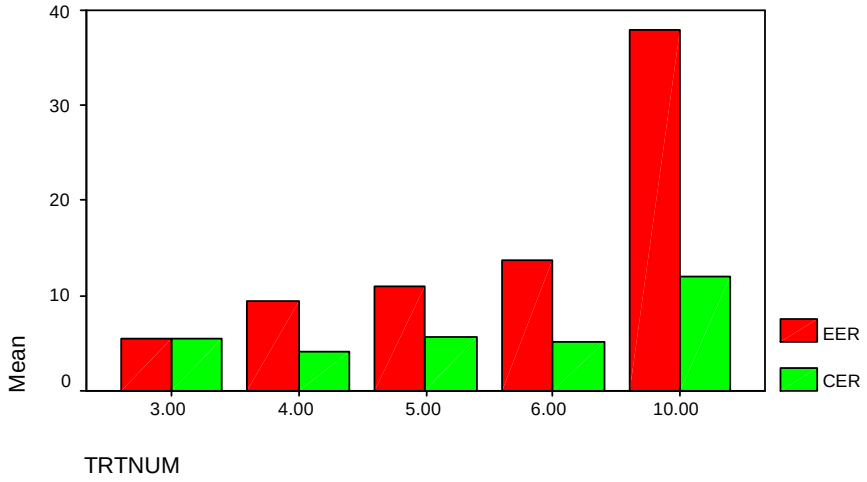


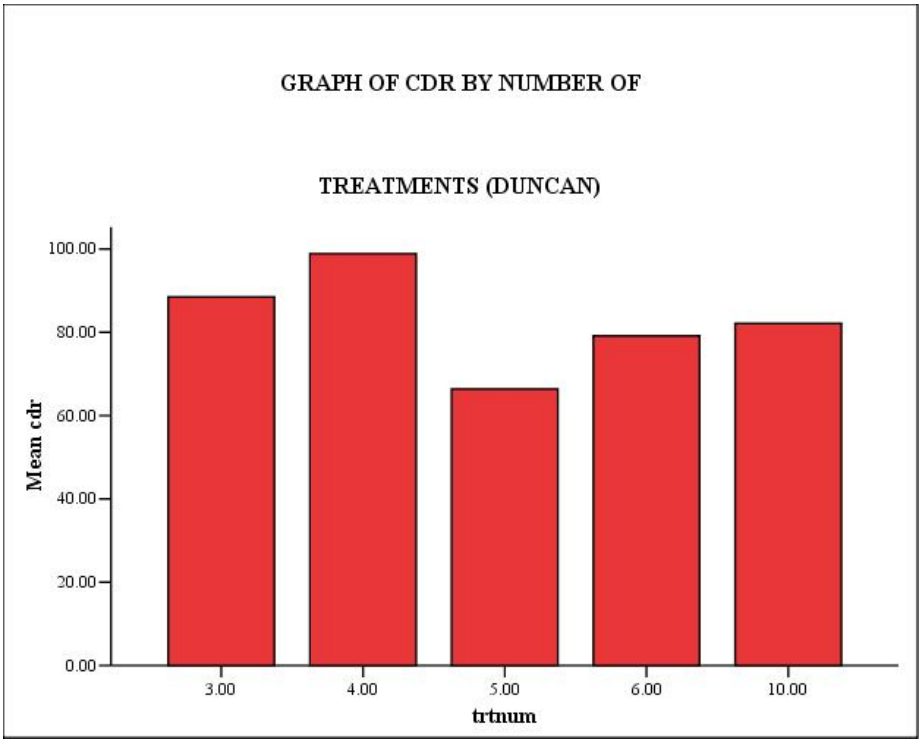

GRAPH OF EER AND CER BY NUMBER
OF REPLICATIONS (SNK)
eer
cer
Mean
12.50
10.00
7.50
5.00
2.50
0.00
4.00
6.00
12.00
reps

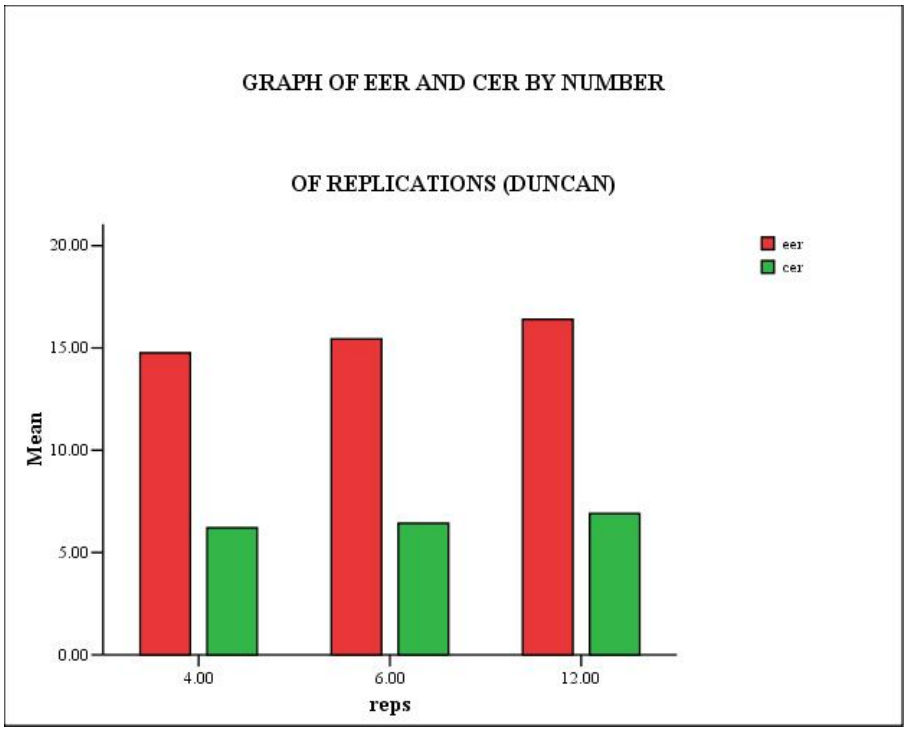

GRAPH OF CDR BY NUMBER OF
REPLICATIONS (SNK)
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
4.00
6.00
12.00
reps

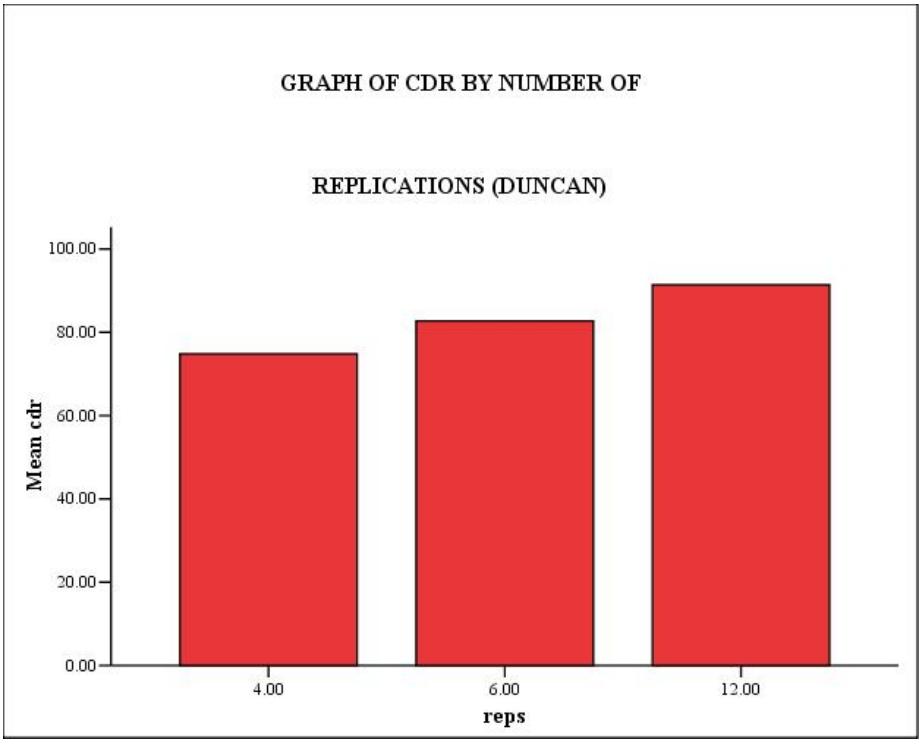
APPENDIX 18 (DUNCAN)

GRAPH OF EER AND CER BY NUMBER OF TREATMENTS (DUNCAN)






GRAPH OF EER AND CER BY NUMBER
OF REPLICATIONS (DUNCAN)
eer
cer
Mean
20.00
15.00
10.00
5.00
0.00
4.00
6.00
12.00
reps


GRAPH OF CDR BY NUMBER OF
REPLICATIONS (DUNCAN)
Mean cdr
100.00
80.00
60.00
40.00
20.00
0.00
4.00
6.00
12.00
reps