

## USES AND ABUSES OF DUNCAN'S MULTIPLE RANGE TEST

VICTOR CHEW  
*Agricultural Research Service,  
U. S. Department of Agriculture,  
Department of Statistics,  
University of Florida,  
Gainesville, FL 32611*

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**Abstract.** Duncan's multiple range test (MRT) is very often inappropriately used to compare treatments that are factorial in nature or that correspond to several levels of a quantitative or continuous variable. Published examples will be cited to show these abuses of Duncan's test. Alternative analyses will be suggested.

The statistical hypothesis that the true average responses of 3 or more treatments are all equal is tested by means of the F-test in an analysis of variance table. If this hypothesis is rejected, it does not necessarily follow that the averages are all unequal. The next stage in the data analysis is to determine which pairs of treatment means are different, using a so-called multiple comparison procedure, of which Duncan's MRT is one example. (A recent survey of these procedures is given in (2).) Quite often, Duncan's MRT is inappropriately applied to compare either factorial treatments or treatments that consist of several levels of a quantitative or continuous factor.

### Factorial Experiments

If the treatments are combinations of the levels of 2 or more factors, the treatment sum of squares should be partitioned into components corresponding to main effects and their interactions. (A major reason for conducting a factorial experiment is to study the possible existence of interactions; i.e., whether differences among the levels of Factor A depend on the levels of another Factor B. For example, the difference between 2 cultivars may depend on soil types. If interactions are known to be nonexistent or are of no interest, one may just as well carry out several small one-factor-at-a-time experiments.) If possible, the sums of squares for main effects and interactions should be further partitioned into single degree of freedom orthogonal contrasts, using linear combinations of the treatment means (2).

If it is not possible, before looking at the data, to partition meaningfully the sum of squares for the main effects of Factor A, it will then (and only then) be proper to use Duncan's MRT to compare the levels of A. In comparing the levels of A (averaged over the levels of Factor B), it is implicitly assumed that there is no A x B interaction. Otherwise, it makes more sense to compare the levels of Factor A for each level of Factor B separately, and vice-versa; e.g., comparing cultivars for each soil type separately. This is the author's preference over the alternative of comparing all (a x b) factorial treatment combinations.

There may be exceptional situations where it is justifiable to compare all (a x b) treatment combinations, irrespective of the significance or otherwise of the A x B interaction. Suppose a farmer is interested in growing 1 of 3 varieties of tomatoes, using 1 of 4 possible types of

fertilizers. He is not interested in the scientific comparisons among the yields from the 3 varieties or from the 4 fertilizers. He is only interested in maximizing his profit. In this case, his response should be "profit per plot" (and not "yield"), and the 12 treatment combinations may appropriately be compared using Duncan's MRT, ignoring their factorial structure.

As an interesting example of a factorial experiment, Dr. Raphael H. Segall at the U.S. Horticultural Research Laboratory in Orlando, Florida studied the effects of 10 treatments on the incidence of post harvest bacterial soft-rot in tomatoes. The 10 treatments were: 18-0-25, 18-0-25 and calcium nitrate, 18-0-25 and calcium chloride, 18-0-25 and potassium nitrate, 18-0-25 and potassium chloride, on mulched and on non-mulched beds. Instead of using Duncan's MRT, the 9 degrees of freedom for treatments were partitioned into single degree of freedom orthogonal contrasts to answer the following 9 questions.

- 1) Did mulching have any effect (averaged over the 5 fertilizers)?
- 2) Was there any difference between 18-0-25 alone and 18-0-25 plus salts?
- 3) Among the 4 salts, was there any difference between the 2 anions?
- 4) Was there any difference between the 2 cations?
- 5) Was the difference between the 2 anions dependent on the cation?
- 6) Did the difference between 'salts' and 'no salts' depend on mulching?
- 7) Did the difference between the 2 anions depend on mulching?
- 8) Did the difference between the 2 cations depend on mulching?
- 9) Did the interaction between anions and cations depend on mulching?

Answers to the above 9 questions are scientifically more enlightening than a series of alphabets attached to the 10 treatment means.

### Quantitative Variables

Variables or factors may be quantitative (e.g., temperature, time, concentration, pH, humidity, etc.) or qualitative (e.g., cultivars, soil types, locations, insecticides, cultural practices, etc.). (The levels of a quantitative variable are continuous, while those of a qualitative variable are not even numerical.) When treatments correspond to levels of quantitative variable, curve-fitting or regression analysis is the appropriate technique (2, 4).

If the regression is significant (i.e., there is a mathematical relationship between the response variable y and the factor variable x under investigation), then *all* treatments (including intermediate levels not used in the experiment) are significantly different in their effects. For example, if in comparing the effects of 10, 20, 30 and 40 ppm of a certain chemical, the estimated regression equation is  $y = 17.5 + 26.2x$ , say, we predict y to increase by 26.2 units for every unit increase in x. Thus, not only will 10 and 20 ppm be different in their effects, but also so will 10 and 10.1 ppm. Of course, the difference between the effects of 10 and 10.1 ppm will be very small and may be of no practical importance; however the usual statistical significance test is *not* concerned with the magnitude of the difference, but only whether or not a true difference exists, no matter how small.

If the response curve rises to a maximum  $y = y^*$  at

some unknown concentration  $x = x^*$  and falls beyond  $x^*$ , we may be interested in estimating  $x^*$  and  $y^*$ , or in finding the range of  $x$  that will give a response higher than  $(y^* - c)$ , where  $(y^* - c)$  is an acceptably high yield. The equation will also give an estimate of the difference between the yields at any 2 different values of  $x$ . If the cost of applying the treatment depends on its level, we should take as the response variable the yield per unit dollar of investment. These considerations are more meaningful than the question that is often asked by the naive experimenter: among 10, 20, 30 and 40 ppm, which ones are different in their effects?

If the response curve approaches an asymptote (i.e., tends to a maximum  $y^*$  but never quite reaches it, except at  $x = \text{infinity}$ ), an asymptotic equation should be fitted to the data (1). One form of such an equation is  $y = a + b(c)^x$ , where  $c$  is a positive fraction. Polynomials will not give a good fit to such data.

If the response curve reaches a maximum  $y^*$  at an unknown concentration  $x^*$ , and  $y$  remains constant at  $y^*$  beyond  $x^*$ , a two-phase regression should be fitted—a polynomial up to  $x^*$  and a horizontal line of unknown height  $y^*$  beyond  $x^*$ . Sometimes  $y^*$  is known; for example, in insecticide studies, the maximum percent mortality above some high concentration  $x^*$  is  $y^* = 100$ .

The same considerations hold with 2 or more quantitative factors. The fitted response surface summarizes the information in the data. It can be used to predict: (a) the response at any point (i.e., for any pair of values of  $x_1$  and  $x_2$ ); (b) the difference in responses at any 2 points; (c) the values of  $x_1$  and  $x_2$  that will maximize the response and the maximum value of the response; (d) the portion of the experimental region that will give an acceptably high yield; etc.

### Examples

Schalk and Stoner (6) conducted a  $3 \times 2 \times 2$  factorial experiment to study the feeding habits of the Colorado potato beetle at 3 stages of development (4th-instar larvae, young adults and old adults) when confined for 7 hours on leaf disks of 2 tomato lines (C28 and PI134417) at 2 temperatures (26.7 and 21.1°C). Duncan's MRT was applied, inappropriately, to compare the 12 treatments. Instead, the 11 degrees of freedom for treatments should have been partitioned into single degree of freedom contrasts to answer the following questions.

1. Was there any difference between larvae and adults (averaged over temperatures and lines)?
2. Did young adults differ from old adults?
3. Was there a temperature effect?
4. Did the 2 lines differ?
5. Was difference between larvae and adults dependent on lines?
6. Was difference between larvae and adults dependent on temperatures?
7. Did difference between young and old adults depend on lines?
8. Did difference between young and old adults depend on temperatures?
9. Did temperature difference depend on lines? (Equivalently, did line difference depend on temperature?)
10. Was interaction between larvae vs. adults and temperature dependent on lines?
11. Was interaction between young vs. old adults and temperature dependent on lines?

Questions 10 and 11 pertain to three-factor interactions and are usually less important than main effects and two-factor interactions. As mentioned earlier, a major reason for con-

ducting factorial experiments is to study the possible existence of interactions.

Tjia, Stoltz, Sandhu and Buxton (8) studied the effects of two surfactants (Hydrowet and Regulaid) on increasing the surface penetration of Ancymidol for height control of hydrangeas in a  $3 \times 4$  factorial experiment — 3 'chemicals' (Ancymidol alone, Ancymidol plus Hydrowet and Ancymidol plus Regulaid) each at 4 concentrations of Ancymidol (0, 50, 100 and 200 ppm without surfactant and 0, 25, 50 and 100 ppm with surfactant). Duncan's MRT was used to compare all 12 treatments. Because concentration is a continuous variable, the most appropriate statistical procedure is regression analysis. If we plot the data for each 'chemical' separately, it will be seen that the biggest difference was between zero and nonzero concentrations of Ancymidol. (If the lowest concentration is zero, it is instructive to analyze the data with and without the zero concentration. Quite often, and it is true in this example, the regression is nonlinear if zero concentration is included, and linear if the zero concentration is deleted. Interactions between chemicals and concentrations may also sometimes vanish on deleting the zero concentration.) Regression analysis will compare the heights, slopes, and curvatures of the 3 graphs. Of course, as mentioned before, if regression is significant, *all* concentrations are different in their effects. A similar example is given in (5), where Duncan's MRT was used to compare 7 treatments consisting of a control and 2 chemicals (Ancymidol and Chlormequat), each at 3 nonzero concentrations, to control growth of *Euphorbia leucocephala* Lotsy for pot production.

Gladon and Staby (3) studied the effect of a solution of sucrose and 8-hydroxyquinoline citrate on the opening of immature chrysanthemums. The flower heights were measured after various days from harvest. Average heights, with results of Duncan's MRT, were 38.8a (0 day), 41.2a (1 day), 44.1a (3 days), 47.4b (5 days), 53.4c (7 days), 83.2c (14 days) and 98.3d (21 days). If the results of Duncan's MRT can be believed, there was no opening of the immature flowers during the first 3 days after harvest, and no growth between the 7th and 14th day. Common sense would say that opening was continuous, starting from day zero. All days should be statistically different. A plot of the results would show that a straight line would give an adequate fit to the data, although a parabola would be better. There should be more graphical presentation of results. With a graph, a statistical analysis is sometimes unnecessary. A similar example may be seen in (9), where Duncan's MRT was used to compare the effects of 8 concentrations (0, 100, 200, 300, 400, 500, 1000 and 2000 ppm) of gibberellic acid to accelerate flowering and increase yield of static.

Seibert (7) studied the effects of 6 levels (0, 2.9, 6.3, 17, 28 and 82  $\mu\text{W}/\text{cm}^2$ ) of lighting on runner production in *Saxifraga sarmentosa* after 5 months of night-interrupt lighting. The average numbers of runners per plant, with results of Duncan's MRT, were Oa, 0.6ab, 1.8abc, 3.0bc, 3.2c and 3.8c. The correct conclusion is that *all* irradiance levels were different. If the above data were plotted, an asymptotic curve would be suggested.

In conclusion, the present author would like to apologize to the authors of the examples cited in this section. Other examples could have been chosen just as easily for illustrative purposes. There is a plethora of examples of abuses of Duncan's MRT not only in the horticultural science journals but also in the other agricultural journals.

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## PLANTING AND CARE OF HYBRID MUSCADINE GRAPES

FLORENCE HALL  
*Hall's Vineyard Nursery,*  
 Rt. 3, Box 352, Lake Wales, FL 33853

*Additional index words.* *Vitis (Muscadinia) rotundifolia,* 'scuppernong.'

**Abstract.** One individual's experience in hybrid Muscadine grape production in central Florida is presented with emphasis on purchasing vines, varietal characteristics, soil types and marketing. Future growth of the grape industry in Florida is also discussed.

History need not repeat itself. The past history of Florida's grape industry clearly indicates that the past problems of growing grapes in this state are now over.

Hybrid Muscadine varieties introduced from the states of Georgia and North Carolina and adapted to Florida are growing exceptionally well in many parts of our state, and furthermore, have been growing here for many years. These vines are extremely resistant to Pierce's Disease and nematodes, which were the two major reasons for failure in the past.

Nematodes destroyed our citrus grove, thus it was necessary to push our trees and have the soil treated. This was quite a loss and looking toward future replanting of citrus was discouraging as the nematode and citrus decline disease is still uncontrolled.

We then discovered the Muscadine grape varieties and decided to test grow a 2-1/2 acre plot. The first 2 years were disappointing as the vines were progressing too slowly. However, the determination to find out *why* brought us into the Nursery Vineyard business which proved vines should not be planted in the field until they meet the qualifications of a 1 year old vine or younger, 5 ft. tall, with at least a 2 gal pot size root system. Since overcoming this problem, we have now planted the remainder of our land.

Our U-Pick-It Program for the past 2 seasons has been very rewarding indeed. However, the Muscadines are not yet well known in Florida and it is necessary to do a great deal of advertising. Once you get the customer to taste the grapes, they will sell for you via "Word of Mouth," the best advertising of all.

Do not let me mislead you, the primary per acre cost of the initial planting, trellising, irrigation and possible drainage and care, through to the full production age is much greater than for citrus. However the financial returns per acre are also greater. Moreover, let it be understood that grape vines demand a great amount of personal attention in pruning and training the first 3 years. Growing

grapes on a commercial basis is *not* for everyone, but the backyard hobby grower can easily care for a few vines.

The best market today for the present varieties of hybrid Muscadines is the U-Pick-It Program and the local markets. As soon as a good commercial method of making wine with the Muscadines is developed, then the wine market will be open. We have good wine grapes now, but the Muscadines at present make a sweet wine and wine connoisseurs advise that we need a better dry wine grape.

### General Information

#### *Plant Characteristics*

*Origin.* The Muscadine vine 'Scuppernong' is the oldest native American variety of grape. The original vine is around 350 years old and is still alive on Roanoke Island, Pamlico Sound, in North Carolina.

There are approximately 15 hybrid varieties released for and adapted to Florida which are nematode and Pierce's Disease resistant.

*Pollination.* Muscadines are not like the bunch grape. There are the female vines and the perfect flowered, self fertile male vines which not only produce fruit themselves, but also pollinate the female vines. The self-fertile male vine must be within 25 feet of the female and can pollinate up to 3 female vines.

*Production* ranges from 2 to 8 tons per acre, depending on the variety, location and proper care. Generally the third year is considered the first productive season.

*Harvesting* is done by hand or mechanical harvester, depending on the kind of market and variety.

#### *Fruit Characteristics*

*Ripening Tendencies.* Some varieties ripen almost all at once. Others stagger their ripening and take 4 to 8 weeks to complete their production. (Note: For Muscadines to reach their full value, all varieties should be fully ripe before harvest. They will not ripen further after harvesting.) Central Florida grapes usually are ready to start harvesting by the first of August.

*Varietal Sizes.* The individual berries of the latest releases are medium (nickle coin size) to jumbo (quarter to half-dollar coin size).

*Colors.* Bronze (pink to light golden green), and black.

*Eye Appeal.* Very attractive and well accepted.

*Taste.* The table grape varieties are outstandingly delicious. The jelly-wine grapes are not quite as enjoyable to eat, but are very good tasting.

*Texture.* Skin—hearty. Pulp—firm and juicy.

*Seeds.* The larger the grape, the less you notice the seeds. Large grapes usually have two to three seeds. The smaller grapes usually have 3 to 4 seeds.