VARIATION of sugar maple sap yield and its influence on EXPERIMENTAL DESIGN

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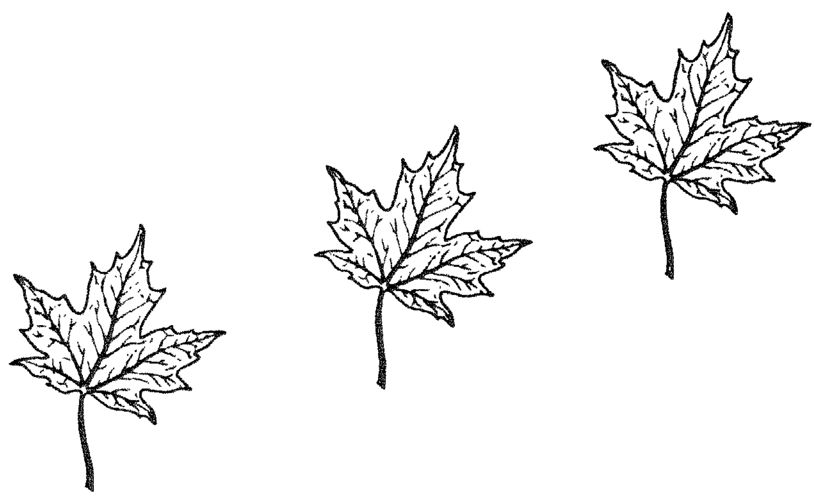

U. S. FOREST SERVICE RESEARCH PAPER NE-108
1968
NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
RICHARD D. LANE, DIRECTOR

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A PROBLEM OF EXPERIMENTAL DESIGN

ANYONE who has ever emptied sap buckets in a sugar maple grove knows that sap yields vary greatly among individual trees. Some trees yield a lot of sap, others very little. When the Northeastern Forest Experiment Station began its research on maple sap production in Vermont a few years ago, we found that this variation in sap yield posed a problem for us in designing our experiments. It precluded the use of random sampling; so we had to find some other basis.

The variation in sap yield may be attributed to many factors. Tree and crown characteristics, stand and site characteristics, taphole dimensions, and location, and the genetic potential of the tree apparently all contribute (*Robbins 1965; Morrow 1955; Jones et al. 1903*).

Statistical testing techniques provide a means of evaluating this sort of variation. If variation between trees that received different treatments is large in relation to the natural variation among individual trees, we can attribute the observed differences to the treatments. However, if natural variation among trees is very large—as it appears to be with maple sap yield—then either the number of trees sampled must be very large or the differences resulting from the treatments must be very large to attain statistical significance with simple randomized experiments.

More efficient experimental designs provide some means of grouping experimental plots into blocks or pairs so as to minimize the natural variation among the members of the block or pair. For example, two trees known to have about equal natural sap yields might be paired; or two tapholes on the same tree might be paired and then each taphole could be considered an independent plot. In both of these examples, the natural sap yields of the two experimental units are about equal, and differences in yield that result after random assignment of a treatment to one member of the pair can be attributed to the treatment with considerable confidence. In making statistical tests, a relatively smaller number of samples is needed for these designs as opposed to completely random designs for detecting a given size difference in yield.

Both of the grouping techniques mentioned above have limitations in maple sap production research. The use of several tapholes on the same tree raises the theoretical objection that these tapholes may not yield independently: the application of a treatment to one taphole might also affect the yield of the other. To avoid this objection, the two tapholes are spaced as far apart as possible but still are kept on the same side of the tree so that exposure, temperature, etc., will be similar. This effectively limits to two the number of tapholes that may be used on all except very large trees. Thus experiments are limited to those involving only two treatments—or one treatment and a control. Another question is whether or not paired tapholes on the same tree can be expected to yield like amounts of sap.

The other technique—grouping trees with similar sap yields—requires that records of the past yields of individual trees be available for making the groupings. Further, this technique assumes that trees grouped on the basis of past yield will continue to yield in the same relative proportions in subsequent years.

When sap production research was begun by the Northeastern Forest Experiment Station in Burlington, Vermont, in 1964, it became apparent that more quantified information on sap yield variation among individual trees and among years was needed to facilitate the designing of efficient experiments. One of the first projects undertaken was to record seasonal sap yields on approximately 140 individual trees on a sugarbush near Jericho, Vermont. Yields were measured in the sap seasons of 1965, 1966, and 1967. Data presented in this report are based for the most part on a random sample drawn from these trees. All sample trees were tapped with two tapholes bored to a uniform depth.

RESULTS

The yield of 24 randomly selected trees was first analyzed to quantify the variation in sap yield. Average taphole yields for this sample of trees ranged from 14 to 80 liters in 1965, 6 to 106 liters in 1966, and 2 to 77 liters in 1967. The coefficients of variation were 42, 52, and 59 percent for 1965, 1966, and 1967 respectively.

Data from these same trees were analyzed to determine the number of sample trees that would be required to detect an average difference of 5 liters per tree in a hypothetical experiment involving two treatments with trees assigned to treatment completely at random.[1]

Using data from 1967—the year with the largest coefficient of variation—we found that approximately 257 sample trees would be required to obtain statistical significance. It would usually be impossible to conduct such a large experiment.

[1]Computations were based on a test of significance at the 5 percent level, assuming an acceptable β error of 10 percent.

Grouping of Trees On Basis of Previous Yield

To determine whether the relative yield of a tree is consistent from year to year, the 24 trees used in the previous analyses were ranked according to their sap yields the first year of measurement—1965. These same trees were again ranked on the basis of yields in 1966 and 1967. The majority of the trees changed their ranking by 3 or 4 places compared to their 1965 rankings, and a few changed as much as 11 places (table 1). However, ranking in 1965 was significantly correlated (at the 99-percent level) with that in 1966 and 1967 (1965-66, $r_k = 0.70$; 1965-67, $r_k = 0.68$)[2], indicating that grouping on

Table 1.—*Trees ranked according to yield obtained in 1965 (base), 1966, and 1967*

Tree No.	*Rank*		
	1965	1966	1967
7	1	1	1
81	2	6	2
15	3	4	6
86	4	2	4
51	5	3	5
71	6	5	7
63	7	10	12
16	8	11	8
76	9	14	3
65	10	13	17
45	11	7	11
78	12	12	19
66	13	16	10
18	14	18	21
40	15	9	13
35	16	19	18
33	17	17	14
80	18	20	15
21	19	15	16
55	20	8	9
24	21	22	22
60	22	23	23
69	23	21	20
48	24	24	24

the basis of previous yield is a valid procedure. This result is similar to that reported by Morrow (*1952*), and is essentially similar to rankings shown by Taylor (*1956*) for sap sugar concentration.

Total sap yield for the same sample of trees in 1965 was also significantly correlated (at the 99-percent level) with yields from 1966 and 1967 (1965-66, r = .84; 1965-67, r = 0.84)[3]. This is another indication that variation in yield among trees in a stand is consistent from year to year.

To carry this a step further, we expanded the sample to 30 trees, which were then paired on the basis of their 1965 yields. Thirty trees were used in the sample so that 15 pairs of trees could be used in the analysis, comparable to the number of pairs used in many of our other experiments. Differences in mean yield for these pairs obtained in 1965, 1966, and 1967 were then tested for significance, using the t-test for paired replicates. No significant differences were found among the mean yields for any of the pairings.

The trees were then paired on the basis of their average yields for 1965 and 1966, and differences between this average and the mean yields obtained in 1967 were tested; they were also non-significant. These t-tests indicate that trees paired on the basis of equal yield can be expected to yield equally in subsequent seasons.

To evaluate the gain in efficiency that might result from grouping trees on the basis of their previous yields, we calculated the number of samples that would be required in a hypothetical experiment using the same data and assumptions previously used for the completely random experiment. We found that only 54 pairs (108 trees) would be required for the pairing design, as opposed to 257 trees for the random design. Similar calculations using other study assumptions revealed that the completely random design generally requires about 2½ times as many trees as the paired design.

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[2] r_k = Kendall's rank correlation coefficient.

[3] r = Standard correlation coefficient.

Grouping of Tapholes On Individual Trees

Many of the initial experiments undertaken by the Northeastern Forest Experiment Station in tubing use and spile design were based on tapholes paired 6 inches apart on the tree bole. The assumption was that these tapholes would yield comparable amounts of sap. This assumption was tested in 1967, using seasonal sap yields from 15 taphole pairs on a sugarbush in Essex Center, Vermont. Differences in the mean yields from the 15 pairs were non-significant, with a calculated "t" of 1.0. The assumption that tapholes paired close to one another would yield comparable amounts of sap was therefore valid, at least in this particular case; and there is no reason to believe the validity of the assumption would differ with a different sample.

Sap yields from tapholes located on the same tree have been observed by many to vary according to location on the tree, in regard to compass direction, although most observers have noted that this variation is not very great (*Jones et al. 1903, Robbins 1965, and others*). Since this variation is primarily the result of differences in temperature regimes at different locations on the tree bole, it would be expected to be greatest between tapholes located opposite one another on the north- and south-facing sides of the tree.

To investigate the feasibility of using paired tapholes on trees regardless of proximity to one another, we tapped 24 trees in 1966 with two tapholes. One taphole faced south, the other north. Taphole dimensions were strictly controlled, and the tapholes were located on the same horizontal plane. Differences in mean yield from the paired tapholes were tested with a t-test for paired replicates, as before. Differences in the mean yield for the 24 pairs were non-significant, with a calculated "t" of 1.17. It would appear valid then, to pair tapholes on the same tree, regardless of location in regard to compass direction, provided external sources of variation, such as the shading of one member of the pair by an understory tree, are not present. This would also allow use of three or more tapholes on a tree in studies involving more than two treatments.

These results are in accord with our previous unpublished findings on the effects of compass direction on sap yield, and are in accord with data reported by Jones et al. (*1903*), Robbins (*1965*), and others.

Another question about the use of paired tapholes on the same tree is whether the two tapholes are truly independent. Independence of yield when a vacuum was applied to one member of the taphole pair was tested in 1967. No evidence of horizontal movement of sap was found between tapholes 6 inches apart under these conditions (*Blum and Koelling 1968*). In view of these results, and because sap movement and wood structure are known to be oriented vertically rather than horizontally, the assumption of independence appears to be valid.

SUMMARY AND CONCLUSION

Measurements of seasonal sap yields in 1965, 1966, and 1967 show that variation in sap yields among individual trees is very large. The magnitude of this variation precludes the use of simple random sampling as a basis for experimental design.

Variation can be reduced greatly by grouping trees on the basis of previous sap yields. This requires spending at least one season determining the yield potential of the trees in question before experiments can begin. However, it provides a much more efficient statistical test and enables detection of smaller treatment differences or the use of fewer samples than simple random designs.

A similar result can also be obtained by grouping or pairing individual tapholes on a single tree. This eliminates the necessity for measuring sap yields before beginning studies.

Which of the two grouping techniques will be best depends upon the requirements of the particular experiment. If there are only two or three different treatments and they can be applied to individual tapholes (for example: comparisons of spile design or tubing vents), the use of grouped tapholes on each tree will probably be most satisfactory. Where there are numerous treatments to be compared, or where the treatments must be applied to entire trees (for example, fertilizer experiments), the use of trees grouped on the basis of previous yields will probably be necessary.

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