Sources of Variation in Olive Flower and Fruit Populations

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Abstract. Olive (*Olea europaea* L.) field experiments involving natural flower and fruit populations are fraught with variability, resulting in large coefficients of variation. We provide evidence that coefficients of variation can be reduced successfully by judiciously selecting four experimental twigs per tree and using only those twigs with an internodal growth ≥ 2 cm, two inflorescences per node, and that are selected from trees with near-maximum bloom density. Although counting flowers at full bloom may establish the population uniformity, only a single node; e.g., node 5, is needed for analysis. Increasing the number of trees will reduce variance more than increasing the number of twigs or nodes.

Olive field experiments designed to measure flower production and fruit persistence are complicated by large coefficients of variation. In our field experiments, we have encountered coefficients of variation >100 . The investigations of Rallo et al. (1981) have done much to describe the olive flower and fruit population and its persistence characteristics; they compared fruiting habits of 'Manzanillo' (strongly biennial), 'Swan Hill' (flowers annually but fruitless), and 'Rubra' (annually fruitful). They found that 1) imperfect flowers of each cultivar abscised immediately after full bloom; 2) the percentages of flowering twigs bearing mature fruit were 91%, 55%, and 0% for 'Manzanillo', 'Rubra', and 'Swan Hill', respectively; 3) abscission occurred in 'Manzanillo' 5 days after full bloom (DAFB), when fruit growth rate increased sharply; and 4) no correlation existed between percentage of perfect flowers and fruit persistence. These authors concluded that competition among fruit occurs first within the inflorescence and later among inflorescences on a twig. In 'Manzanillo', Rallo et al. (1981) found 1.3 and 1.1 fruit/inflorescence at 14 DAFB and harvest, respectively. Thus, the final fruit set was established soon after anthesis. Note that each node bears two inflorescences and each inflorescence contains 15 to 25 flowers.

In later studies, Rallo and Fernandez-Escobar (1985) found that the number of fruit per inflorescence in the cultivars tested was nearly stable 21 DAFB and that, despite the number of perfect flowers or initial fruit per inflorescence, ≈ 1.1 fruit/inflorescence remained at harvest. Thinning flowers in the inflorescence—even removing 87% of all flowers—altered the time of abscission but not the final number of fruit per inflorescence.

The experiments of Rallo et al. (1981) revealed that fruit abscission is controlled at

the individual inflorescence. The work described here was designed to count natural flower and fruit populations periodically to compare coefficients of variation and to determine variance in fruit set among trees, twigs, and nodal positions.

Uniform, unbranched 'Manzanillo' olive twigs containing 12 to 14 consecutive nodes, each having two inflorescence buds per leaf were selected and flagged before flower opening. The 12-year-old trees were selected in the Univ. of California, Davis, experimental orchard based on extensive bloom in the "on" year and uniform vigor. In 1989 and 1990, four twigs per tree on each of 10 trees and, in 1991 and 1992, six twigs per tree on each of 10 trees were used. Beginning at the most distal node on each twig, the first pair of inflorescences was marked with ink. The mark served as a reference point for future counting (node 1) and to distinguish between nodes after inflorescence abscission. Each twig was identified with a tag indicating tree and twig number. To maintain "on" year trees, the orchard was treated with naphthaleneacetic acid to produce alternating "on" and "off" years, and only "on" year trees were used.

Just before anthesis, each flower on each twig was counted and the flower count per inflorescence and nodal position was recorded. Flowers and fruit were counted weekly until 28 and 42 DAFB, after which little further abscission occurred. The total number of flowers or fruit per node was recorded and the data were statistically analyzed using SAS (Cary, N.C.) software.

At full bloom (day 0), the flower counts per nodal position ranged from slightly >40 at node 3 to <30 at node 10 (Fig. 1A). In each of the 4 years examined, the most flowers per node were found in the terminal portion of the twig at nodes 1, 2, and 3 and the fewest were near the base of the twig at nodes 9 and 10. At 7 DAFB, abscission had reduced the number of developing fruit drastically (Fig. 1B). All node positions reacted similarly, and two positions are shown for clarity of illustration. Abscission was greatest each of the 4 years at the twig apex. Less than 15% of the original

population remained at 7 DAFB. By 14 DAFB, the population decreased again by half, when about three fruit per node remained, with the lowest population again at the twig apex (Fig. 1B). The fruit population was nearly stable by 21 DAFB, when ≈ 1.5 fruit/node remained. The population had declined to about one fruit per node at 42 DAFB (Fig. 1).

The coefficient of variation was calculated from the number of reproductive units per node. In each of the 4 years of the investigation and at each of the node positions, the lowest coefficient of variation occurred at full bloom, a result indicating that all inflorescences contained about the same number of flowers. From a coefficient of variation ≤ 40 at full bloom, this component increased gradually to its highest value at 42 DAFB (Fig. 2). In all 4 years, the highest coefficient of variation was at the twig apex at nodes 1 through 4 (Fig. 2). In each of the years measured, minimal change in coefficient of variation occurred for a given number of reproductive units beyond 7 DAFB.

The percentage of variance was calculated for nodes, twigs, and trees. Minimal variance was found for twigs and trees, whereas most of the variance was found at the nodes. Percentage of variance at node 5 and grouped nodes 6 through 8, 5 through 8, and 4 through 10 were compared (Table 1). At 0 or 42 DAFB, the percentage of variance at node 5 was similar to that of the grouped nodes.

The magnitude of the labor needed to conduct olive flower and fruiting experiments is revealed in these investigations. Selecting four twigs per tree, each having 10 nodes, with a total of 10 trees resulted in flower counts $\geq 16,000$ at full bloom. This increased to $>24,000$ flowers with six twigs per tree. Thus, with six twigs as the replication for the control, then each treatment for comparison is a multiple thereof; e.g., with four treatments, the flower count would be 96,000. The purpose of our investigation was to discover a method for

Fig. 1. Number of reproductive units (flowers or fruit) per node: (A) comparison at 0 and 42 days after full bloom at each node; (B) comparison at nodes 3 and 9 at each counting time. Average of 4 years of data.

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Fig. 2. Coefficients of variation for the number of reproductive units (flowers or fruit) per node. Average of 4 years of data.

Table 1. Variance (percent) for single- and multiple-node positions compared each of 4 years at 0 and 42 days after full bloom (DAFB).

Node no.	Variance (%)							
	0 DAFB				42 DAFB			
	1989	1990	1991	1992	1989	1990	1991	1992
5	57.9	36.4	36.9	33.5	80.7	71.6	82.0	80.3
6-8	53.8	35.2	30.8	32.9	83.4	71.2	76.5	75.4
5-8	57.9	36.4	34.7	33.5	80.7	71.6	79.6	80.3
4-10	64.4	39.0	38.4	35.1	77.1	73.5	85.3	83.1

reducing flower counting drudgery in the experimental plan, and we also hoped to reduce the mammoth coefficient of variation.

Some useful labor-saving methods and improvements inaccuracy have emerged from our research. For flower and fruit development experiments, careful twig selection decreases the magnitude of variation. These twigs should be spaced around trees whose flower density is near maximum. Each experimental twig must have only two inflorescences per node on 10 successive nodes. Starting from the apex, nodes 1 through 4 should not be used, as lower coefficients of variation are found at nodes 5 through 10. Twigs with more than 10 nodes can be used, but we have found that the most basal nodes (11 and beyond), similar to the apical nodes, have the largest variation. The latter finding is also evident when extrapolating the data from Fouad et al. (1986). Although we did not measure twig exposure to light or twig vigor, we contend that selected twigs should be exposed to light and have at least 2 cm of internode growth. Twigs of lower vigor and in low-light positions will likely result in a higher coefficient of variation.

The basis for nodes 1 through 4 to have higher coefficients of variation than at other nodal positions is not clear. Clearly, there are few perfect flowers at the apical posi-

tions (one of the reasons for the early massive abscission shown in Fig. 1); however, only 1 perfect flower per inflorescence is necessary for fruiting. The lower final fruit population at the apex may be a problem of incomplete flower bud development taking place at the close of the growing season; this event would, in part, explain why fewer perfect flowers are found at the twig apex.

Calculating the percentage of variance for nodes 4 through 10 and comparing the components among nodes, twigs, and trees over the four years revealed that experimental error accounted for 76%, 59%, 75%, and 74% of the error. The next largest error source was for nodes. Increasing the number of nodes from seven to 14 reduced the standard error by 12%, increasing the number of twigs per tree from eight to 20 reduced the standard error by 17%, but increasing the number of trees from eight to 20 reduced the standard error by 36%. A final important feature is that, by using a single node (e.g., node 5), a similar percentage of variance was found as when nodes were grouped. The latter method will reduce labor requirements greatly.

These data show that the coefficient of variation increases in the flower-fruit population as time passes from full bloom until 42 DAFB. This change occurs because the popu-

lation decreases to a low point during that time and can be 0 to a few fruit per node by 42 DAFB. A single comparison at 14 and 28 DAFB for any year will illustrate how the low population at those times increases the coefficient of variation. At 14 DAFB, there are $\approx 5 \pm 1$ fruit/node and at 28 DAFB 1.5 ± 1 fruit/node. In this comparison, the standard error is the same, but the coefficient of variation is 20% and 67%, respectively. In another comparison, the difference was even greater at 28 DAFB, with 1 ± 1 fruit/node; this difference resulted in a coefficient of variation of 200.

Another labor-saving method emerges from these data. Full-bloom flower counts are not necessary to ensure a reliable experimental field plan. Our data and that of others (Fouad et al., 1986; Rallo and Fernandez-Escobar, 1985; Rallo et al., 1981) show that, among many varieties, final fruit count per node is similar. Thus, by judiciously selecting experimental twigs from trees with dense bloom, about one fruit per node can be expected.

For field experiments involving fruit set, we suggest selecting four sun-exposed twigs spaced around each tree, tagging node 5 and using ≥ 10 trees/treatment to achieve low variation.

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