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A reevaluation of alternate bearing in pistachio

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ABSTRACT

Studies documenting pistachio fruiting patterns (*Pistacia vera* L.) conclude this species shows evidence of alternate bearing; fruit production fluctuates between an 'on' year of high yields and an 'off' year of low yields. However, alternate bearing in pistachio has never been statistically tested. We collected yields of 4288 trees over six years to test for alternate bearing in a mature orchard planted with 'Kerman' scions grafted onto *P. integerrima* rootstock – the combination planted on the bulk of the acreage in California. A majority (58%) of the trees exhibited statistically significant alternate bearing patterns. Yet 42% showed yield patterns that were indistinguishable from random fluctuations, the standard measure of alternate bearing (I) was only modest (mean $I = 0.48$), and I varied considerably among trees (range = 0.04–0.83). These findings support that pistachio shows alternate bearing behavior but suggest alternate bearing is less ubiquitous and fruiting patterns are more complex than previously suspected. The presence of such a diversity of yield dynamics creates considerable challenges for crop management and research.

1. Introduction

Many economically important species of fruit crops, including pistachio, have been suggested to alternate bear (Monselise and Goldschmidt, 1982); that is, a tree's fruit production fluctuates between 'on' years of high yields and 'off' years of low yields. These cropping patterns result in surpluses and deficits in production and affect many facets of crop management including: price, marketing, quality, demand for labor (Chung et al., 1995; Kallsen et al., 2007), nutrient uptake (Picchioni et al., 1997; Rosecrance et al., 1998), and pruning (Ferguson et al., 1995). A greater knowledge of fruiting patterns is needed to optimize crop production.

The fundamental hypothesis underlying alternate bearing behavior is that yield in one year affects yield in the subsequent year. To quantify the extent to which this serial dependence takes place, Hoblyn et al. (1936) recommends the alternate bearing index (I):

$$I = \frac{\sum_{t=2}^{n}(|y_t - y_{t-1}|)/(y_t + y_{t-1})}{n-1}$$

where I equals the sum of the absolute value of the difference in yields between two successive years t and $t-1$, scaled by the sum of the yields over these two years; and then standardized over the total number of years in the time series, n, minus one. I varies between 0 and 1, with $I = 0$ representing no alternate bearing behavior and $I = 1$ corresponding to strict alternate bearing behavior. Hoblyn's statistic has become the accepted standard for describing alternate bearing. Yet using I to quantify the extent to which a tree alternate bears can be misleading because this statistic is biased. I is sensitive to the tree's total fruit production (Huff, 2001). Therefore, the accepted interpretation of I as a measure of the magnitude of alternate bearing is questionable and the comparative application of I among trees, orchards, or studies may be unsound. To address this issue, Huff (2001) proposes a significance test of I but it has been used only once – with citrus (Smith et al., 2004).

Studies documenting pistachio fruiting patterns conclude that this species demonstrates alternate bearing. Across a diverse range of pistachio species and cultivars, I ranges between 0.1 and 0.8 (Esmailpour, 2005). For the widely planted *Pistacia vera* 'Kerman' and 'Peters' orchards of California, I ranges between 0.67 and 0.76 (Johnson and Weinbaum, 1987; Ferguson et al., 2002; Kallsen et al., 2007) and yields fluctuate by as much as an order of magnitude between on-years and off-years (NASS, 2003). While these results suggest pistachio is alternate bearing, no study to date has statistically tested alternate bearing in this species.

Numerous logistical and biological factors potentially confound research on alternate bearing. It is challenging to collect yields of entire trees over long periods of time and thus most studies are restricted to four years and a limited number of trees are sampled (Crane and Iwakiri, 1986; Johnson and Weinbaum, 1987; Esmailpour, 2005), or data are aggregated across blocks of trees (Ferguson et al., 1995). Yield, however, can vary considerably

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among trees (Johnson and Weinbaum, 1987) and a tree's maturity (Obeso, 2002), environmental factors (Monselise and Goldschmidt, 1982), and genetic dissimilarity among trees (Wood, 1989; Garner and Lovatt, 2008) have all been demonstrated to affect fruiting patterns. Thus, research performed over a few years with few replications on young trees may not capture the true behavior of the species.

The absence of statistical testing, the bias of *I*, and the many potential confounding factors raise questions about the predominance of alternate bearing in pistachio. Therefore, the objective of this study was to statistically test alternate bearing using a large number (4288) of trees with six years of production data and determine the yield behavior of a mature pistachio orchard of the cultivar 'Kerman' grafted onto *P. integerrima*. Since alternate bearing is based upon the premise that deviation of yields from the mean are not random in time, we tested the null hypothesis that yields were random patterns against the alternative hypothesis that yield was dependent on yield the previous year, alternate bearing.

2. Materials and methods

2.1. Experimental site

The experimental orchard consisted of 32.5 hectares in the center of a larger orchard, located near Kettlemen City, Kings County, CA (35°86′N, 119°87′W). The orchard reached peak production prior to the start of the experiment; data collection began when trees were 19 years old. The field site was planted at a 24:1 female to male ratio. Female trees were the scion cv. Kerman, while male trees were scion cv. Peters, both grafted onto seedling *P. integerrima*, known as Pioneer Gold I (PGI), rootstock. The 'Kerman'/PGI combination is the most widely planted in California and is grown on 60% of the acreage (CASS, 2003). The grower controlled production practices reflected industry best management for irrigation, fertilization, pest and disease control. There were no apparent abiotic or biotic stresses. The field was located entirely within a single soil type, Panoche Series fine-loam, with minimal gradation.

2.2. Yield data collection

Individual tree yields were determined on 4288 trees for six years in a single, highly productive orchard. We collected tree yields with a precision harvester, The Pistachio Yield Monitor (Brown et al., 2007). It was developed by UC Davis in collaboration with Paramount Farming Company (Lost Hills, California). In short, a standard commercial pistachio harvester was retrofitted with a weighing system that allowed tree yields to be discretely determined. In-field calibration and verification of the weighing system was checked against a scale by hand for weights ranging from 3 kg to 63.5 kg. Tree location in the field was simultaneously determined with a number of redundant mechanisms including differential GPS for row identification, physical markings, and an odometric encoder wheel.

Yield measurements were taken in-field and represent pre-processed wet weights. We did not exclude nonsplit or blank nuts. The rationale for this was that both split and a nonsplit fruit represent a near identical resource demand and therefore, should be included in any resource allocation analysis, statistical or biological, of fruiting patterns. Furthermore, the contribution to yield of blank nuts would have limited biological or statistical significance. As a percentage of total tree yield, the relative weight of blank nuts during off-years would be less than during on-years because of the substantially less total weight, even though trees produce a greater percentage of blanks at this time. When contrasted with data based on commercial edible yields, the use of pre-processed in-shell weights better represents true biological yield and is the most appropriate measure of alternate bearing.

2.3. Statistical analysis

The alternate bearing index, *I*, of individual trees was tested for significance by data resampling, as proposed by Huff (2001). This resampling process estimated a distribution of *I* for each individual tree compared to the alternate bearing index calculated from measured tree yields. Each distribution was based upon calculating *I* from a random re-ordering of the respective tree's yield 500 times. In other words, for each tree the yield time series (2002–2007) was sampled without replacement six times randomly to form a new randomly ordered yield time series, specific for that individual tree. We then calculated *I* from the new time series. For each individual tree, this process was repeated 500 times. These simulated 500 *I* values form a distribution of alternate bearing indices based on random re-ordering of yields of the individual tree. This distribution was then used to test the null hypothesis that yield patterns were random against the alternative hypothesis that yields were not random (alternate bearing). The actual alternate bearing index for each tree was considered significant if it was more extreme than 95% of the values of the resampled distribution.

In addition, we calculated the alternate bearing index for each individual tree based on only four years, 2002–2005 and 2004–2007, to simulate the results we would have obtained if we had collected data over two bearing cycles.

We performed all statistical analysis using the program R (R Development Core Team, 2006).

3. Results

Yields among years and within years were variable (Table 1). Mean yields in the two highest producing years, 2005 and 2007, were three times greater than mean yields in the two lowest producing years, 2004 and 2006. Deviations from mean yield were relatively largest during less productive years.

A clear alternating pattern was not consistently present in this orchard. In the first three years mean yield decreased between both the first and second and second and third years of the study, while in the second three-year period a more pronounced orchard level alternate bearing was exhibited. Based upon the procedures of Huff (2001), (2), 502 trees demonstrated significant alternate bearing ($p < 0.05$), while 1786 trees did not.

The value of the alternate bearing index *I* depended on the number of bearing cycles used to calculate it. Over the six years, the individual tree alternate bearing index was 0.48 ± 0.14 (mean ± sd) and ranged from 0.04 to 0.83. The mean individual tree alternate

Table 1
Productivity and variability of yields for 4288 individual pistachio trees.

Fruit production (tree^{-1})	Year						
	2002	2003	2004	2005	2006	2007	Mean
Mean (kg)	40.2	32.7	22.2	42. 9	6.9	48.1	32.1
Standard deviation	9.4	9.4	12.7	11.6	4.9	8.4	9.4