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Time series application for quantification of Alternate Bearing Intensity (ABI) in mango (*Mangifera indica*) cv Langra

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ABSTRACT

The alternate bearing intensity (ABI) in mango (*Mangifera indica* L.) cv Langra, a distinct alternate bearer was statistically appraised through application of time series methods by subjecting yield data of one hundred trees growing under uniform cultural conditions at Central Institute for Subtropical Horticulture, Lucknow, Uttar Pradesh, over five years (2007-11). They were considered as 100 time series of short duration and arranged in 100 × 5 matrix for appraisal. The lag-one autocorrelation was calculated from the residual yield data obtained by removing year and tree effects. The quantification of ABI separately also by applying 'I' value and time series methods to the same set of data clearly brought out the limitations of 'I' value quantifying ABI as a descriptive statistic that sans inference test for significance thus, accounted for less than 60 percent of actuality *vis a vis* time series, attributable due to eliminating of trends generating a series of non-negative values by ignoring asymmetrical phase changes, an exclusive nature of a crop like mango. In the present analysis, higher precision of time series approach in quantification of ABI is largely by taking into account, the yield residuals and hence was found more efficient as compared to 'I' value. The autocorrelation was found negative and highly significant implying, distinctiveness in manifestation of alternate bearing rhythm. This analysis besides confirming strong and distinct alternate bearing tendency of Langra trees, provides a precise approach for quantification of ABI. The results of the present investigation could eventually lead to development of predictive models of yield in cv Langra as a component of decision support to empower growers for optimizing inputs management for sustained Langra mango tree health. In this paper, we present a simple but precise methodology to quantify alternate bearing intensity in Langra through autocorrelations that take into account unexplained components of alternate bearing phenomena.

Key words : Alternate bearing (AB), Alternate bearing intensity (ABI), *Mangifera indica*, Time series, Yield residuals, Yield prediction models.

Alternate bearing (AB), synonymously termed biennial bearing is a phenomenon that refers to the tendency of a fruit tree to produce a high yield ('On' year) followed by a low yield ('Off' year). This results in the operation of fundamental hypothesis that yield in one year affects yield in the subsequent year, however necessitating the need to quantify the extent to which this serial dependence takes place (Rosenstock *et al.* 2010). Evaluation of Alternate Bearing Intensity (ABI) has been a matter of intense deliberations by many researchers of fruit crops in the recent past as it has severe negative economic impacts on the commercial mango industry. The occurrence of AB is also highly variable among the mango (*Mangifera indica* L.) varieties, across mango producing agro-ecologies impacted by diverse factors. Different researchers have attempted to address this problem from many angles in the past but without appreciable success (Ravishankar 1987, Chacko 1991). However, a chemical manipulation of this problem has been successfully demonstrated subsequently (Singh and Singh 2003) which however could have serious consequences on tree and environment health if pursued on a continuum besides posing the problem of consistency of results obtained across varieties and geographical areas. Despite existence of voluminous understanding of AB phenomenon in mango, no study till date statistically outlines AB in this species that captures the true behavior of the crop/variety. There exists extensive biological/horticultural literature on AB, although they are crop-specific with different issues dealt relevant for the respective crops. These broadly though highlighted different explained and unexplained factors of AB, many of them however, failed to come to grips with the precise approaches for quantification of ABI including mango. Evaluation of ABI itself has been a matter of considerable interest to

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researchers of perennial fruit trees for quite sometime. Based upon exhaustive survey of literature available on the subject, we strongly believe that the precise evaluation of degree of AB has either been under estimated or seriously misestimated in majority of the studies. For, Example, Hoblyn *et al*. (1936) proposed two parameters 'B' and 'I' to quantify alternate bearing tendency, with 'B' expressing bienniality as a percentage of occasions (pairs of successive years) where each trend of increase or decrease in yield are reversed in calculations. This was subsequently re-evaluated by Pearce and Doberšek-Urbanc (1967) who concluded that 'B' is very insensitive, as alternation of positive and negative signs can continue by chance for eight years so that cent per cent value would become significant at the 5% level only if obtained after 9 consecutive years. Full bienniality as per this approach, however may not accrue in actuality due to its very nature of simplicity, parameters used for calculation of bienniality over long period of years. The other index 'I' is a measure of intensity of deviation in yield in successive years which is estimated by adopting the procedure outlined by Pearce and Doberšek-Urbanc (1967).

The 'I' value was applied for the first time in mango to quantify ABI following application of different treatments (Ravishankar 1987) in Alphonso mango by applying the method of Pearce and Doberšek-Urbanc (1967). Huff (2001) reported that I =1, shows an extreme alternate bearing in which no crop is produced in "Off" years and I =0, shows an absence of influence between successive crops, rather than a complete absence of variation. It is opined that 'I', a descriptive statistic has a limited value in the absence of a test for significance (Huff 2001).

The absence of statistical testing, the long prevailing bias of 'I', the differential behavior of mango varieties across agro-ecologies/years generate questions about the predominance of AB problem in mango. The primary objective of this study was therefore, to statistically test AB occurrence using one hundred physiologically matured twenty five years old Langra mango trees grafted on seedling rootstock with five years of production data under uniform cultural conditions. The study tested the null hypothesis that yields were random patterns against the alternative hypothesis that yield of subsequent year is dependent on yield of previous year, a long standing premise to define AB phenomenon in mango. It may be the case that if yield residuals are positive and negative, then calculation of 'I' may provide erroneous values and under such situations, autocorrelation method could be a preferred option as it explains how much of the AB fluctuation is due to missing variables. The autocorrelation was a preferred requirement as reported by Huff (2001) and Rosentock *et al.* (2010) through which future studies on alternation of fruiting behavior must be rigorously appraised. Attempt was, therefore, made in the present analysis for understanding the alternate bearing intensity in mango cv Langra through the application of autocorrelation approach by adopting time series methods which could be very useful for documenting and predicting the magnitude of yield variations across years based on historical yield data.

MATERIALS AND METHODS

In the present study data on yield (kg/tree) of one hundred, twenty five years old cv. Langra mango trees, spaced at 10 × 10 m at Central Institute for Subtropical Horticulture, Lucknow in the subtropical zone of India growing under uniform cultural conditions were sampled consecutively for five years (2007-11). The data were arranged in matrix of order 100 × 5 and log transformation of data was undertaken to stabilize the variations in yields. All statistical analysis was performed using software SAS 9.3.The usual method of calculation of ABI is as follows:

$$I = (1/n)\ \{\sum_{i=2}^{n} |y_i - y_{i-1}|/(y_i + y_{i-1})\} \qquad \ldots\ldots\ldots (1)$$

(Hoblyn *et al.* 1936)

where I = the alternate bearing index, n = number of years for which the alternate bearing index is calculated and y_i = yield in the i^{th} year with y_i being the first year in which harvest occurred. 'I' may vary between 0 (no alternate bearing) and 1 (complete alternate bearing).

In this study however, a two-way multiplicative model was assumed by arranging yields of one hundred trees over five years in a matrix of order 100 × 5.

$$y_{ij'} = \mu'\ t_{i'}\ s_{j'}\ \exp\,(e_{ij}) \qquad \ldots\ldots\ldots\ldots (2)$$

where y_{ij} is the yield of the i^{th} tree (i = 1, 2,…100) in the j^{th} year (j =1, 2, …..5), μì: a common effect, $t_{i'}$: is i^{th} tree effect, s_j': the j^{th} year effect (seasonal effect) and exp (e_{ij}) is the residual error.

We have considered in the present analysis, a multiplicative rather than an additive model as the year effects usually affects in a multiplicative way, as in unfavorable years the differences in tree effects are found smaller and in favorable years they become larger. This is similar to seasonal effects in time series which is usually considered to be of multiplicative nature (Box, Jenkins and Reinsel 1996). Here log transformation of yield data provided 100 × 5 matrix and we have considered e_{ij} as normally distributed with mean zero and variance σ^2. Thus, taking logarithm of y_{ij}', obtained an additive model in log y_{ij}',

$$y_{ij} = \mu + t_i + s_j + e_{ij} \qquad \ldots\ldots\ldots\ldots (3)$$

where, $y_{ij} = \log\,(y_{ij}')$, $\mu = \log\,(\mu')$, $t_i = \log(t_i')$ and $s_j = \log(s_j')$.

This is the usual two–way additive model. Usually, the years effects s_j is a dominating factor. Logarithmic transformation not only rendered the model additive but made the variance σ^2 constant for all i&j, where σ^2 = Var (e_{ij}). In the foregoing analysis, it is very important to remove the trends and years effects s_j before considering the lag-one autocorrelation among y_{ij}'s. In case it is negative, then it shows an alternating tendency of yield from a mango tree.

For this, log transformed data of yield vs years in every plant over years was calculated resulting in log yield matrix of order 100 × 5. We further, conducted two way analysis of variance for log yield matrix of order 100 × 5 and obtained '*residuals*' (r_{ij}) after removing the effect of general mean μ, tree effects t_i and year effects s_j from y_{ij} .

$$r_{ij} = y_{ij} - \hat{\mu} - \hat{t}_i - \hat{s}_j, \qquad \text{............ (4)}$$

where, $\hat{\mu} = \bar{y}_{..}, \quad \hat{t}_i = \bar{y}_{i.} - \bar{y}_{..}, \quad \hat{s}_j = \bar{y}_{.j} - \bar{y}_{..}$

This gives r_{ij}'s which are not only free from tree effects and year effects but also free from any trend effects which may be there across years. This is not so with the indices 'B' and 'I' as both get affected by trend effects. The length of each time series in the present analysis however, is too small as there were only five yearly observations per tree. Hence, average autocorrelation was calculated by pooling of data over all the one hundred trees. The present analysis has a strong assumption that trees have same population autocorrelation of lag-one denoted by ρ_1. This assumption has a strong justification as all the trees belonged to the same variety and age and sampled from the the plot receiving uniform cultural attention across the years though some trees may have manifested different reproductive phases ('Off' and 'On' years) during the period of study. Autocorrelation ρ_1 is defined as

$$\rho_1 = E\,(r_{ij} - \bar{r}_{i.})(r_{ij-1} - \bar{r}_{i.})/E(y_{ij} - \bar{r}_i)^2 \qquad \text{............ (5)}$$

Its estimate for ith tree is given by $\hat{\rho}_{1i}$

$$\hat{\rho}_{1i} = \sum_{j=2}^{5}\{(r_{ij} - \bar{r}_{i.})\,(r_{ij-1} - \bar{r}_{i.})/4\}/\sum_{j=2}^{5}\{(r_{ij} - \bar{r}_{i.})^2/5\} \qquad \text{.......... (6)}$$

The pooled estimates from all one hundred trees of ρ_1 is given by

$$\hat{\rho}_{1i} = \sum_{j=1}^{100}\sum_{j=2}^{5}\{(r_{ij} - \bar{r}_{i.})\,(r_{ij-1} - \bar{r}_{i.})/4\}/\sum_{j=1}^{100}\sum_{j=2}^{5}\{(r_{ij} - \bar{r}_{i.})^2/5\} \qquad \text{.... (7)}$$

In case all observations are independent and identically distributed with same mean and same variance then (Kendall 1976)

$$E\,(\hat{\rho}_{1i}) = -\{1/(n-1)\}$$

$$Var\,(\hat{\rho}_{1i}) = \{(n-2)^2/(n-1)^3\}$$

where n is the length of the time series. Here $n = 5$,

$$E\,(\hat{\rho}_{1i}) = -\,¼ = -0.25$$

$$Var\,(\hat{\rho}_{1i}) = 0.1406$$

Thus,

$$E(\hat{\rho}_{1i}) = -\,0.25$$

$$Var\,(\hat{\rho}_1) = \{(n-2)^2/(n-1)^3\}/100 = 0.0014$$

$$S\,E\,(\hat{\rho}_1) = \surd(Var\,(\hat{\rho}_{1i}) = 0.0375$$

RESULTS AND DISCUSSION

The tree yields among and within years varied. The mean yields of the three highest producing years, 2008, 2009 and 2011 were higher than the mean yields of the two lowest producing years, 2007 and 2010 (Table1). Deviations from the mean yield were low during less producing years suggesting a multiplicative model (Equation 2) thus a clear alternating bearing tendency pattern emerged in this variety. This tendency clearly indicated occurrence of a trend of increase/decrease (Fig 1). Alternate bearing tendency effects observed this way are also found confounded with the year (season) effects which are usually dominating. This trend pattern illustrated and corroborated the view that alternate bearing tendency is not accurately described as a single state ('On' or 'Off') probably due to unexplained factors (Roy and Perloff 1985). Unless alternate bearing tendency is effectively described and quantified, it becomes difficult to examine the precise cause(s) of alternate bearing (Fig 1). The presence of complex and diverse fruiting patterns, lack of clear cycle of variation between years and large variability among Langra trees create problems for researchers to precisely elucidate the tendency.

Hence for separating the effects by modeling the yield y_{ij} which is combined effects of general yield, year, tree behavior and deviation from them and denoted as '*residuals*' (Fig 2). It can be verified from '*residuals*' that for every tree, time series extracted positive and negative values. Due to being negative values, for every series has a trend of increase and decrease and phase changes are well taken into consideration via autocorrelation approach. For yield data in matrix of order 100 × 5, the error residuals were calculated by applying equation (4), estimates of autocorrelation were obtained by using equation (6). The pooled autocorrelation

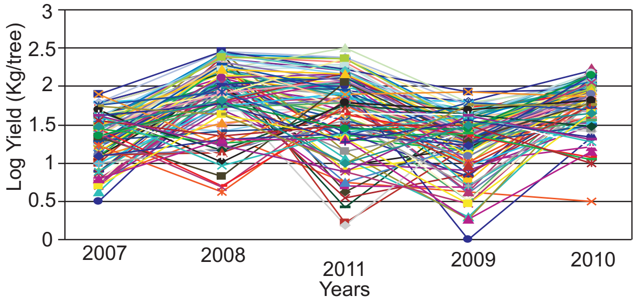

Fig 1 Plot of log yields of one hundred trees of mango cv Langra over five years (2007–11)

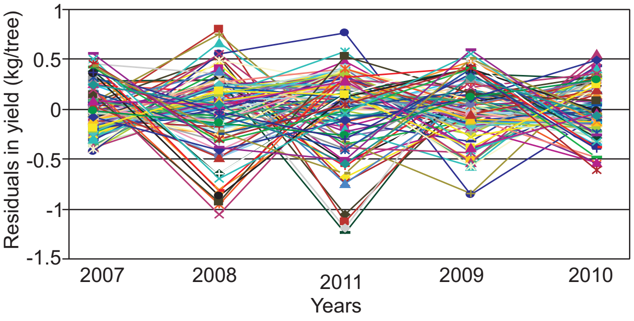

Fig 2 Plot of the residuals of log yields one hundred trees of mango cv Langra over five years (2007-11).

of lag-one was estimated from equation (7) and was extracted as

$$\hat{\rho}_1 = -0.46.$$

Application of equation (1), 'I' value obtained is as below:

$$\hat{I} = 0.186 \text{ (average over trees)}$$

Asymptotic Test

In the present study, asymptotic test was applied as follows

$$H_0: \rho_1 = -0.25 \text{ vs. } H_a: \rho_1 < -0.25$$

Approximate normal test under H0 is given by,

$$Z = \{\hat{\rho}_1 - \rho_1\}/S\,E\,(\hat{\rho}_1) = (-0.46 + 0.25)/0.0375$$
$$= -5.60 \qquad (p < 0.00034)$$

This shows that statistic Z is very highly significant though autocorrelation value of –0.46 is only moderate but the above test showed that it is definitely less than –0.25, which is its expected value, when there is no alternate bearing tendency. In case series were large, i.e. large '*n*', then the population autocorrelation ρ_1 would have been zero. The null autocorrelation of -0.25 is obtained due to subtraction of row mean for calculations of autocorrelation r_{1i}. This shows a very high negative autocorrelation (–0.46) between the yields of successive years.

By application of Equation (1), the value of 'I' = 0.186 was obtained. This value of 'I' is low and indicated less bienniality in mango cultivar Langra under the study which is at strong variance with the actuality. The low value of 'I' obtained may be due to that the hundred tree log yield varied from value 0 (2010) to 2.51 (2009) (Fig 1) and '*residual'* in log yield of hundred trees varied from -1.19 (2009) to 0.8 (2008) (Fig 2). It is clear from the Fig 2 that 100 trees had both positive and negative yield '*residuals'*. The computation of I (values 0 to 1) ignores the negative deviations and considers only positive deviations and the present data contained both negative and positive deviations (Fig 2), therefore quantification of ABI through application of 'I' lead to such wrong inferences as low bienniality in case of Langra which otherwise manifests strict bienniality thus implying that 'I' does not extract the actuality of bearing tendency. 'I' as a descriptive statistic lacking inference test ignored asymmetrical phase changes and thus lead to wrong conclusion. While subjecting the same data to time series application, autocorrelation value as –0.46 obtained which is negatively significant as tested by application of Z-test, that considered positive and negative deviations, computed from yield '*residual'* after eliminating year and tree effects clearly extracted 'On' and 'Off' year of bearing behavior in this cultivar. The negative significant value obtained, further validated the distinct AB phenomenon of this cultivar. Similar views were documented by the works of Pearce and Doberšek-Urbank (1967) who reported that 'I' is relatively insensitive to trends as compared to autocorrelation and Huff (2001) in his studies on biennial bearing in oranges using data resampling in calculation of 'I' observed that the technique is somewhat insensitive to phase changes.

Monte – Carlo (M-C)Test

The '*residual'* yields of one hundred Langra trees over five years (2007-11) represented a 100 time series of short duration of five years and all the time series had variations in '*residuals'* ranging from –1.24 to 0.80 (Fig 2). These time series have lag-one pooled autocorrelation value as –0.46. Now question arises what will be the behavior of these one hundred time series when population autocorrelation is zero. In order to study this behavior, Monte-Carlo test was applied. The distribution of autocorrelations for 1000 set of data was obtained by applying this test assuming five years as five variables and hundred trees as one hundred value assumed by each of the five variables. One thousand data set of five variate independent (year-wise yield data) normal with mean zero and variance one {N(0,1)} were generated and for each data set, pooled autocorrelation of lag-one was estimated by applying equation (7).

Pooled autocorrelation of lag-one thus obtained was plotted. (Fig 3) which showed a good fit of normal distribution with mean –0.258 and standard deviation 0.061. In this simulation effort, there is no value below –0.46 which was obtained from the data on yield (kg/tree). This corroborated that the value of autocorrelation (–0.46) is highly significant. Thus Monte-Carlo (M-C) test agreed well with the asymptotic test implying that it could be applied very well to large set of data as well. Nevertheless, majority of the studies barring few (Ravishankar 1987 and Singh *et al.* 2011) application of 'I' value to quantify the alternate bearing intensity was in temperate fruit crops which are not well known for their distinct alternate bearing tendency while it avails no test of significance, thus the accepted interpretation of 'I' as a measure of the magnitude of alternate bearing tendency for a crop becomes questionable and the comparative application of 'I' among trees, orchards or studies may be misleading. Autocorrelation as applied in the present analysis has asymptotic test of significance and Monte-Carlo (M-C) test

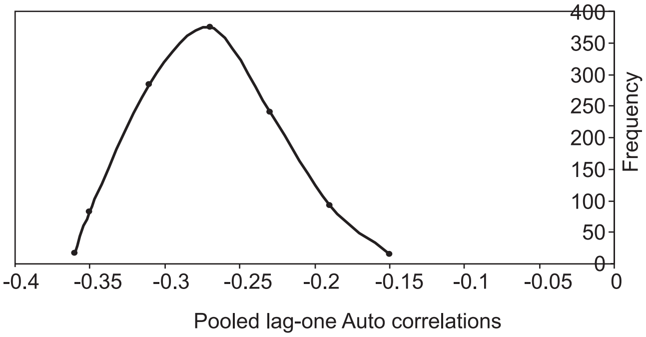

Fig. 3 Plot of the pooled autocorrelations of lag-one of one hundred trees of mango cv Langra over five years (2007-11) from 1000 simulated data.

Table 1 The analysis of variance for log-yield of one hundred trees of mango cv Langra over five years (2007-11).

Source of variation	Degree of freedom	Sum of square	Mean square
Trees	99	30.47	0.30
Years	4	61.67	15.41
Error	396	61.27	0.15
Total	499	153.41	

Table 2 Mean yield

Years	2007	2008	2009	2010	2011
Mean yield (kg/tree)	26.3	107.3	73.6	25.9	79.0
S E of Mean (kg)	1.68	7.63	6.54	1.84	4.13

for further validating the findings of autocorrelation for appraisal of alternate bearing intensity (ABI) in mango cv Langra. Such inference is not possible through the application of 'I' value. Similar views are held by Huff (2001), Rosenstock *et al.* (2010) and Singh *et al.* (2011) in his study and suggested that rigorous application of statistics is necessary to extract the actuality of alternate bearing intensity (ABI).

The tree vs year analysis of yield data provided a 100 × 5 matrix for yield residuals and further analysis indicated that pooled autocorrelation of lag-one of hundred trees over five years was negative (–0.46) and highly significant at five percent level of significance. This autocorrelation has been obtained after adjusting for year (seasonal) and tree effects. This showed a very high negative autocorrelation between the yields of mango cv Langra over successive years. The significance of autocorrelation further tested by asymptotic test and Monte-Carlo test further endorses the usefulness of the time series approach in elucidating that cv Langra possessed a strong alternate bearing tendency which otherwise could not be precisely appraised through application of 'I' value.

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