ALTERNATE BEARING IN CITRUS

Alternate bearing is a widespread physiological phenomenon affecting crop load and therefore productivity, and occurs in both deciduous and evergreen fruit trees. The current status of what is known about alternate bearing in citrus and practical ways to reduce the impact of this physiological problem are presented.

1 Introduction

Alternate bearing (sometimes referred to as biennial bearing) is the tendency of a fruit tree to produce a heavy crop in one year ("on"-year) followed by a very light crop ("off"-year) in the following year (Photo 1, Figure 1). In some cases, however, an "off"-year can be followed by another "off"-year, which is called irregular bearing, and which occurs when a tree produces flowers and fruit in an irregular intensity with one or more seasons of low fruit yields following an "on"-year, or vice versa. Irregular bearing is therefore different to alternate bearing which is more common in citrus and can occur on an individual shoot-level, on a branch or tree, or across an entire production region.

Alternate bearing can be initiated either by an "on"-year of excessive cropping or occasionally by low cropping due to environmental conditions during flowering and/or fruit set. Typically in citrus, the primary trigger that initiates alternate bearing is excessive crop load which is then followed by very low flowering levels and consequently an "off"-year. Production practises can perpetuate or reduce further alternate bearing.

Alternate bearing occurs in any climatic region regardless of growing conditions. Young trees with higher vegetative vigour typically exhibit less alternate bearing than older trees.

Alternate bearing is a major problem in citrus production worldwide, especially among mandarin cultivars. Marketing and logistical issues result from alternate bearing; for example, "on"-trees normally produce a large amount of small fruit and "off"-trees produce small amounts of large, rough and unattractive fruit. These variations in fruit quality make cultural practices such as irrigation, fertilisation and the application of plant growth regulators more complicated and may cause significant financial losses.

Photo 1. *A typical example of alternate bearing; 'Valencia' orange with an "on"-crop and light blossom (top) followed by an "off"-crop and heavy blossom (bottom). Note the yellow leaves on the tree with an "off"-crop.*

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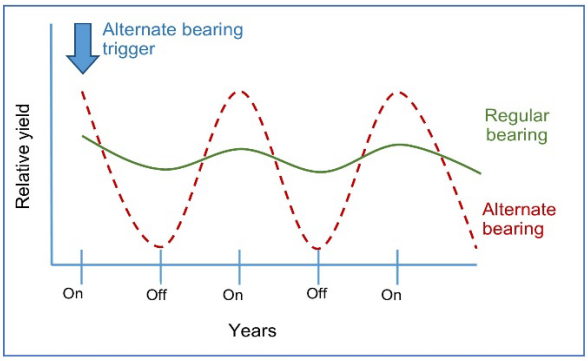

Figure 1. *An illustration of the difference in the cyclic cropping of a regular and an alternating cultivar in response to the conditions, such a very high crop load, triggering alternate bearing.*

2 Cultivar differences

Different citrus cultivars suffer from varying degrees of alternate bearing. In certain citrus cultivars with a high tendency for alternate bearing the phenomenon first seemed to have obvious causal factors, e.g. the level of seediness (cultivars with many seeds per fruit) and time of harvest (cultivars that are harvested late). However, discrepancies have been reported for these factors to be accepted as a rule, since in other cultivars with the same attributes, alternate bearing can be less severe or absent. In a recent poll, South African citrus producers reported alternate bearing as a problem in 'Star Ruby' grapefruit, lemon, mandarin (cvs. Nules Clementine, Nova, Orri, Nadorcott and Mor) and in 'Valencia' sweet orange (cvs. Midknight and Delta). However, on a whole-tree level, alternate bearing is most notable in mandarins as well as tangelos and tangors, and alternate bearing occurs irrespective of seed content.

Alternate bearing has been reported in high seeded mandarin cultivars, viz. 'Murcott', 'Moncada', 'Wilking' and 'Kinnow', as well as in low- to medium-seeded mandarins, e.g. 'Michal', 'Nadorcott', 'Orri', 'Winola', 'Pixie' and 'Ponkan'. Even 'Nadorcott' mandarin produced under protected shade netting structure to prevent cross-pollination, has been shown to develop alternate bearing.

In sweet oranges, alternate bearing has been reported in low-seeded 'Salustiana' and 'Shamouti' sweet orange, as well as in various seeded and seedless 'Valencia' cultivars.

Alternate bearing furthermore occurs in some of the earliest maturing citrus cultivars, as well as in some of the latest maturing cultivars, and therefore, as a whole, appears to manifest irrespective of the timing of a cultivar's period of fruit growth and maturity.

3 Severity of alternate bearing

The alternate bearing index (I) is a measure of an orchard's tendency to produce high and low yields in an alternating cycle over consecutive seasons, and is calculated as the ratio of the difference in yield between two seasons divided by the sum of the yield of the two seasons. The index (I) ranges from 0 to 1; if I=0 there is no alternate bearing and if I=1 there is complete alternate bearing. This index is useful to quantify alternate bearing, and is mainly used for research purposes, e.g. to compare treatments, cultivars, production regions, etc.

Some cultivars are prone to an absolute alternate bearing habit, which involves a total lack of flowering in the "off"-year following a heavy fruit load, rather than excessive flower abscission or poor fruit set. In such a case, the very heavy "on"-crop can cause dieback and eventually the death of the tree.

4 Effect of fruit on vegetative growth

Citrus flowering should not be viewed independently of the previous season's crop and vegetative growth flushes, and is part of a continuous process. Fruit have an inhibitory effect on vegetative shoot growth in the current season, which leads to a reduction in potential flower- and fruit-bearing positions in the following spring. Alternate bearing can therefore be induced by a lack of flowering positions following an "on"-year as a heavy

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crop load results in less and shorter summer shoots. Therefore, "on"-trees have very little or no summer and autumn vegetative flush which reduces the following season's potential to bloom.

The number of new vegetative shoots that develop in "off"-trees in spring and summer is almost double that of "on"-trees. Therefore, fewer new vegetative shoots develop when fruit load is high ("on"-trees), compared to when fruit load is low ("off"-trees). The higher number of new vegetative shoots in "off"-trees affects flowering positively in the subsequent spring due to the higher number of potential flowering sites. In a sparse flowering year, most of the spring flush shoots will be vegetative and the few floral shoots produce only a light crop, which in turn allows the development of many floral shoots in the subsequent spring, resulting in a heavy fruit load. To reduce the severity of alternative bearing it is critical to maintain a balance between vegetative and reproductive growth to obtain a consistent yield, year after year.

5 Effect of fruit on return bloom

Fruit have an obvious effect on the number of flowers and the number of spring shoots in the following season, or so-called return bloom. The lack of flowers in an "off"-year is a characteristic of a season following a heavy fruit load. The presence of a large number of fruit has an inhibitory effect on vegetative shoot growth as well as flower induction and, thus, reduces flower number and yield, rather than by adversely affecting fruit set. The number of flowers and subsequent yield is inversely proportional to the previous season's crop load in terms of the number of fruit produced. Furthermore, the length of time the crop remains on the tree after maturity may increase the severity of alternate bearing.

Excessive fruit therefore limit the number of new vegetative shoots during the "on"-year. In addition, excessive fruit adversely affect the potential of buds to undergo flower induction. Early harvest and fruit thinning, together with judicious pruning, are key techniques to minimise alternate bearing.

6 The role of hormones

The primary triggers in the alternate bearing mechanism in citrus appear to be related to high concentrations of two plant hormones (see Figure 3). ***Firstly***, high concentrations in leaves and buds of the auxin, IAA, (likely transported from fruit) and to a much lesser extent metabolites of abscisic acid (ABA) (presumably transported from stressed roots or directly from fruit) are the cause of reduced new vegetative shoot development during the summer flush leading to a lack of new flowering sites for the following season. "Off" shoots and trees sprout more new vegetative shoots and have lower IAA and ABA concentration in leaves and buds compared with "on" shoots, from which very few new vegetative shoots sprout.

The ***second*** major trigger in alternate bearing is high gibberellin (GA) concentration in leaves and buds during late-autumn and winter (presumably transported from fruit) which inhibits flower induction in fruit bearing shoots in "on"-trees. The concentration of GA is high in fruiting shoots, and experimental treatment of "off"-tree shoots with GA during flower induction was shown to completely inhibit return bloom. May and June are the months when citrus buds are most sensitive to GA, i.e. when maximum inhibition of flowering is obtained by foliar GA application or by GAs from the fruit.

7 The role of carbohydrate reserves and mineral nutrient concentrations

The correlative relationship of carbohydrates (especially starch) with flowering has led researchers and citrus farmers to believe that low carbohydrate availability plays a *direct*

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regulatory role in limiting citrus flower formation and therefore alternate bearing. However, no causal relationship has been established between carbohydrates and alternative bearing. A lack of carbohydrate reserves is not the mechanism causing low flowering levels and hence alternate bearing and flowering is not primarily influenced by carbohydrates, but most likely by a hormonal signal transmitted from the fruit (see Figure 3). Nevertheless, *carbohydrate reserves* are important for flowering in the absence of over-riding hormonal signals and more particularly for *fruit set and fruit growth.*

An indirect role of carbohydrate reserves in alternate bearing exists, where an "on"-crop results in the lack of accumulation and/or depletion of starch in the roots leading to reduced root development, which in turn, may exert to some extent an inhibitory effect on new shoot development and hence flowering. In heavily-fruiting ("on") trees, the fruit load disturbs the balance between root growth and vegetative shoot development. In "on"-trees, root growth is almost completely absent in the late-spring/early-summer period (Figure 2), and the number of new vegetative shoots is half that of "off"-trees.

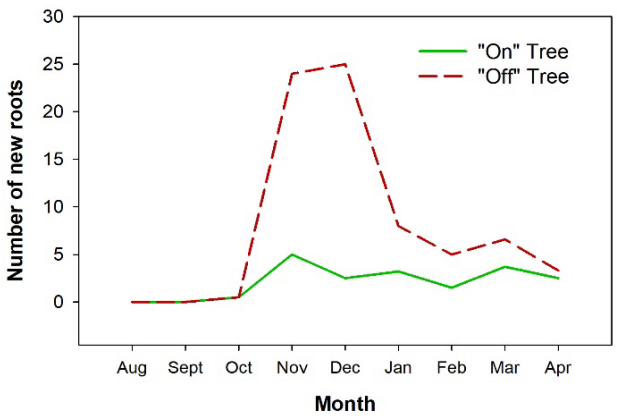

Figure 2. *The effect of fruit load ("on"- vs. "off"-trees) on root growth (Stander et al., 2018).*

In some cases, starch could be depleted to such an extent that trees collapse and die (Smith, 1976). The lack of new shoot production during an "on"-year and the lack of flowering after an "on"-year followed by the eventual decline and death of the tree, have been associated with a complete loss of carbohydrates from the entire tree and with the degeneration of feeder roots.

Crop load has a similar effect on leaf mineral nutrient concentration: excessive fruit load invariably results in lower leaf mineral nutrient concentration, but typically not to the detriment of vegetative shoot flush or flowering, unless N levels are excessively low. In "off"-trees, macro-nutrients can accumulate in leaves to concentrations between 20% and 30% higher than that of "on"-trees, but in most cases, leaf mineral nutrient concentrations show no consistent relationship with return bloom flowering and/or with fruit load in the subsequent season. Therefore, mineral nutrition and imbalances thereof are the result of an established alternate bearing pattern and not the reason for the establishment of alternate bearing. Furthermore, additional fertilisation will have a limited impact within a season on reducing the alternate bearing pattern, although fertilisation can be a useful tool to enhance new shoot development in the late-summer/autumn of an "on"-year (as discussed in more detail in section 8 below).

Separately, a phenomenon associated with alternate bearing that is noteworthy and relates to leaf colour deserves mention. Leaf yellowing or chlorosis in the winter in "off"-trees is not related to mineral nutrient depletion but rather to excessive starch build-up resulting in chlorophyll degradation and apparent yellowing or leaf chlorosis (Stander et al., 2017). Application of soil- or foliar-applied fertilisers at this stage has neither an effect on leaf colour nor on reducing the severity of alternate bearing.

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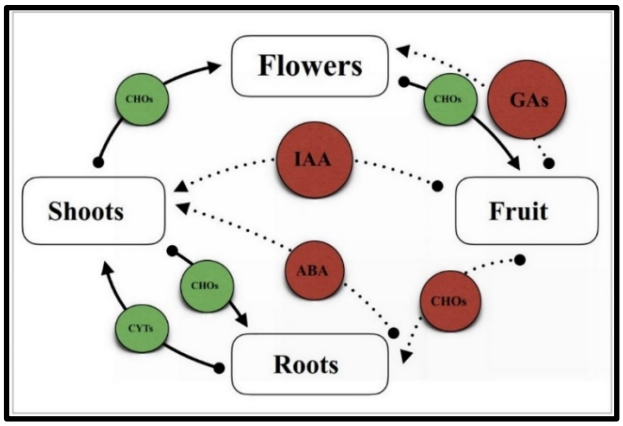

Figure 3. *A schematic model proposed to illustrate the interactions of those factors known to affect alternate bearing in citrus. Solid arrows indicate a positive relationship between the organs, viz. roots, vegetative shoots, flowers and fruit, and dotted arrows indicate a negative relationship. A factor in green is responsible for the endogenous stimulation (promotive action) of the organ to which its arrow is pointed, and a factor in red is responsible for the endogenous inhibition (inhibitive action) of the development of the organ to which its arrow is pointed (Stander, 2018).*

8 Production practices to reduce alternate bearing

Once trees are in an alternate bearing cycle it is difficult to break that cycle without extreme measures. Nevertheless, the severity of alternate bearing can be reduced by decreasing the heavy crop load in the "on"-year or by increasing the light crop in the "off"-year to ensure a moderate and less alternating crop, year after year. In general, the most appropriate option is to reduce the severity of alternative bearing cycle in the "on"-year rather than attempting to do so in the "off"-year (Figure 1). As mentioned previously, the initiation of new bearing shoots during the late summer/autumn and the early harvest of fruit during an "on"-year are the critical requirements to minimise alternate bearing, and consequently the role of fertilisation is key to managing alternate bearing and to reduce the severity of the alternate bearing cycle.

Scenario 1: The previous crop was relatively light ("off"-year) or fruit set is extremely heavy and an **"on"-year is anticipated**:

- During the "on"-year increased nutrient levels (especially N) during the early-summer could help overcome the inhibition of new shoot growth by the high crop load and increase the possibility of late-summer and/or autumn shoot growth.
- Pruning is a well-established cultural practice to minimise alternate bearing. Heavier winter pruning to reduce the high number of bearing positions is used following an "off"-year (when an "on"-year is expected) and when the orchard has a history of alternate bearing. Selective or mechanical pruning during bloom in the spring can also be used as a "thinning" method to reduce flower numbers. Pruning during November followed by early regrowth management provides the best balance between sunlight penetration and the production of new bearing shoots, and also allows selective pruning of shoots with fruitlets in an "on"-year. In alternate bearing trees, summer-pruned trees (during the "on"-year) have more spring flush or vegetative shoots, more nodes per shoot and more growth per shoot, compared to unpruned, heavily-fruiting trees, with the intention of an increased potential for flower development.
- Depending on the fruit set achieved, a heavy "on"-crop can be reduced by fruit thinning. Thinning can be done by hand or with synthetic auxins, Corasil P® (dichlorprop) or Maxim® (3,5,6-TPA) – *refer to product labels and latest MRLs for thinning options and usage restrictions*. Selective hand thinning of the smallest fruit that would not attain acceptable fruit size at harvest increases the value of the remaining crop (size) and reduces alternate bearing, by decreasing

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the intensity of the following "off"-crop (Table 1).

- Reduction of excessive flowering can be achieved by applying gibberellic acid in the winter prior to floral differentiation, but *it is not registered for this use in South Africa* and is not commonly used.
- Harvest the "on"-crop as soon as possible. Early harvest in an "on"-year can play an important role in improving the intensity of the return bloom. In some instances, rows in large orchards harvested last will have a lower flower intensity in the return bloom than the rows where harvesting started and was completed earlier. However, early harvest in an "on"-year is often constrained by smaller fruit size, higher acidity and slow rind colour development.

Scenario 2: The previous crop was heavy ("on"-year) and an **"off"-year is anticipated**:

- During the "off"-year, a more vigorous summer flush typically occurs, therefore irrigation and fertilisation (especially N application) should be adjusted downwards to not stimulate excessive vegetative growth.
- Vigorous summer vegetative growth can be reduced by light summer pruning or so-called "heading" or thinning cuts of vigorous shoots.
- Techniques to increase flowering levels can be used, including controlled water stress for flower induction, late-autumn girdling before the onset of flower induction in late-April/early-May for early cultivars. When trees or branches are girdled, leaf starch concentration increases and often results in increased flower intensity. However, the practise is not always effective in fruiting trees or branches and is not advisable, until first evaluated on a small scale.
- The anticipated light bloom before an "off"-year can be increased by applying pre-bloom foliar urea spray to improve flower intensity.
- Techniques to increase fruit set include gibberellic acid application (on selected cultivars) or girdling of the trunk or individual branches. In an "off"-year special attention should be given to the correct time, concentration and application efficiency of gibberellic acid foliar sprays.

When trying to moderate crop load using these techniques, special care should be taken in a few specific situations:

- Girdling trees with root disease in late-autumn when an "off"-year is expected can lead to very low levels of carbohydrates in the tree and return bloom will be adversely affected. Very low carbohydrate levels in the roots of some mandarin types due to girdling after an "on"-year can predispose trees to root diseases.
- The severity of pruning is also important; pruning too heavily in the winter after an "on"-year before an expected "off"-year can exacerbate alternate bearing.
- Late hanging of fruit to achieve fruit size, rind colour or internal fruit quality requirements can also increase the severity of alternate bearing.

9 Conclusions

Crop load is the most important determinant of return bloom and severity of alternate bearing in citrus. This is due to fruit imparting its influence via hormonal control directly on the formation of new bearing shoots and the inhibition of flower development. Fruit load should therefore be carefully managed for each situation.

In contrast, carbohydrate reserves and mineral nutrient concentration are the result of and not the cause of alternate bearing, although

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incorrect fertilisation can contribute to or exacerbate severe alternate bearing.

Unnecessary nutrient applications during an "off"-year, in addition to the regular fertilisation programme based on standard leaf analysis, is not the reason for a subsequent "on"-year. Carefully consider any adjustments to fertilisation programmes during both "on"- and "off"-years in accordance with the expected crop load, keeping in mind that fertilisation during the current season will influence the result of the current as well as the following season.

Furthermore, a heavy fruit load disturbs vegetative shoot development by restricting root growth through carbohydrate limitation.

On a whole-tree level, alternate bearing seems to be due to the inability of branches to simultaneously support flowering and vegetative shoot growth processes in the same crop-year. It is imperative that this balance between reproductive and vegetative growth be maintained or created to ensure a moderate crop load year after year.

Table 1. The benefits of hand thinning 80 days after full-bloom (24 January) in the summer of an "on"-year on alternate bearing 'Nadorcott' mandarin trees (Adapted from Stander and Cronjé, 2016).

Treatments	Fruit removed (no./tree)	Total weight of removed fruit (kg/tree)	Fruit yield (kg/tree) *Season 1*	Fruit yield (kg/tree) *Season 2*
No thinning (control)	0 [c]	0 [c]	79 [ns]	65 [c]
Hand thinned fruit <20 mm	72 [b]	0.26 [b]	68	93 [b]
Hand thinned fruit <25 mm	151 [a]	0.63 [a]	69	115 [a]

* Means with a different letter within a column differ significantly at the 5% level (least significant difference)
[ns] no significant difference

11 Sources and additional reading

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12 Acknowledgements

The Authors acknowledge the valuable editorial and technical inputs by Dr. Etienne Rabe, Hein Gerber and Ballie Wahl.

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