Journal of Environmental Protection, 2015, 6, 995-1002
Published Online September 2015 in SciRes. http://www.scirp.org/journal/jep
http://dx.doi.org/10.4236/jep.2015.69088

Heavy Metals and the Alternate Bearing Effect in the Date Palm (*Phoenix dactylifera*)

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Received 29 July 2015; accepted 11 September 2015; published 14 September 2015

Abstract

The alternate bearing effect is when plants produce abundant crops of fruit in some years, but sparse yields in others. This review summarises recent studies that suggest a connection between the alternate bearing effect in the date palm, *Phoenix dactylifera*, and the presence of certain chemical elements (mostly metals) in the tree tissues. So far, there is evidence that levels of Ag, B, Ba, Ca, Cd, Cu, Fe, K, La, Mg, Mn, N, Na, Se, Tl, and Zn in the dates and leaflets are affected by the alternate bearing phenomenon. The significance of this work, therefore, emphasises the prospect of using our experimental data to overcome sparse yields, due to the alternate bearing effect, and producing more prolific growth of fruits. The potential agricultural, economic, environmental and health implications of these findings are considered.

Keywords

Alternate Bearing, Date Palm, Chemical Elements, Heavy Metals, Review

1. Introduction

Alternate bearing is when plants produce good crops of fruit in some years ("on" years) followed by poor crops ("off" years) [1]. The date palm is known to experience alternate bearing. Both "on" and "off" palms were considered in this review. Recent evidence suggests that the alternate bearing phenomenon in the date palm affects the distribution of certain elements in the tree.

Alternate bearing in some date cultivars is of growing concern [2]. High yields are associated with low-quality fruits; in other words, small dates with high acidity and tannin, but low sugar content [3]-[6]. It is still unclear how alternate bearing works. In many cases, however, it has been associated with depletion of nutrients after a heavy cropping in the "on" year. In addition, alternate bearing is affected by several factors, including genetic

How to cite this paper: Williams, J.R. and Pillay, A.E. (2015) Heavy Metals and the Alternate Bearing Effect in the Date Palm (*Phoenix dactylifera*). *Journal of Environmental Protection*, **6**, 995-1002. http://dx.doi.org/10.4236/jep.2015.69088

factors, abiotic and biotic influences, and poor culture methods during the "on" year [1] [7].

On several occasions, attempts have been made to reduce the effect of alternate bearing on the date palm through the judicious use of horticultural techniques. Many groups have reported attempts to balance vegetative and reproductive growth [8]-[13]. These studies focused on girdling, nutrition, and thinning of fruits.

Alternate bearing seems more difficult to control and understand in monocotyledonous plants such as the date palm than in dicotyledonous ones. In the latter, some branches could be "on", but others could be "off" [14]-[16]. The alternate bearing effect is known to be controlled by chemicals that regulate growth. Thinning by the use of plant hormones can be used to reduce or prevent biennial bearing [17].

In the Fard cultivar of the date palm, alternate bearing is not in regular annual cycles. The gap between "off" and "on" states is in the range of 1 - 3 years [3] [18]. There will be competition between leaflets and fruit for nutrients and carbohydrates during this time. The fruit and leaf developmental stages would be expected to control movement of these substances [2] [19]-[22]. El Mardi *et al.* [2] investigated the changes in mineral nutrients during fruit developmental stages in relation to alternate bearing in the Fard cultivar of the date palm. Their findings are considered in this review.

There are three fruit growth stages in the Fard cultivar and these occur from May to September. The first stage is known as the Kimri stage. Here, the dates are immature and green in colour. The second stage is called the Bisir stage. The dates are more advanced now and their colouration is yellowish-red. Finally, there is the Rutab stage. By this time, the dates are mature, soft and honey coloured. They are eaten by humans at this stage of their development.

This review will show that the concentrations of certain elements vary in "on" and "off" date palms, suggesting a possible link between the alternate bearing effect and the levels of these chemicals. The elements could be manipulated by the phenomenon.

What follows is an element-by-element summary of published findings of the effect of the alternate bearing phenomenon on the levels of selected chemical elements in the date palm. Generally, six "on" and six "off" Fard cultivar date palms of the same age and location were considered, unless stated otherwise. A palm was considered to be "on" when it possessed eight or more bunches of dates, but "off" when it had six or less bunches of fruit. Typically, the date palm samples were pre-treated using standard literature digestion and ashing techniques [23]. Chemical analysis was performed mostly using ICP-OES [24] [25]. This sensitive, multi-elemental technique uses a plasma to atomise samples prior to analysis by emission spectroscopy. In the case of Hg, however, a specialised, non-ICP analyser was used [26]. It works on the principle of cold vapour atomic absorption at 253.7 nm. For the determination of N, the Kjeldahl method was exploited [2] [24]. Here, the sample is digested in boiling sulphuric acid and subjected to several further steps before finishing with an acid-base titration.

2. The Alternate Bearing Effect and the Chemical Elements

2.1. Barium (Ba)

Barium is not an essential element in plants [27] and is suspected of playing a role in the demise of European forests [28]. It was found in the fruits and leaflets of "on" and "off" date palms (**Table 1**). It was, however, found more frequently in the "on" specimens [29]. Put another way, an "on" date palm was more likely to contain Ba in its tissues than an "off" one. This was surprising when the suspected role of Ba in the reduction of European forests is considered. Furthermore, Ba levels in the *Bisir* fruit could be used as a way of differentiating between the "on" and "off" date palms. Ba was present in the *Bisir* fruit of "on" trees (**Table 1**), but was not detected in the corresponding "off" samples [29]. Similarly for the leaflets, but now the *Kimri* stage can be considered as well. Ba was detected in the *Kimri* and *Bisir* leaflets from "on" trees (**Table 1**), but was not detected in the "off" palm leaflets for these two stages [29]. How Ba could cause abundant fruiting in date palms should be the subject of a further investigation.

2.2. Boron (B)

Boron is a micronutrient and one of the 16 elements classed as essential in plants [27]. It plays a role in energy transfer reactions and carbohydrate movement [27]. It was found in both "on" and "off" date palms at the parts per million level [30]. A distinction, however, could be made between the "on" and "off" trees by comparing the B concentration in the Bisir leaves. It is probable that an "on" palm could be determined as having a B

Table 1. Summarising mean elemental concentrations (in mg/kg) in "on" and "off" fruit and leaflets for each development stage for most of the elements considered in this review [2] [25] [29] [30]. ND = not detected.

Element	Development stage											
	Kimri				Bisir				Rutab			
	Fruit		Leaflets		Fruit		Leaflets		Fruit		Leaflets	
	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off
Ag	ND	1.28	ND	ND	ND	2.20	ND	ND	ND	0.09	ND	ND
Al	37.1	32.7	55.1	54.0	1.55	5.68	17.5	19.4	18.2	8.86	22.6	24.7
B	4.6	4.5	1.3	1.5	2.5	2.2	4.4	2.7	2.8	3.3	2.3	3.0
Ba	0.85	0.57	0.68	ND	2.74	ND	6.3	ND	18.2	7.7	5.2	6.5
Ca	1041.3	969.2	2075.4	1948.8	537.1	558.8	3509.6	3341.3	709.2	724.6	2491.3	2575.8
Cd	0.054	0.096	0.038	0.057	0.004	0.012	0.066	0.004	0.020	0.025	<0.001	0.004
Cu	2.8	3.1	1.5	1.7	2.0	1.3	2.0	1.2	3.4	1.9	0.4	1.8
Fe	6.8	5.3	74.1	67.3	6.6	302.9	7.5	1.3	8.5	176.4	27.9	37.9
K	6666.7	6779.2	3446.7	3666.7	3704.2	5025.0	2172.1	1576.3	5325.0	5591.8	2556.7	2424.2
La	ND	ND	ND	ND	ND	2.45	0.07	ND	ND	ND	ND	ND
Mg	1515.4	1487.5	2155.8	2088.3	765.0	844.2	1209.2	1297.9	906.3	976.3	1433.3	1714.6
Mn	5.2	4.6	9.3	8.9	2.2	8.2	9.6	7.9	3.7	3.1	7.2	7.7
Na	180.5	165.3	116.1	126.6	43.4	35.5	136.4	133.9	66.4	74.0	132.2	121.9
Se	0.23	ND	0.17	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tl	0.47	ND	ND	ND	1.04	ND	ND	ND	ND	ND	ND	ND
Zn	1.7	2.8	1.1	1.9	6.0	4.5	7.5	1.3	1.2	6.2	0.6	2.2

concentration in the leaflets of greater than 3.5 mg/kg during Bisir, whereas an "off" palm has less than this (**Table 1**). This demonstrates that a lack of B could contribute to the poor growth seen in "off" palms [30]. Interestingly, the highest K/B ratios (>2500) were discovered only in the leaflets of some "off" palms during the Kimri stage. This supports the possibility that this cut-off ratio could point to a lack of B playing a part in the poor date growth of "off" palms [30].

2.3. Cadmium (Cd)

This heavy metal has no known metabolic function in living organisms [31]. It may be possible, however, to use the levels of this element in the leaflets of the date palms as a way of distinguishing between "on" and "off" trees [25]. As an illustration, Cd levels in the Bisir leaflets of the "on" trees were significantly higher than those in the "off" trees (**Table 1**). More specifically, an "on" tree was signified by a Cd level greater than 25 ng/g in the leaflets and the leaflets from an "off" tree had a Cd level less than this value. In addition, only the "off" palms have fruit levels greater than 125 ng/g during the Kimri stage (**Table 1**). These findings could provide some evidence for a chemical basis for the alternate-bearing effect. It could be related to physiological factors. The fluctuations of Cd observed could be due to metabolic transport of the element in the tree.

2.4. Calcium (Ca)

Calcium is an essential element and helps maintain ionic balance in plants [27]. For the date palm, it has been found that significant differences in the Ca concentration exist between the "on" and "off" trees during one of the fruit developmental stages [2]. More specifically, the "off" palm leaflets had higher Ca levels than the "on"

palm leaves during the Rutab stage [2] (**Table 1**). Furthermore, the Ca content in the fruit followed similar trends to the "off" palm leaflets at the Rutab stage [2] (**Table 1**).

2.5. Copper (Cu)

Copper is an essential element in plants [27]. It is important in the synthesis of anthocyanin and is expected to be used for that purpose during the development of colour in dates [32]. It was found that Cu levels were, generally, higher in dates from "on" trees those from "off" ones [2] (**Table 1**). This contrasts with the situation in the leaflets. During the Rutab stage, the "off" palm leaflets have higher Cu levels than those from "on" palms [2].

2.6. Iron (Fe)

Like Cu, Fe is also classed as an essential element in plants [27]. It enables electron transport and acts as a catalyst for plant enzymes [27]. Significant differences in the levels of Fe in dates between the "on" and off" palms have been observed, particularly during the Rutab stage [2]. More specifically, in the Rutab fruit, Fe content was higher in dates from the "off" trees than those from the "on" trees [2] (**Table 1**). Similarly, the "off" palm leaflets had higher Fe levels than those from "on" palms during the Rutab stage [2] (**Table 1**).

2.7. Lanthanum (La)

The role of lanthanum in plants is relatively under studied. There may, however, be some relationship between La and the alternate bearing effect in the date palm. The *Bisir* stage could be used to distinguish between "on" and "off" date palms. More specifically, *Bisir* "off" fruit contained La, but *Bisir* "on" fruit did not [29] (**Table 1**). Furthermore, *Bisir* "on" leaflets contained La, but *Bisir* "off" leaflets did not [29] (**Table 1**). These interesting results are deserving of further study.

2.8. Magnesium (Mg)

Magnesium is an essential element in plants and a macronutrient [27]. It is a constituent of chlorophyll and many of the enzymes involved in carbohydrate metabolism require Mg as an activator [27]. Significant differences in the levels of Mg in the leaflets between the "on" and off" palms were found [2]. More specifically, leaflets from "off" palms have higher Mg levels than those from "on" palms during the Rutab stage [2] (**Table 1**). In addition and again at the Rutab stage, the Mg content of the dates followed a similar trend as for the leaflets [2] (**Table 1**). This correlates with Mg being a component of chlorophyll: the fewer dates associated with the "off" palms require less chlorophyll and, hence, less Mg.

2.9. Manganese (Mn)

Manganese is an essential element in plants and a micronutrient [27]. It enables electron transport and acts as a catalyst for enzymes in plants [27]. Significant differences in the Mn concentration of the dates were observed between the "on" and off" palms [2]. However, the general trend during Rutab indicates that "off" palm dates have lower Mn levels than "on" palm dates [2] (**Table 1**). In contrast to the fruits, Mn levels were lower in "on" palm leaflets [2] (**Table 1**).

2.10. Nitrogen (N)

Nitrogen is an essential element in plants and a major constituent of organic substances [27]. It was found that "off" palm leaflets have higher N levels than "on" palm leaflets during the Rutab stage [2]. This is surprising, unless lush date growth depletes essential nutrients from the surrounding plant tissues such as leaflets.

2.11. Potassium (K)

Potassium is a macronutrient and an essential element in plants, where it maintains ionic balance [27]. Significant differences in the levels of K in the dates and leaflets between the "on" and "off" trees were found [2]. Concentrations of K were higher in the "on" palm leaflets than in the "off" [2] (**Table 1**). Contrastingly, "off" palm dates contained higher levels of K [2] (**Table 1**). The lower K content of leaflets from "off" palms infers

that these trees may have been lacking in this element [2].

2.12. Selenium (Se)

Selenium has not yet been identified as essential for plants [27]. Levels of Se in the date palm, however, could be used as a way of distinguishing between "on" and "off" date palms. Moreover, the Kimri fruits obtained from "on" palms contained Se, but those collected simultaneously from the "off" palms did not [29] (**Table 1**). Similar results were obtained for the leaflets [29]. These findings infer that, although not essential for plants in general, Se may be needed for alternate bearing in the date palm.

2.13. Silver (Ag)

This element is believed to have no known metabolic function in living organisms. There may be a connection, however, between Ag in dates and the alternate bearing effect. It is noticeable that date palm fruits growing on the "off" trees had amounts of Ag in them, but in the "on" trees, this element was not detected [29] (**Table 1**). This could help to distinguish between "on" and "off" date palms. In light of these findings, it is probably best to avoid feeding early- to mid-season "off" dates to livestock. That Ag, previously thought to have no useful purpose in living organisms, could play a role in the alternate bearing effect is worthy of further investigation.

2.14. Sodium (Na)

Sodium is classified as non-essential in plants [27]. It may, however, play a role in the alternate bearing effect, because levels of Na were, generally, higher in leaves from "on" trees than from "off" ones [2] (**Table 1**). In light of these findings, further studies involving Na should be pursued.

2.15. Thallium (Tl)

The role of Tl in plants is unclear, but it is known to be a trace element [27]. Levels of Tl could, however, be used as a way of differentiating between "on" and "off" date palms. Generally, fruits from "on" trees contained Tl while those from "off" palms did not [29] (**Table 1**). More specifically, it was the *Rutab* "on" fruits that did not contain detectable levels of Tl (**Table 1**). This needs further investigation to ensure these observations are not a coincidence. If these findings are confirmed, feeding early- to mid-season "on" dates to livestock should be avoided due to the high toxicity of Tl.

2.16. Zinc (Zn)

Zinc is an essential element and micronutrient in plants [27]. It enables electron transport and acts as a catalyst for enzymes [27]. It may have a role to play in the alternate bearing effect in the date palm. During the Rutab stage, it was found that "off" palm leaflets have higher Zn levels than "on" palm leaflets [2] (**Table 1**). Similarly, the concentration of Zn was higher in Rutab dates from "off" palms than from "on" ones [2] (**Table 1**).

2.17. Other Elements

Several other elements have been considered in the scientific literature regarding a possible connection to the alternate bearing effect. It was found that there was no discernable connection between the presence of detectable levels of Al [29], As [33], Be [29], Cr [33], Ga [29], Hg [26], Mo [29], Ni [34], Si [29] and V [29] in the date palm tissues and the alternate bearing effect. Of these, the results for Mo are the most surprising, because it is an essential element in plants [27].

3. Potential Impact

The findings in this review could potentially impact agriculturally, economically, environmentally and on human health.

From an agricultural point of view, knowledge of levels of relevant elements (Ag, B, Ba, Ca, Cd, Cu, Fe, K, La, Mg, Mn, N, Na, Se, Tl, and Zn) in date palm tissues analysed at the very beginning of the fruiting season could be exploited to identify "on" and "off" palms. Consequently, it may be possible to predict whether the

date palms will produce abundantly or sparsely in the coming fruit-growing season or even which individual palms will do this. In addition, date producers may attempt to manipulate the date palms with elemental supplements added to the soil to circumvent the "off" seasons and obtain the large quantities of dates synonymous with "on" palms more frequently.

The economic impact could manifest in chemical companies producing fertilisers to try to produce a specialist supplement to overcome alternate bearing in date palms and other plant species of agricultural importance. If successful, this may create new jobs in that area. On the other hand, such supplements would be relatively expensive and may increase the cost of dates to the consumer. This could be countered, however, by a drop in the global date price caused by overproduction of the fruit. This could leave the date growers no better off or even worse off economically.

The environmental impact of an excess use of fertilisers or custom-made mineral supplements could be felt in the surrounding area by, for example, contaminating the land. This pollution could run off into nearby bodies of water following heavy rain and cause eutrophication [35].

The impact on health is a cause for concern too. Feeding early-season dates to livestock could adversely affect their health or cause hazardous elements such as Ag and Tl to bioaccumulate in their tissues [35]. This may impact on human health when milk and meat from the livestock are consumed.

4. Conclusion

The data show clearly that the alternate-bearing effect influences some, but not all, elements in the date palm. Certain trace elemental levels could be used to predict good or bad growth of dates in advance. Our work, thus, makes a marked contribution to environmental studies by highlighting the potential of implementing the experimental data to benefit agriculture and the environment by overcoming sparse yields of fruit. However, not all the elements in the periodic table have been studied yet. As an illustration, the effect of the alternate bearing phenomenon on levels of essential elements such as carbon, hydrogen, oxygen, phosphorous, sulphur and chlorine levels could be studied in the future. This review has also highlighted the potential impact of the alternate bearing effect in the date palm on agriculture, the economy, the environment and human health. Furthermore, alternate bearing showed significant effects on the levels of Ca, K, Mn, Fe and other elements in the dates during some or all of the development stages, but in the leaflets only in Mg and K. Regular application of fertiliser containing these elements could be effective in reducing the effect of alternate bearing on the date palm. The experimental data showed inconsistent variations in the levels of elements in the fruit and leaflets from "on" and "off" date palms. This infers the need for studies over more than one fruit growing season to prove the influence of alternate bearing on the mineral composition of the date palm tissues. One season may influence the next season and be influenced itself by the previous season. To know with greater certainty the effect of the alternate bearing on individual elements or small groups of elements in the date palm, carefully controlled experiments should be undertaken with fewer uncontrolled variables. An interesting extension of this review would be to widen the field of study to alternate bearing in other perennials in arid lands. Are the same general trends found in the date palm observed in other species affected by alternate bearing?

Acknowledgements

The authors wish to thank the staff and students of Sultan Qaboos University, Sultanate of Oman for their assistance with the original research that formed the basis of this review.

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