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THE PHENOLOGICAL BEHAVIOUR OF FRUIT CROPS IN BARBADOS

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ABSTRACT

Over a 10-year period (1984–1994), observations were made on the phenological changes occurring in fruit trees/crops. In an orchard at Codrington Agricultural Station, internationally important cultivars of mango (*Mangifera indica*), citrus (*Citrus* spp.), avocado (*Persea americana*) and carambola (*Averrhoa carambola*) were monitored. Other species were observed at various locations. Information on flowering and fruit production trends is presented. The period of February to April was a strong flowering peak for species that exhibit synchronous rhythmic bearing habits, although a weaker peak often occurred in the October to November period. July to October was a strong peak period for fruit maturation when all species were taken into account. A particular group of species had fruiting peaks only in the May to July period. Some species had two fruiting peaks; one occurring around May to July and a second around October to January. The observed variations in annual growth and production rhythms among and within species seem to be sufficiently distinct as to require different management strategies (including spatial arrangement). The phenological patterns of the species/cultivars are discussed in relation to orchard management approaches in the Barbados environment.

INTRODUCTION

During the last decade more than 200 ha of fruit crops have been planted in Barbados. Productivity of these orchards has been highly variable. One of the biggest limitations to production might be lack of an understanding of the requirements of fruit crops. The more recent rush towards export-oriented production has spurred increased efforts to produce many crops, including the 'new-wave' exotics such as golden apple. The requirements of these crops are even less understood. The quality, productivity and profitability of such ventures depend, in the final analysis, on the ability of growers to manage moisture and fertility. Water management has been characterized by a two-pronged problem. On one hand, most orchards are rainfed; on the other hand there has been a tendency towards over-enthusiastic irrigation where the facility exists.

The typical cause and effect research that is done for vegetable crops is inadequate for fruit crops. For branched species (most fruit crops) it has been recognized that productivity depends on complex interactions occurring in a physiological system (Cull, 1986). The phenological cycle describes a resultant morphological development pattern of the plant and is seen as a more sound basis for management of fruit crops (Cull, 1986). Cull (1986) noted that phenological patterns are influenced by species, cultivar, environment and management. Tropical tree crops have been classified on the basis of branching habit and growth rhythm as outlined in Table 1 (Verheij, 1986). Nearly all branched species fall in subclass 2.2. of the classification (Verheij, 1986). For those trees that experience a temporal separation of vegetative growth and floral development, the growth rhythm may be synchronous or asynchronous (Verheij, 1986; see Table 1 for a description of rhythm patterns).

This research work was conducted as a contribution to an area where very little information has been documented. Using the concepts of previous authors, floral and fruit maturation trends were analyzed. It should, however, be noted that the other phases of the cycle (flushing, root growth etc.) are also important 'productivity determinants' (Cull, 1986) in the system.

Table 1. The Verheij classification

1 **Single-stemmed species**
- 1.1 Continuous growth, concurrent with floral development (papaya)
- 1.2 Continuous growth culminating in flowering
  - a. largely supported by current photosynthesis (banana))
  - b. largely supported by accumulated reserves (bamboo)

2 **Branched species**
- 2.1 Floral development concurs with extension growth (passion fruit)
- 2.2 Extension growth and floral development separated
  - 2.2.1 According to loci (cacao)
  - 2.2.2 In time:
    - a. Growth *rhythm asynchronous , branches or sectors of individual trees change phase in their own time (soursop)*
    - b. Growth *rhythm synchronous , entire population change phases simultaneously (mango) (includes some deciduous species [mombin])*

METHODS

Blocks of grafted mango, avocado and citrus cultivars were established at Codrington Agricultural station in St Michael, Barbados in 1986. The carambola cultivars were planted in 1988. The blocks consisted of eight trees of each of the cultivars. Cultivars are listed in Figures 1 and 2; scientific names of all species are listed in Table 2. The trees were rainfed in most of the years except 1990 and 1991 when trees were given supplementary irrigation. Cultivars were observed over a 6-year period (1987–1992). Weekly, recordings were made with respect to the growth rhythm for each of the cultivars, i.e. flushing, blossoming, fruit set, fruit growth, maturity, ripening and rest. Results are compiled in Figures 1 and 2 for flowering patterns and seasonality of fruiting only. The 'tendency to flower or have mature fruit' for each species was calculated by an arbitrary formula: percentage number of cultivars in the phase x the percentage number of observations when the phase occurred. This

Table 2 Classification, growth rhythms, and best climate as outlined by Verheij

Crop	Botanical name	Classifications	Growth rhythm	Best climate
Mandarin	*Citrus reticulata* Blanco	2.2.2.b	sync	seasonal
Tangerine	*C. reticulata* Blanco	2.2.2.b	sync	seasonal
Tangelo	*C. reticulata x C. paradisi*	2.2.2.b	sync	seasonal
Orange	*C. sinensis* (L.) Osbeck	2.2.2.b	sync	seasonal
Grapefruit	*C. paradisi* Macf.	2.2.2.b	sync	seasonal
Lime	*C. aurantifolia* (Christm.) Swing.	2.2.2.b	sync	seasonal**
Avocado	*Perseaamericana* Mill.	2.2.2.b	sync	seasonal
Mango	*Mangifera indica* L.	2.2.2.b	sync	seasonal
Cashew	*Anacardium occidentale* L.	2.2.2.b	sync	seasonal
Plum (Jamaica/Red mombin)	*Spondias purpurea* L	2.2.2.b	sync	seasonal.
Plum (Chile)	*Spondias purpurea* forma *lutes* Fawc. & Rendle	2.2.2.b	sync	seasonal
Plum (hog)	*Spondias mombin* L.	2.2.2.b	sync	seasonal
Golden apple*	*Spondias cytherea* Sonn.	2.2.2.b	sync	seasonal
Tamarind	*Tamarindus indica* L.	2.2.2.b	sync	seasonal
Genip*	*Melicoccus bijugatus* Jacq.	2.2.2.b	sync	seasonal
Soursop	*Annona muricata* L.	2.2.2.a	async	seasonal
Sea grape *	*Coccoloba uvifera* (L.) L.		sync?	seasonal?
Carambola*	*Averrhoa carambola* L.	2.2.2.a	async	non-seasonal
Guava	*Psidium guajava* L.	2.2.2.a	async	non-seasonal
Barbados cherry*	*Malpighia emarginata*	2.2.2.a	sync	seasonal**
Dunks*	*Ziziphus mauritiana* Lam.	2.1 ?	contin	non-seasonal?
Passionfruit	*Passiflora edulis* Sims	2.1	contin	non-seasonal
Breadfruit	*Artocarpus altilis* (Park.) Fosberg	2.1	contin	non-seasonal
Gooseberry*	*Phyllantus acidus* (L.) Skeels	2.2.1.a	contin	non-seasonal
Pineapple	*Ananas comosus* (L.) Merr.	1.2.a	contin	non-seasonal
Banana	*Musa* spp.	1.2.a	contin	non-seasonal
Coconut	*Cocos nucifera* L.	1.1	contin	non-seasonal
Papaya (pawpaw)	*Carica papaya* L.	1.1.	contin	non-seasonal

* = input of author; sync = synchronous; contin = continuous; decid = deciduous; ** = special cycle

was plotted on a graph as an 'incidence score' for some citrus species, mango and avocado. Other species (individual trees) were observed monthly at various locations. Formal data collection was done during 1984–87 and 1992–94. The trees were rainfed.

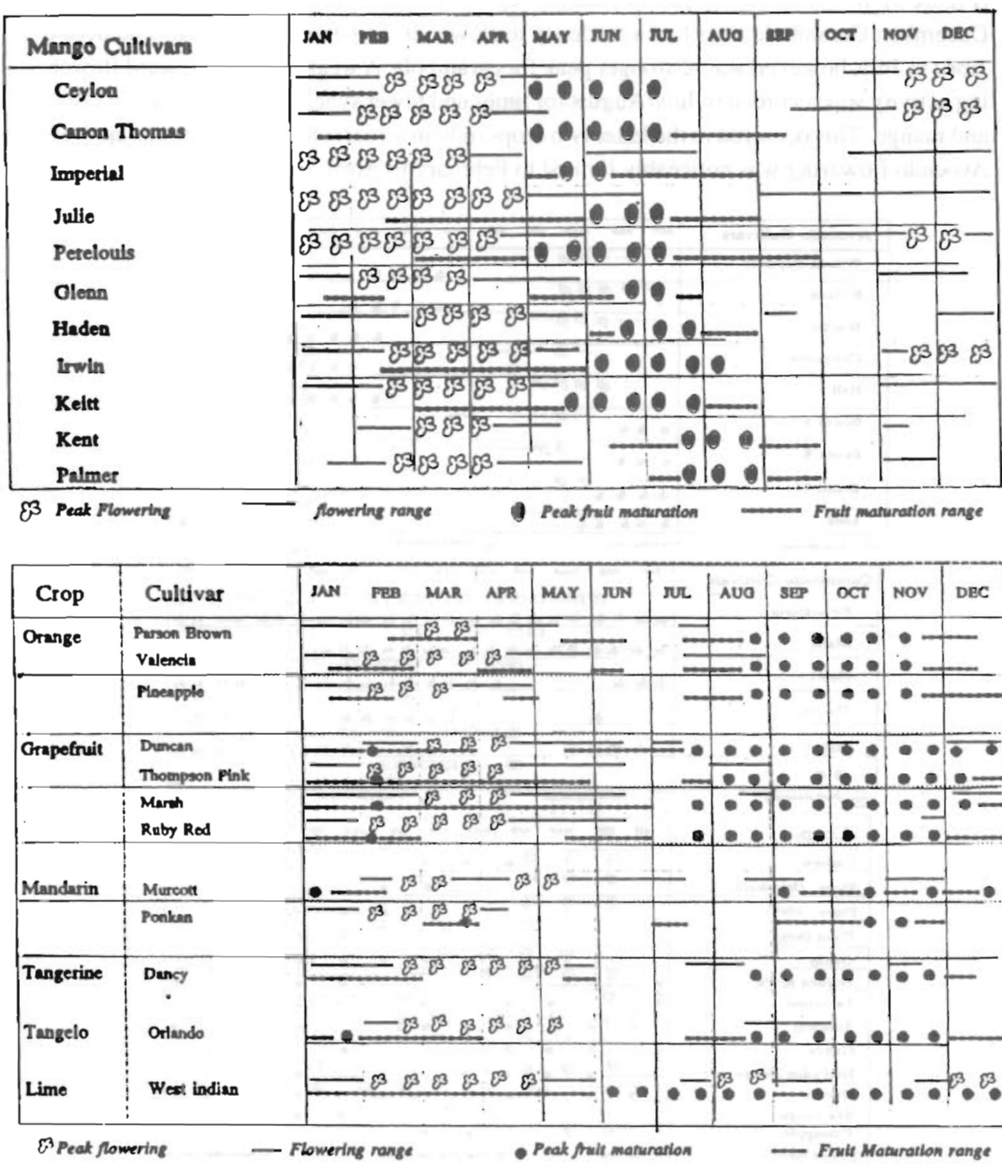

Figure 1 Flowering and fruit maturation periods of mango and citrus species/cultivars

RESULTS

Mango, avocado, citrus spp. and carambola

Peak flowering periods and inter-specific variation

Flowering activity peaked during February to April for citrus, avocado and mango (Figure 3). In some years, citrus and mango began flowering activity as early as November/ December. Carambola trees had a tendency to flower at the latter time as well. The period April to July, however, was a stronger peak for carambola. A weak tendency toward flowering activity was recorded in July/August for limes and fewer synchronous cultivars of citrus and mango. This occurred in the latter two crops only in a year when irrigation was applied. Avocado flowering was noticeably limited to February to April (except one cultivar).

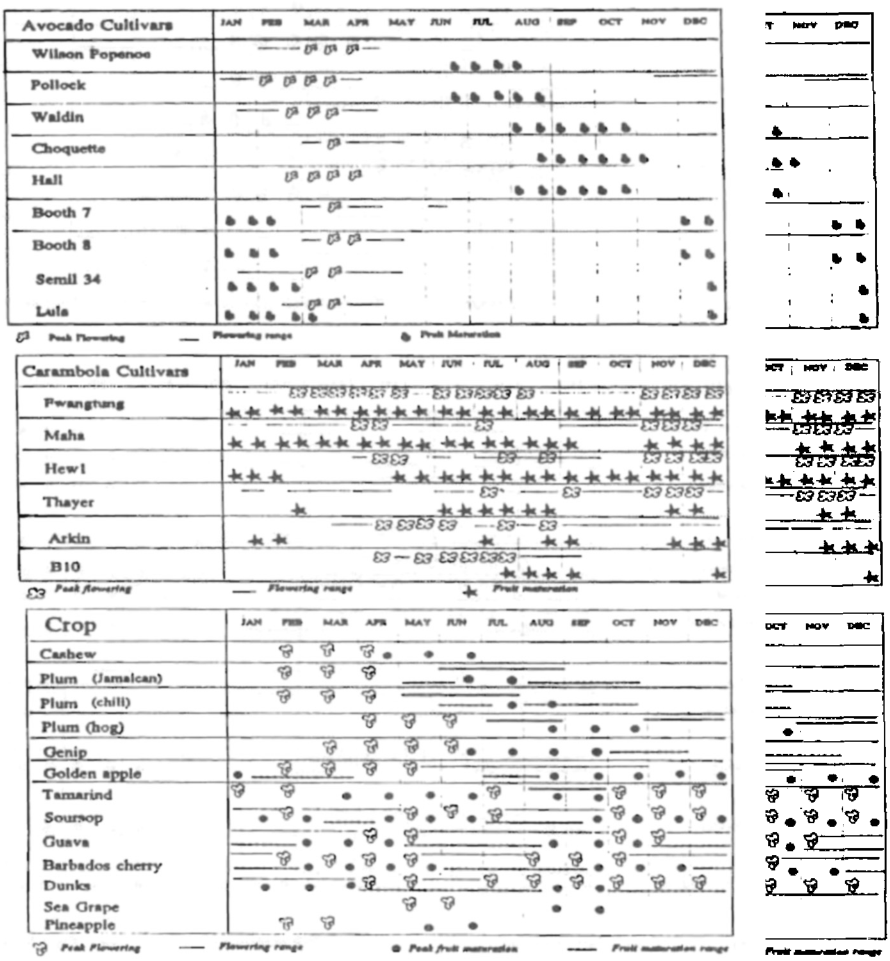

Figure 2 Flowering and fruit maturation periods of avocado and carambola cultivars, and other species

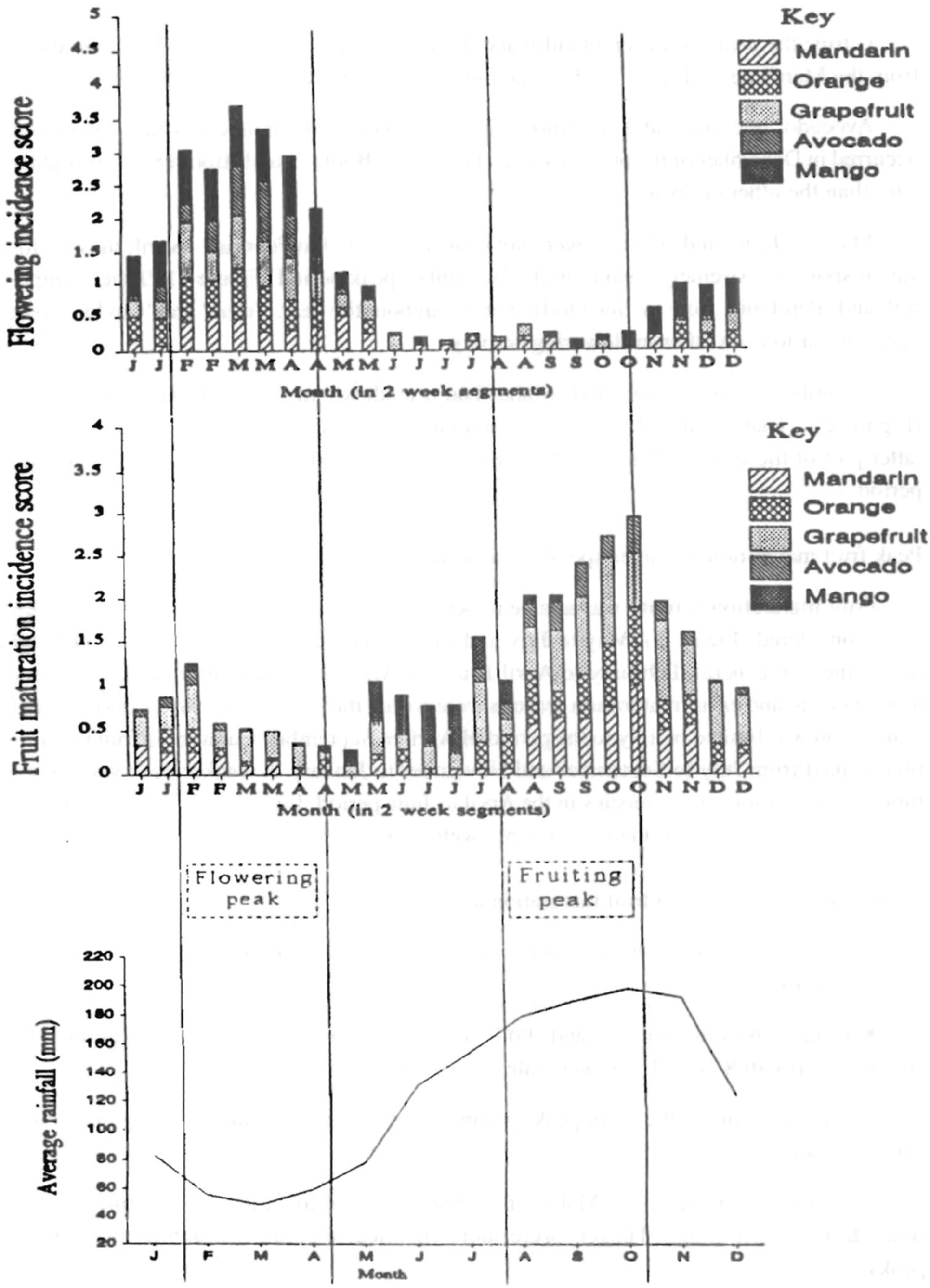

Figure 3 Comparison of the annual trend in flowering and fruit maturation (some citrus, mango, avocado) with rainfall pattern

Intra-specific variations in flowering activity

Citrus: the peaks of different cultivars of the citrus species displayed slight variations from the March peak (Figure 1). The magnitude was as much as ± 1 month.

Avocado: one noticeable variation was the flowering of 'Pollock' which sometimes occurred in December of the previous year (Figure 2). 'Booth 7' and 'Booth 8' were slightly later than the other cultivars.

Mango: 'Kent' and 'Palmer' were noticeably restricted to February–April; these cultivars responded extremely weakly in the November peak period (Figure 1). 'Julie', 'Imperial' and 'Perelouis' were inclined to flower throughout the year. 'Irwin' and 'Ceylon' were very similar to each other in flowering activity.

Carambola: 'Fwangtung' and 'Maha' had a tendency to flower throughout the year (Figure 2). 'Thayer' and 'Hew1' had a similar pattern but were more restricted to the latter part of the year. 'Arkin' and 'B10' were more inclined to flower in the April to July period.

Peak fruit maturation and inter-specific variation:

Fruit maturation activity was at a peak between August and October when all species were considered (Figure 3). May to July and January/February were respectively weaker peak times. In general, February to April is a time when fruit maturation activity is very low. Avocado and citrus maturation seasons were within the July to February period. Mango maturation was limited mainly to the period of April to September. Carambola fruit maturation peaked from July to September and November to January. A weaker peak was sometimes seen for some citrus species in the April to June period. Limes tended to have mature fruit for the greater part of the year (mainly wetter part).

Intra-specific variations in fruit maturation activity.

Citrus: cultivar variations were not very distinct although variations can be seen on the chart in Figure 1.

Avocado: 'Wilson Popenoe' and 'Pollock' were very early in maturation. 'Semil 34', 'Booth 7', 'Booth 8' and 'Lula' were late types compared with others.

Mango: in terms of the main peak, 'Palmer' and 'Kent' were late maturing and could extend to September.

Carambola: 'Fwangtung', 'Maha' and 'Hew 1' tended towards all year fruit maturation. 'B10', 'Arkin' and 'Thayer' were more inclined towards two annual maturation peaks.

Other species

Flowering activity

February to April was a peak period for this phenophase in terms of the number of synchronous species that tended to be flowering (cashew, genip) (Figure 2). Another peak was noted in May to July for specific crops such as soursop, sea grapes, etc. September was a relatively low period but there was another weak peak in October/November. Variations in the flowering range for most species were largely due to the differing microclimates. Soursop or guava trees, for example, in wet locations often blossomed throughout the year. Continuous species such as breadfruit and gooseberry etc. were seen to flower throughout the year.

Fruit maturation activity

The fruit maturation season was mainly from May to December. Discernable peaks in activity were seen in June and September. Normally asynchronous crops, e.g. soursop, and quick maturing crops such as Jamaica plum, had the tendency to mature fruit in the May to July season. Dunks and the Annonacae had a tendency towards developing and maturing fruit in the wetter part of the year (maturity often occurring in the following year, depending on duration of fruit development). For continuous bearing spp. (e.g. gooseberry) the fruit maturation activity was related to the rainfall pattern. In wet microclimates these species produced fruit all year. Papaya fruit maturation was limited to a 3 to 6-month period before the crop declined due to the 'bunchy top' condition. The overall phenology of papaya emulated an annual, rather than perennial, crop cycle.

DISCUSSION

Analysis of the behaviour on the basis of current phenology concepts.

The results of this study concur with the suggestion of Verheij (1986) that there is not a very sharp distinction between synchronous and asynchronous growth rhythms. Normally synchronous species like mango were seen to revert to asynchronous flowering rhythms in years when irrigation was applied. In reverse, species like soursop developed pseudo-synchronous rhythms when grown in dry rainfed areas. Barbados cherry in particular seems to defy any attempt for classification. This species normally displays an asynchronous rhythm but actually does best in a highly seasonal climate. The unique phenological cycle can be precisely synchronized by moisture manipulation (author's observations; Michelini and Chinnery, 1988). Observation of Barbados cherry trees gives the impression that it is a highly synchronous crop growing in a non-aligned climatic cycle. In the rainfed situation flowering is intense after rainfall occurs in the dry season but there is no further moisture to sustain fruit development; in the latter part of the wet season vegetative growth is vigorous at the expense of flowering.

The final phenological behaviour for any fruit crop is determined by genotype as well as climatic and management factors (Cull, 1986; Verheij, 1986). In this investigation the influence of genotype is clearly seen in the differences among mango, avocado and carambola cultivars observed in the same climatic environment (Figures 1 and 2). Avocado trees in particular seemed to have a strong endogenous mechanism controlling the phenological cycle.

In the rainfed situation under which most of the observations were made, the climatic cycle (dominated by rainfall) seems strongly to influence the timing of the floral phenophase. Nearly all synchronous species had a peak of flowering activity in the February to April period. The flowering incidence curve (Figure 3) had an inverse relationship to the annual average rainfall curve. Other authors have reported the tendency for many tree species to enter the reproductive phase in the dry season (Janzen, 1967; Huxley and van Eck, 1974; cited by Verheij, 1986). Rainfall also seemed to influence the blossoming activity of asynchronous species. This is more likely due to its influence on the state of vigour, than as a 'triggering' process per se. Such species are dependent on an endogenously controlled cycle that works best when the climate is non-seasonal (Verheij, 1986).

The range of flowering incidence (for individual species) that occurs on the charts is also a result of annual and geographical variations in rainfall. Soil moisture (fertility) trends also seem ultimately to influence the timing of fruit production peaks. Thus, heavy flowering peaks do not imply subsequent maturation peaks for some species. For dunks and Barbados cherry for example, although flowering was prolific in drier parts of the year, fruit set did not always take place. Presumably such species must reach a given physiological state before fruit set can be successful. Such a state would be influenced by pre-existing moisture and fertility. Sometimes the influence of rainfall is more related to its effect on pollinators and on fruit rot diseases (e.g. mango). Sometimes fruit set occurred but the fruit later aborted (cherry, mango, carambola, avocado, citrus). These observations emphasize the notion that productivity in branched species is determined by complex physiological reactions (Cull, 1986).

In all species the duration and intensity of fruit development activity seemed to further influence the actual phenological rhythm that occurs. Synchronous species tended not to produce blossoms when fruit development peaks were occurring (Figure 3). The fruiting cycle of 'Booth 7' avocado trees, for example, seemed to be almost too long for the annual climatic cycle. Similarly, the annual peaks observed for guava (Figure 2) might be a result of the domination of a heavy load of fruit. In the latter situation, vegetative (and floral activity) did not occur even after heavy rainfall.

Implications for management of fruit crops.

Results of the study suggest that rainfed production perpetuates a fruit availability peak from August to October (and other preset peaks for some species). While this may be a productive pattern, it does not necessarily lead to the best profitability for growers. There are limitations in a grower's ability to meet marketing 'windows' on local and export markets.

There is an indication that some species and cultivars are open to manipulation. Citrus (limes in particular), mango and cherry seem particularly amenable to strategic use of irrigation in medium to dry locations. The flexible species/cultivars have the potential for increasing profitability of production. A grower must however be mindful of the crop protection and other measures that may be required to preserve the quality of off-season production for some species. The economic feasibility of water use must also be considered. The suggestion that fruit crops should be zoned in high rainfall areas is appropriate only for some species (continuous and asynchronous mainly). Some synchronous species in high rainfall zones are either non-productive, e.g. mango (Alvim and Kozlowski, 1977), or are non-profitable (limes). Avocado is unique in that different cultivars can be combined in a high rainfall zone to achieve good productivity and profitability. Table 3 provides more details on the approach to managing the water requirements of the range of species.

The results suggest that in commercial orchards there should be at least lines of cultivars if not pure stands of some cultivars. This would be especially critical for export oriented ventures. The differences in the phenology of some species/cultivars, make erratic mixed stands seem inappropriate for proper water and fertility management. In compromised situations some groups of species (e.g. citrus-mango-avocado) may be grown together. This has been done for many years in the orchards that characterize the landscape of most sugar estate houses.

The phenology charts presented in this document may be useful to growers in planning crop protection and irrigation programmes. Water management is best done on the basis of the growth rhythm. Continuous and asynchronous crops should be zoned in high rainfall areas, if possible, or supplemented in medium rainfall areas. For synchronous crops the aim is to allow a distinct dry season to facilitate flowering (which may even involve covering root zone), but, any dry spells in the wet season have to be nullified by irrigation. It has been already noted that some synchronous species/cultivars require strategic timing of irrigation for best production. Table 3 provides further information for individual crops. The information should also be useful for plant propagators.

Table 3 Suggested approaches to water management for various crops on basis of growth rhythms and considering profitability

Crop	Water management approach (considering profitability)
Manadarin	HRZ or (LRZ with strategic irrigation)
Tangarine	HRZ or (LRZ with strategic irrigation)
Tangelo	HRZ or (LRZ with strategic irrigation)
Orange	HRZ or (LRZ with strategic irrigation)
Grapefruit	HRZ or (LRZ with strategic irrigation)
Lime	(LRZ with strategic irrigation) or HRZ
Avocado	HRZ or (MRZ with supplemental irrigation) (irrigation combination)
Mango	MRZ to LRZ with supplemental/startegic irrigation
Cashew	MRZ to LRZ (drainage critical)
Plum (Jamaica)	MRZ to LRZ (distinct dry period at flowering/fruiting)
Plum (Chili)	MRZ to LRZ (distinct dry period at flowering/fruiting)
Plum (hog)	HRZ to LRZ
Golden apple	HRZ to LRZ
Tamarind	HRZ to LRZ
Genip	MRZ to LRZ?
Soursop	HRZ to MRZ
Sea grape	HRZ to MRZ? or seaside
Carambola	HRZ to MRZ or (LRZ with strategic irrigation)
Guava	HRZ to MRZ or (LRZ with strategic irrigation)
Barbados cherry	MRZ or (LRZ with strategic irrigation/special cycle)
Dunks	LRZ with strategic irrigation
Passion fruit	MRZ or (LRZ with supplemental irrigation) [disease in HRZ]
Breadfruit	HRZ to MRZ or (LRZ with supplemental irrigation)
Gooseberry	HRZ to LRZ
Pineapple	HRZ or (MRZ to LRZ with supplemental irrigation)
Banana	HRZ or (MRZ with supplemental irrigation)
Coconut	HRZ or seaside
Papaya/pawpaw	HRZ or (MRZ with supplemental irrigation)

HRZ = high, MRZ = medium, LRZ = low rainfall zone; strategic irrigation = water applied with specific timing; supplemental irrigation = water applied to supplement annual rainfall

To be of full research value phenology data have to be taken in conjunction with meteorological data. However, scientific analysis of the influence of climatic variables on phenophases is not done by typical empirical correlations (Lieth, 1974). In this study, therefore, only simple comparison of phenophases with the general rainfall pattern was made. Because of the influence and unreliability of rainfall patterns, it seems that further research should be aimed at a deeper analysis of the interrelation of climate and phenological changes. Strategic irrigation approaches would benefit tremendously from the prediction models that could be developed.

The challenge for future research is seen as having two frontiers. The first, and perhaps easiest, is to understand the annual requirements of different genotypes so that the minimum of inputs (especially water) can be used. The second facet involves mastering the manipulation of crop and environment in order to programme' production of responsive crops. In a world where competition is already strong, and becoming more open, the success of local growers will depend on if or how these frontiers are negotiated.

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