2. A WHOLE PLANT APPROACH TO PRODUCTIVITY RESEARCH FOR MANGO

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INTRODUCTION

Tree crop productivity research which is directed to cultivar selection and the establishment of field management practices has been traditionally discipline orientated. Findings are often related to specific situations and can be incompatible with other research results when developing crop management packages. This is because research commonly examines treatment effect on yield without fully investigating and understanding the interplay of the plant's response and the interacting environment. This paper provides a whole plant approach for productivity management research which assures compatible packages that can be developed far quicker than traditional methods. The research is based on understanding the plant's interaction with the environment when challenged or manipulated with treatments making the results far easier to apply widely and to be understood and used by the farmer.

The term productivity encompasses both fruit yield in numbers and weight and the fruit's market quality in a storage and transport performance and eating acceptability sense. The productivity research approach for mango is based on the morphological and physiological nature of a perennial evergreen tree. The tree is a complex structure highly influenced by the distinctive environment in which it grows. The environment varies through a calendar year in a common pattern for a given locality known as the weather or annual climatic cycle. Similarly the annual growth and development pattern of the evergreen mango tree responds to the environment and follows a distinctive cycle which can be identified. This is known as the annual plant phenological cycle.

As the weather pattern in each locality varies from year to year so the tree similarly responds, giving variation in the plant cycle. Progressive stages of the plant cycle interact and have influence over succeeding stages of the cycle throughout the year. An example is the impact of vegetative growth on the level of the subsequent flower development. This interaction can have an influence extending twelve months with variation in any stage being felt in crop production.

The paper establishes the relationship of the mango with other tropical fruits with respect to the mechanisms of productivity control. In addition an understanding of the phenological cycle of the mango and its response to the environment is described. On the basis of this model, an outline of how this understanding can be used to more effectively design and conduct research related to cultivar selection, nutrition and irrigation management, pruning and use of growth and flowering regulators is provided.

Genotype Control of Crop Productivity

Research in other crop species is used as a guide or stimulus for work in mango. To make use of these results we need to be aware of the productivity controlling factors, for those crops and mango, which are either similar or different. Because of differences only some research is applicable with some crops being more relevant than others.

The commercial fruit crops of the tropics are drawn from a broad range of plant families. The actual species in use have different plant structures and growth habits. Productivity is related to how the flowering and fruiting organs are produced on the plant in position and timing with respect to the vegetative, mainly leaf development. This relationship is due to the fact that the commercial product of the tree is the fruit which is primarily developed from carbohydrates generated by and dependent on the photosynthetic capacity of the leaves. This is somewhat complicated in that in some species, total fruit development is dependent on current photosynthesis while others are variably dependent on both current and stored carbohydrate. This storage occurs in both the limbs and root system but is initially derived from the leaves. An example of the grouping of species is given by the limited list set out in Table 1. Another is provided by Verheij (1986). Plants within the subgroups have similar control mechanisms for productivity - hence avocado, lychee and mango are aligned.

Table 1 **The grouping of species with respect to productivity control mechanisms.**

EVERGREEN SPECIES	
UNBRANCHED PLANTS	BRANCHED PLANTS
TERMINAL FLOWERING	TERMINAL FLOWERING
. Banana	. Avocado
. Pineapple	. Mango
AXILLARY FLOWERING	. Lychee
. Papaya	AXILLARY FLOWERING
. Coconut	- Present Seasons Wood
	. Orange
	. Guava
	. Passionfruit
	- First & Second Year Wood
DECIDUOUS SPECIES	. Coffee . Macadamia
BRANCHED PLANTS	CAULIFLOROUS FLOWERING
AXILLARY FLOWERING	. Cacao
. Custard Apple . "Subtropical" Peach . "Tropical" Apple	. Jackfruit
	. Durian

Some of the key differences between subgroups are as follows. The unbranched evergreens have greatest yields where near maximum vegetative growth is maintained throughout the year related to continuous favourable temperature, water and nutrient conditions. These plants have a consistent root to shoot ratio, dry matter yield is in direct relationship to total plant weight and productivity is mostly dependent on current photosynthesis. Yield is consistent and predictable provided the above environmental factors are maintained.

The branched evergreens differ significantly within the group depending on the position of flowers. As a group with the exception of the cauliflorous plants they perform best where there are distinct seasonal periods of vegetative growth, dormancy and flowering. This is associated with annual climatic patterns related to hot and cool or wet and dry periods. Commonly highest performing plants have one harvest period in the year. The root to shoot ratio fluctuates in relation to the other parts of the plant. Yield is variably, (including negatively) correlated with total plant weight and hence vegetative growth. Yields are also irregular to biennial in nature, being very difficult to forecast. Productivity is dependent on both stored carbohydrate and current photosynthesis.

A good example of differences between subgroups of branched plants is that avocado productivity requires active summer vegetative growth while late winter spring growth, in association with flowering, is competitive and can reduce yields. With orange the summer vegetative flush only adds to the size of the tree and not productivity while the amount of spring leaf growth associated with flowering is positively correlated with yield. The cauliflorous crop Cacao performs best with small bursts of vegetative growth through the year although it can also perform well under a more defined seasonal pattern.

The management of the branched group differs greatly from those of the unbranched. The management of nutrition, irrigation and growth regulators between the branched subgroups is markedly different making the relevance of research results across subgroups very difficult to interpret.

The differences between groups and subgroups can best be understood by an appreciation of the differences between their annual phenological cycles.

The Annual Phenological Cycle of Mango

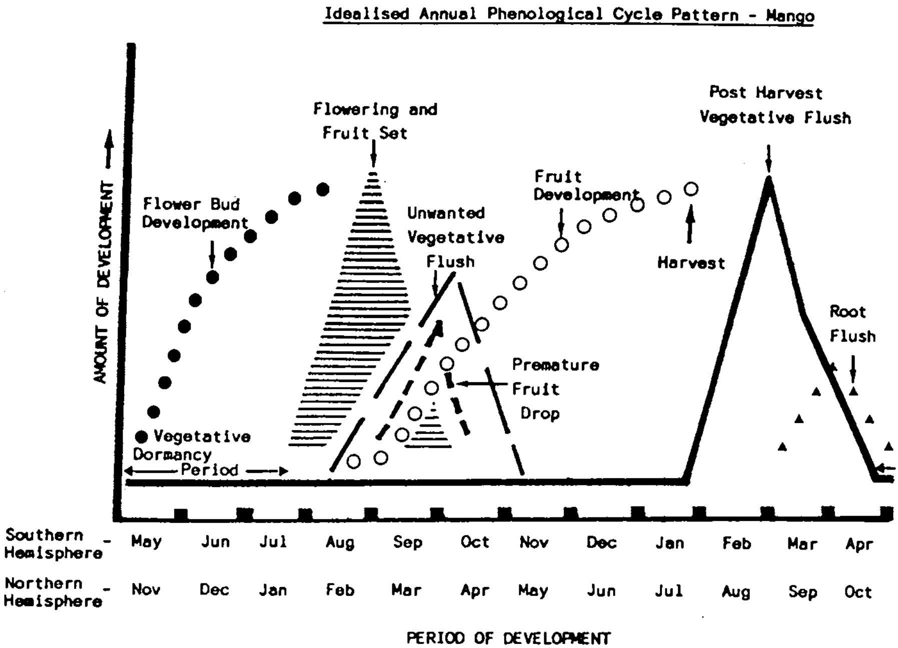
The phenology of mango relates to the periodic stages of the plant's visual development. On an annual basis this refers to the seasonal cyclic changes of vegetative growth, root growth, flower and fruit development.

In a given locality a species follows a "normal" phenological cycle. In this sense "normal" refers to that phenological pattern which is characteristic of a tree which has consistently high yields. It is known that in a year when a tree varies markedly from this normal pattern, yields are reduced or are non existent. This pattern is a function of the genotype as influenced by the local environment. The "normal" pattern reflects the ideal annual seasonal climatic pattern for the genotype.

The phenological pattern is strongly under environmental control, hence it does change somewhat from year to year. The pattern is also advanced or retarded in calendar time from locality to locality with respect to the commencement of the seasonal changes, particularly the rise and fall in temperatures or onset of wet or dry season. As cultivars within species have different vigour levels and variable responses to temperature the cycles vary between cultivars. Hence phenological cycles must be defined on a cultivar by locality basis when researching a crop for a country and indeed districts of that country where there are variable environments.

For this paper an idealised phenological cycle for mango, Figure 1, is used as a basis for discussion and for the associated research considerations. An example for avocado is given by Cull (1986). The graphical lines define the amount of development occurring at a given time (vertical axis) and the month in which it occurs (horizontal axis).

Figure 1



The idealised cycle presented is for a sub-tropical environment where the season and plant cycles are well defined. With such a cycle annual flowering and yields will be consistent. As you advance into the tropical zone where plant development is not so much under seasonal temperature control, but the onset of wet and dry seasons, the patterns are more variable due to locality and the inconsistent nature of rainfall as compared to temperature. Here the application of the phenological model is more difficult but the principle still applies which will be explained as follows.

Casual observers are often unaware of the defined cyclic patterns of branched evergreen trees, the large amount of growth and development that occurs with each vegetative flush or flowering, but more importantly they do not register the massive movement of plant reserves at these given times. It is this build up and effective redistribution and use of these reserves by the respective cycles of the tree which controls productivity. If the reserves do not have a period to accumulate or they are used in the development of non-productive tissue then productivity suffers.

To gain any understanding of productivity control of trees in each country and to establish a research base for mango an accurate record of the annual phenological cycle is required. As research progresses this is required for each of the principal cultivars under test and for each significantly different environment where mangos are to be grown in the country. It is important to identify the pattern which best and most consistently correlates with yield. From this a "normal" pattern for each locality is established. If yields are not high or those expected for a cultivar then this indicates that the environment is preventing that cultivar from settling into its required pattern to give good yields. This optimum pattern for that cultivar may be identified in another locality or another country.

The high yields associated with the normal cyclic pattern described in figure 1 are achieved because of the following. The mango produces its flowers on the terminals of the previous vegetative flushes, ideally those occurring soon after the harvest of the previous year's crop. They can be borne on older flushes than this (up to two years old), but such instances are on lower yielding, erratic bearing trees. The flowers dominate the terminals and if fruit or fruits are set then vegetative growth from that terminal will not occur until after the crop is harvested. The vegetative buds arise axillary at the base of the flowering panicle which abscises or is removed with the fruit allowing the vegetative growth to develop. At fruiting time those terminals which do not flower can and will develop vegetative growth. Also if flowers fail to set or fruit drops prematurely, this means no fruit are being carried on the terminals and they can develop vegetatively.

With this pattern the vegetative growth occurring after fruit removal provides the effective leaf area by leaf replacement and renewal of the photosynthetic capacity of the tree. This vegetative cycle ceases in April/October (figure 1) with maturation of the leaves. The plant remains visually dormant for three months during which time the plant lays down carbohydrate reserves and it is believed, reorganises its growth regulatory control to stimulate flower initiation and flower development. This process is little understood but it is thought that there is a need for the development of a certain carbohydrate concentration threshold in the terminal tissue plus some specific level of growth regulator or growth regulator trigger to stimulate flowering. The key point to register is that both these factors depend on a vegetative dormant period, flowering is commonly correlated with terminals which are healthy and have been dormant for 2 - 3 months and where temperatures are satisfactory for panicle growth.

These requirements are easily met in the very seasonal subtropical environment. Closer to the tropics, temperature control is less significant and the ability to achieve terminal dormancy for 2 - 3 months depends on the occurrence of sufficiently long dry periods. Under these conditions the actual cycles can become erratic. This is one reason why relatively dry localities with defined seasonal rainfall patterns are considered better for mango production. Here the ideal situation is where a 3-5 month dry period is followed by storm rain to stimulate flowering, and good ground water or irrigation is used to develop the crop. The wet season should start with harvest or shortly after to push the vegetative phase and thus complete the annual cycle.

In the tropics where temperatures are ideal for growth (vegetative or flowering) at any time of the year, trees often develop different phenological patterns between separate trees and within one tree, due to spasmodic dry and wet periods. On a given tree, flowers, maturing fruit and vegetative growth can be seen at one time. This pattern is seen in citrus in the tropics but it is claimed that oranges following such an erratic pattern have an annual total yield significantly less than that achieved in a subtropical area with one crop. The spread of fruit maturity is an advantage for local markets but conflicts with the organisation of a commercial large-scale crop and the development of an export market.

Cultivar vigour plays a large part in the response to applied water. Very vigorous cultivars such as Tommy Atkins are reported to always stay vegetative in wet tropical locations, only seldom bearing fruit. On the other hand Julie with its lower vigour, almost dwarfing character, obviously can more regularly hold dormancy long enough, at least on part of the tree, to initiate flowering. This low vigour character could be one reason for the historical widespread adoption of Julie in the Caribbean region.

Other performance characteristics of a mango cultivar can be understood by a knowledge of its phenological response to the local environment. Where some terminals fail to flower or carry fruit and do grow vegetatively in conjunction with other flowering/fruiting terminals there is competition for plant reserves. If mango reacts like avocado and lychee, the other members of its subgroup, such competition will lead to increased fruit drop and lower yields because vegetativeness has a stronger draw on reserves than fruit. In subtropical areas late maturing fruit cultivars which carry good crops have only a short period to grow vegetatively before low winter temperatures induce dormancy. Such trees have low annual growth rates, giving stunted trees with low leaf area canopies. Such cultivars have to be planted at close spacings to achieve satisfactory returns per hectare and their actual productivity can be retarded and in some instances biennial bearing develops. Early flowering cultivars in cool areas can have pollination problems with small parthenocarpic fruit developing which have no commercial value.

Research Approach

The application of the phenological cycling approach to research requires two stages of work. The first is to define the base model for future work. This is done by identifying, recording and defining the "normal" cyclic pattern for each significant event in the environment under study.

The second stage is directed to studying methods of manipulating the plant so it can be made to conform as closely as possible, under a range of conditions, with the optimum normal pattern of assessing if and how other tree management procedures, such as pruning influence the cycle and hence productivity.

Preferably, work in the first stage uses research sites in plantations of known high performance. Alternatives are less formal plantings or if no plantings are available then traditional varietal research plots have to be established. At least three sites representing different environmental conditions and two cultivars are used. Monthly recordings of the phenological cycle of 10 trees of each cultivar (where two are used) per site are made. The period over which each feature extends for its development and the pattern and degree of development within each stage is measured. If practical leaf and soil nutrient analysis are also monitored through the year to provide additional basic data. By step-wise multiple regression analysis the features (ie amount of vegetative flush or length of vegetative dormancy) of the phenological cycle and their relevant degree of development can be correlated with their influence on yield and quality. By this analysis the key features of the cycle and their required level of development are identified and the "normal" cycle established. The status, or degree of development, of these key features can be used as a predictive measure of potential yield. The optimum status being equivalent to maximum potential yield.

With this basic phenological cycle by productivity relationship, cultivars can be more reliably selected for trial in new sites of known environment. In trial sites more rapid and meaningful evaluation of cultivars can be made with respect to the environment using their adherence to the normal cyclic pattern for that locality as a selection criteria. Crop yield losses to pest, disease or climatic disaster do not negate totally a year's results. In addition it is feasible that meteorological records may be used to develop 10 or 20 year crop reliability predictions.

Second stage research, using replicated designs, sets out to test treatments which have potential to manipulate the cycle. Treatments are timed to influence specific stages of the cycle and treatment effects are measured as changes in the status of these stages and their variation from the "normal" pattern coupled with final harvested yield and quality measurements. Correlations between the status of stages and yield and quality further enhances the understanding of the "normal" cyclic pattern of the cultivars under test.

In the wet tropics where cycles are erratic the major manipulation aim is to bring the plant under control and force it into some form of cycling with emphasis on establishing significant dormant periods. In this instance locality or site selection for growing mango could be the key to success. Areas which do have observable "dry" periods or where soils have low water holding capacity are those where useful control may be achieved. Treatments which reduce vegetative vigour such as cincturing, growth regulators, or low nitrogen rates should be considered. The plant is however dominated by the environment and if control is to be reliably achieved with treatment, the cycles, no matter how weak, will have to be monitored so treatments can be timed to achieve a synergistic rather than antagonistic effect.

Nutrition is the major manipulator of productivity commonly used. Experience suggests that nitrogen is the major manipulator in branched evergreen trees and initial work should concentrate on this element. The required status of the other elements both major and minor can be determined by monitoring leaf nutrient levels in high yielding orchards as suggested above, in association with the first stage work. Using these results and optimum levels reported in the literature a fair estimate of the optimum leaf range for each element can be defined. Experience has shown that the range over which productivity is not influenced is wide and is readily maintained in practice. The principle of management is then based on yearly leaf analysis and through normal soil reserves or application of a designed supplementary fertiliser mixture the elements are kept within the optimum range. If optimum levels cannot be achieved research will be needed to assess rates, by soil types, by environment to understand how leaf levels can be adjusted to the optimum range. Yield type research may not be necessary.

Research with the manipulators such as nitrogen, water, growth and flowering regulators is aimed at specific stages in the cycle. Value for money is more likely to be achieved by applying nitrogen to stimulate the vegetative flush after fruit removal or produce more vigorous flowers at flowering. Nitrogen could however decrease productivity by shortening or interfering with the dormancy period prior to flowering or increasing the vigour of vegetative flushes which occur concurrently with flowering and result in excessive fruit shedding. Research treatments in nitrogen and water should be designed to produce low, medium and high vegetative vigour levels and timed to influence important phenological stages of the crop. Results are recorded as impact on the development of these stages and yield and quality.

Flower regulator work is timed in conjunction with dormancy periods. Limited experience suggests that the regulators only enhance the dormancy effect and have their major benefit where length of dormancy is limited or borderline. Such regulators applied at the commencement or middle of a major vegetative flush are unlikely to have an effect. The concept to follow is to time treatments with respect to stages of the cycle and not calendar time and record responses in the cycle even at the expense of neglecting detailed yield results (ie yield estimated). A better understanding of treatment timing and response level will be forthcoming. Similar principles apply to the use of growth regulators and cincturing with respect to developing or extending the dormancy period.

Research in such cultural practices as pruning can also be related to its likely impact on the plant entering an unwanted extended vegetative phase. This phase can last for years at the extreme or interfere on a shorter scale with length of dormancy periods or fruit set stages. Cultivar reaction to pruning will vary and their reaction will determine how applicable pruning is for each cultivar. One could expect less vigorous cultivars to be more receptive to pruning.

Field research and marketing

It should be acknowledged that fruit at harvest is at its peak with respect to its ability to store, transport and be acceptable to the consumer. Post harvest treatments can only hold this peak or lessen the rate of decline. Field management and hence research establish the level to which the peak market quality rises at harvest and hence the ultimate success of the marketing chain.

Although reference in this paper has been mainly limited to yield for brevity the phenological cycle approach to research does also relate to fruit quality. Quality aspects such as fruit size, colour, texture, total soluble solids and sugar levels, all can be related to the competition and redistribution of carbohydrate reserves to the various stages of the cycle. Excess vegetativeness at the wrong period is most competitive in this regard. Mineral nutrient content and its relation to storage life can be monitored and managed using the nutrition research approach described in the paper.

The integration of pre- and post-harvest research is the ideal approach to assuring quality success in the market place.

Extension of Research Results

As all results can be related to a diagrammatic representation of the plant (Figure 1) and its responses, farmers can more readily see and understand in the field the application of the research findings and their implications to the long term cycle and performance of mango in commercial management. Because of this ability to see the technology in visual plant terms, adoption of research results is high, and there is better use of a fuller integrated crop management package.

References

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