

Crop Physiology of Bananas-quo vadis?

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The world produces about 45 million tonnes of bananas each year. Some 15 per cent of this constitutes the international banana trade and the remainder is consumed locally (Anon 1979). The banana is an important food crop for man, especially in the tropics. Experimental work aimed at testing new agronomic practices or at understanding growth and development has been relatively limited for a crop of its importance. Forty per cent more bananas are produced than citrus but research effort on citrus has been five to six times greater judged by the number of articles abstracted in *Horticultural Abstracts* in recent years. There may be many reasons for this but one is that the results of banana field investigations are often unusually difficult to interpret.

Early workers recognized these problems and Summerville (1944), working in Southeast Queensland, thought that climatic factors had such a large effect on the growth and development of the plant that until these were assessed it was not possible to study accurately other factors, such as fertilizers, which can be more closely controlled. A lot of effort has been put into field experiments in recent years, for

example over 630 reports on mineral nutrition of bananas were produced throughout the world between 1960 and 1978 (Lahav, 1980). Attention to the growth-climate-cultural practice relationship has been much less, perhaps because of the difficulties involved. A knowledge of the physiology of the crop in the field would not only lead to better understanding of the results of field experiments, but to a more rational approach to cultural practices used in different environments.

Physiological information is available for a number of crops (Evans 1975) and, while the banana lags behind there is more information available than indicated by the review of Tai (1977). Since crop physiology involves the complex system of the plant, environment and edaphic factors simulation models have been used to integrate the available data in a formal way and to explore its use in breeding, productivity and bio-climatological studies (Loomis, Rabbinge & Ng 1979).

It is my purpose here to outline an approach to the physiology of the banana which will allow us to describe the growth of the plant in relation to

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the variable climate in which it grows. It is envisaged as a means of integrating all influences throughout each growth cycle and when adequately developed should aid the interpretation of field experiments. Indeed, it should eventually lead to a reduction in this costly and inefficient procedure. It is similar in outline to that presented in general terms by Milthorpe and Moorby (1974), and in concept follows a model of the wheat crop developed by Morgan (1976).

For convenience five sections are defined :

ontogeny - formulations describing the growth of each organ

photosynthesis - the production of assimilates in the leaves

mineral nutrition-formulations describing the uptake and utilization of minerals

water - where the water status of soil and plant is followed

environment - where standard meteorological observations are converted into usable quantities.

There is a need to formulate relationships between the various parts of the system; sometimes these are well developed but often even the form of a suitable relationship is missing. Even if the relationship is known in general terms, reasonable values for its parameters are frequently unknown. Despite these limitations I think it is worthwhile to consider the whole system thereby delineating the various components and putting these together in a usable form. We do not have sufficient information to make a working model of the banana but the exercise will emphasize the relationships which need to be estab-

lished and those parameters for which we have too little quantitative information

Banana Plant Growth

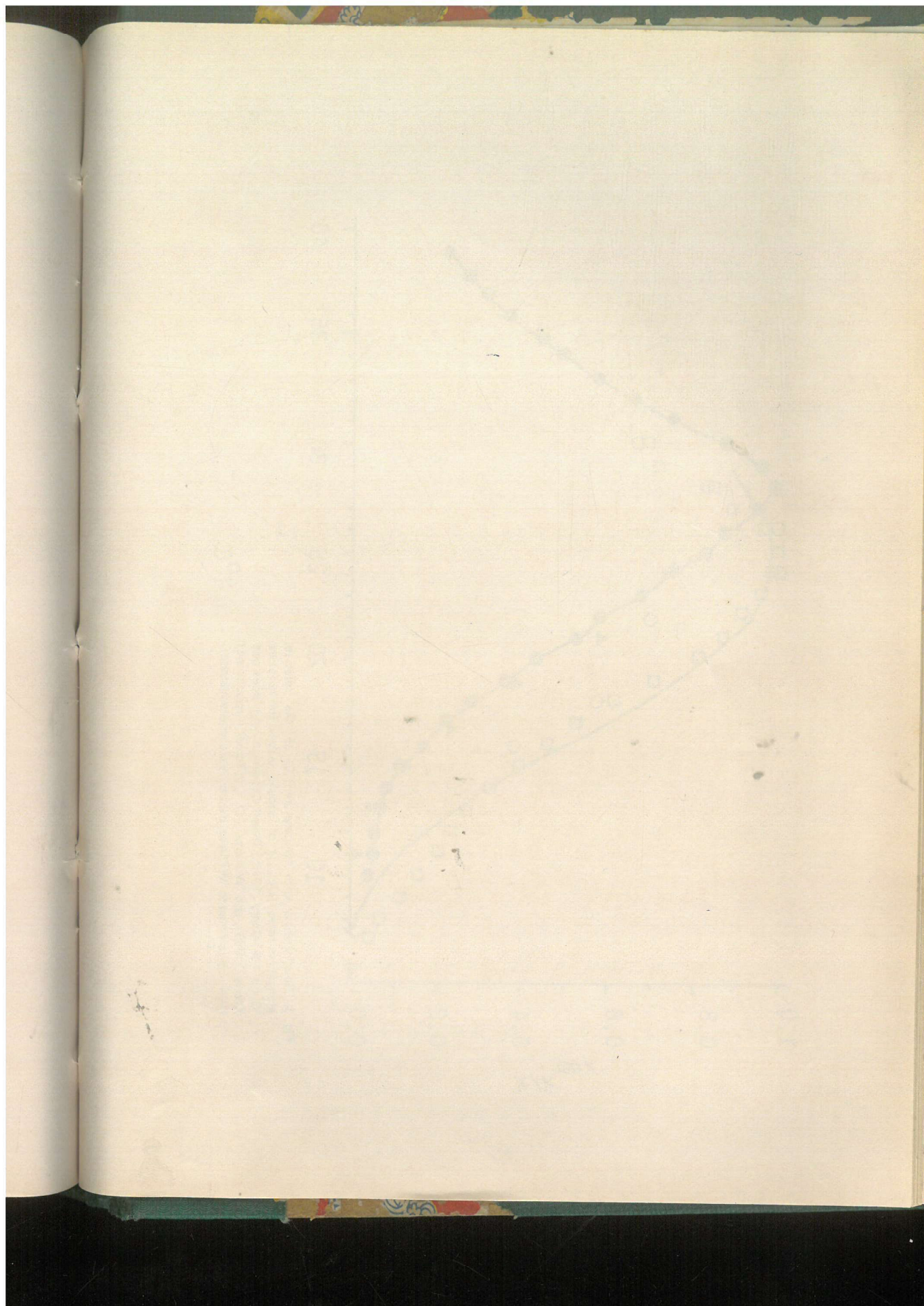
Formal relationships to describe the growth of the growing point, leaves, corm, bunch stem, roots and fruit are required. Two aspects are presented here - growing point growth and the determination of fruit numbers per bunch, the latter being conceptual only.

The growth of the apex

The growth of the growing point can be assumed to be exponential so that

$$W = W_0 e^{kt} \quad 1$$

where W and W_0 are the growing point dry weights at time t and time zero respectively and k is a rate constant. When the growing point reaches a given size it buds off a new leaf. This size increases with ontogeny. It is assumed that supply of assimilates and nutrients to the apex is never limiting since the absolute amounts required are very small and no differences exist between the size of the apex from agronomically good and poor plants (Barker and Steward 1962); however its rate of growth is influenced by temperature and water. The diameter of a 'Gros Michel' apex increases from $100 \mu\text{m}$ to $500 \mu\text{m}$ between young sucker and flowering (Barker and Steward 1962). Treating it as a hemisphere and taking the volume of a single meristematic cell as $1000 \mu\text{m}^3$ and the dry weight as $6 \times 10^{-10} \text{ g}$ (Milthorpe and Moorby 1974), W increases from $0.157 \mu\text{g}$ at the first leaf to $19.6 \mu\text{g}$ at leaf number 40. The amount of apex forming each leaf is about one-third (Barker and Steward 1962).



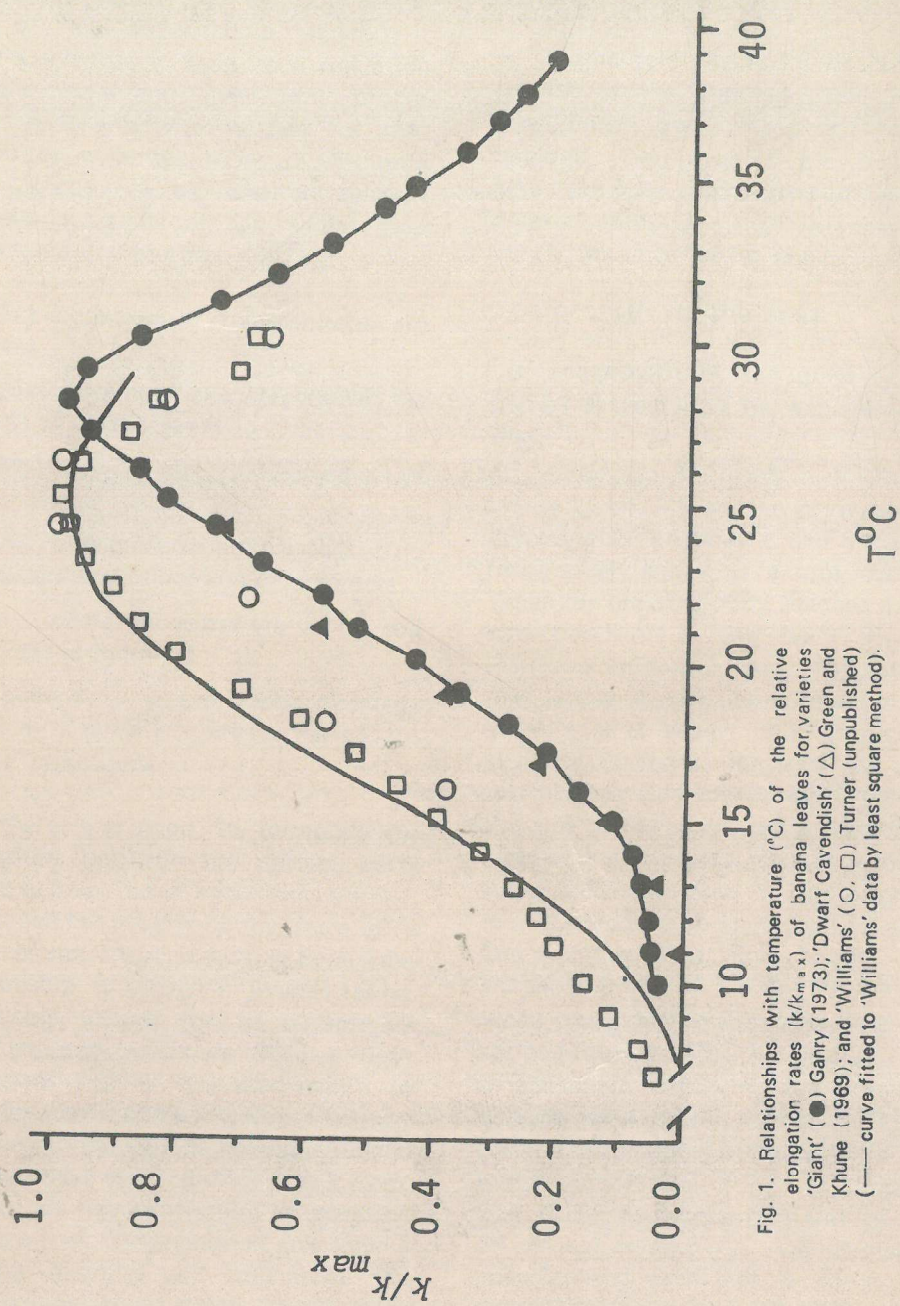


Fig. 1. Relationships with temperature ($^{\circ}C$) of the relative elongation rates (k/k_{max}) of banana leaves for varieties 'Giant' (●) Garry (1973); 'Dwarf Cavendish' (△) Green and Khune (1969); and 'Williams' (○, □) Turner (unpublished) (— curve fitted to 'Williams' data by least square method).

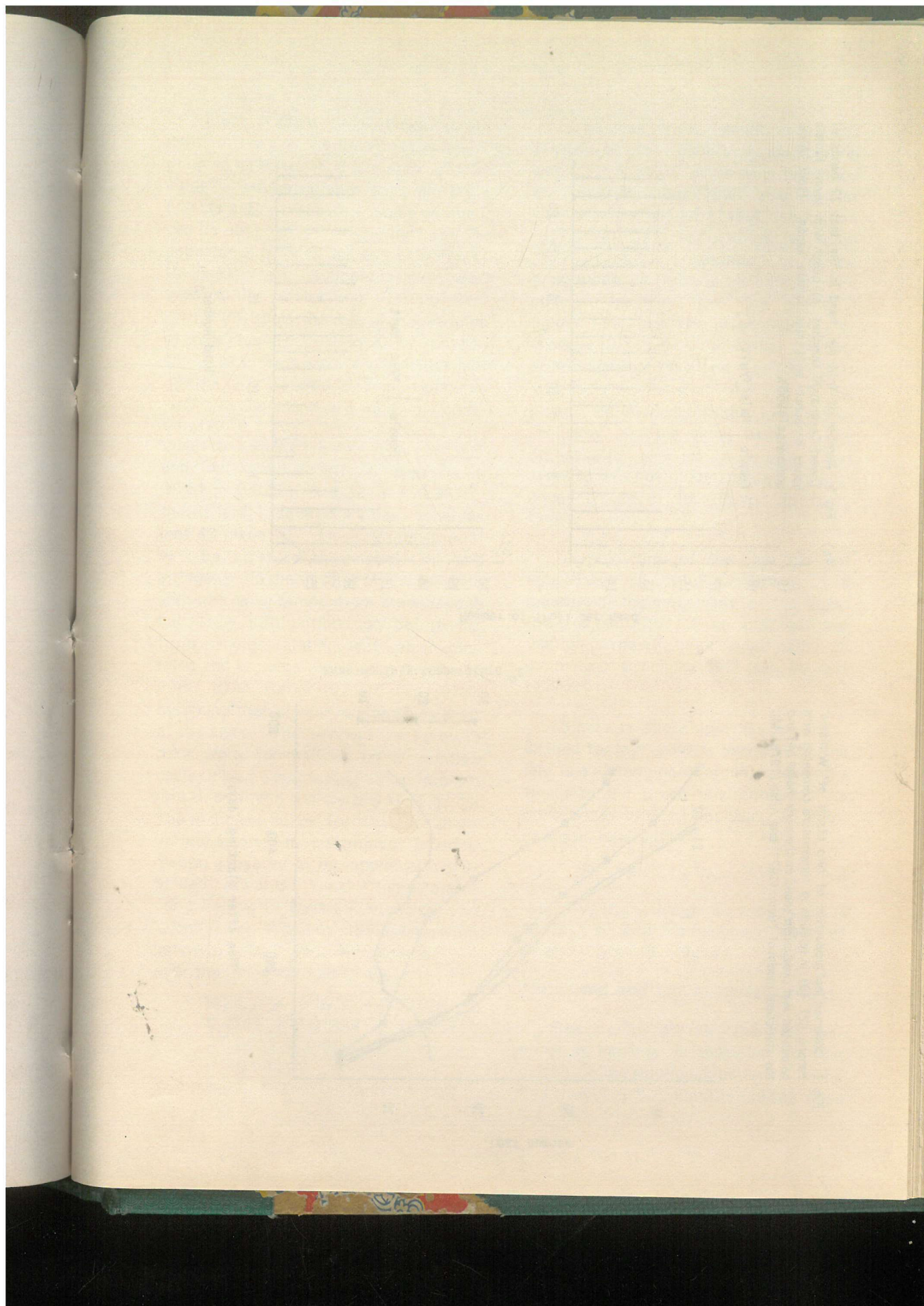


Fig. 2. Observed leaf production of two plants of 'Williams' banana (21, 40) in relation to temperature compared with calculated leaf production based on the apex model (A) and the statistical model of Turner (1971) and Allen (1978) (M).

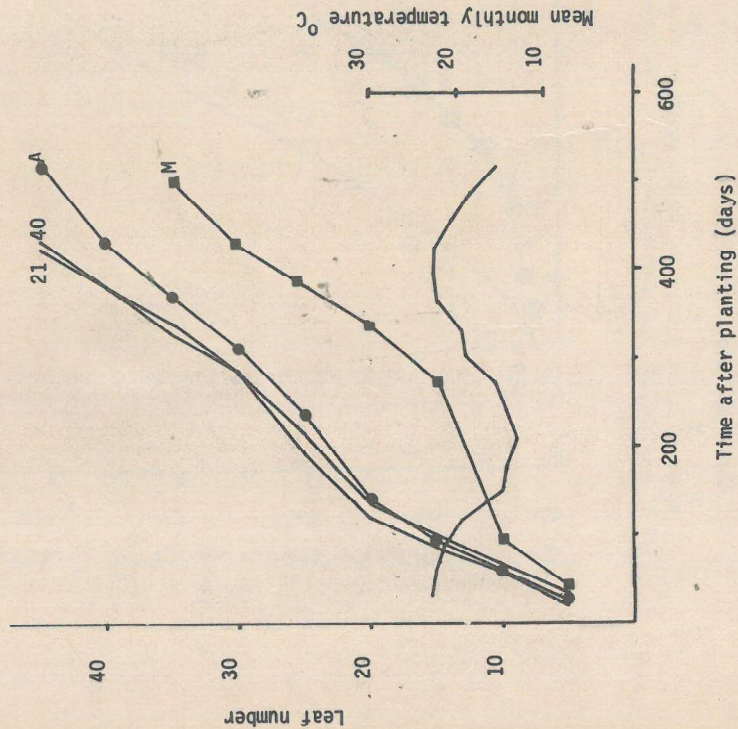
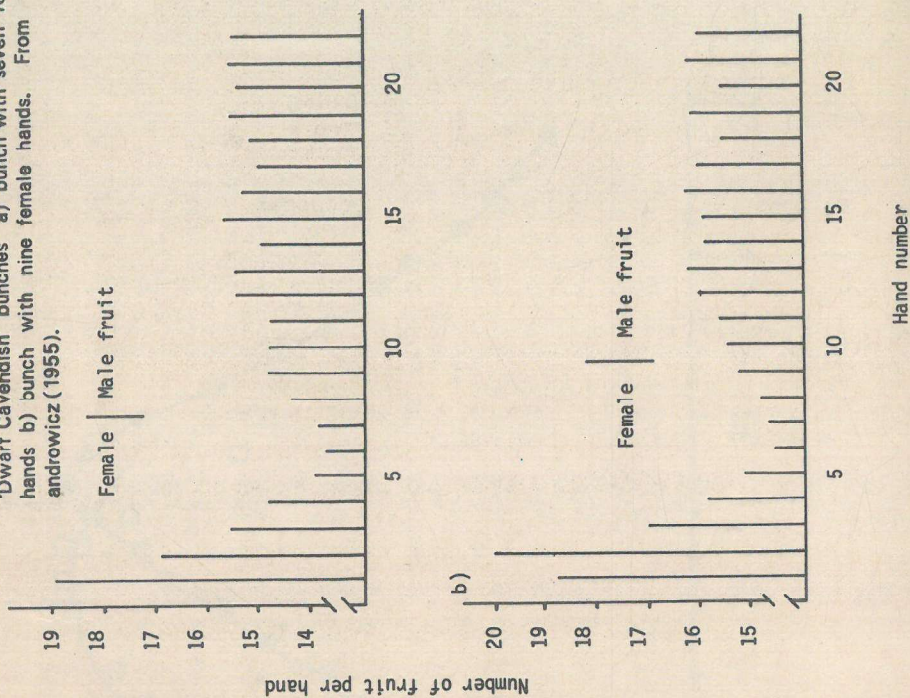


Fig. 3. Number of fruit per hand in the first 22 hands of 'Dwarf Cavendish' bunches a) bunch with seven female hands b) bunch with nine female hands. From Alexandrowicz (1955).



Stage of plant development (ontogeny) influences the time between initiation of new leaves at the apex (plastochron) although reliable data on these effects are unavailable. Some estimate can be obtained if the time between the appearance of new leaves at the top of the pseudostem (phyllochron) is assumed equal to the plastochron. Data of Barker (1969) show the rate of appearance of new leaves (reciprocal of phyllochron) at three stages of development (leaves 12, 27 and 43) in Honduras where temperatures are relatively constant (27 to 30°C). The relationship between the phyllochron (t , days per leaf) and leaf number (n) is linear ($t = 0.161 \pm 0.025 n + 4.27$, $r = 0.95^{**}$); that is leaf 1 required 4.4 days whereas leaf 40 takes 10.7 days. k (equation 1) will be affected by temperature and ontogeny. No direct data on the relationship of k with temperature are available but some information can be gained from studies relating leaf emergence rates and temperature (Green and Khune 1969, 1970; Turner 1971; Ganry 1973), assuming that similar relationships exist at the apex. The temperature - growth data were summarized on a relative basis (k/k_{max} - where k_{max} is the growth rate at optimum temperature) (Fig. 1). The response curve for the 'Williams' variety (grown in subtropical environments) appeared to be appreciably displaced towards lower temperatures compared with 'Dwarf Cavendish' and 'Giant'. For 'Williams' the relationship between k/k_{max} and temperature (T) over the range 8 to 30°C was:

$$\begin{aligned} k/k_{max} &= 0.875 - 0.22429 \pm \\ &0.024T + 0.01854 \pm 0.0014T^2 \\ &- 0.0038 \pm 0.00002T^3 \\ r^2 &= 0.992^{**} \\ \text{below } 8^\circ\text{C } k/k_{max} &\text{ is taken as } 0. \end{aligned}$$

The apex model (equation 1) was tested against observed phyllochron data of two plants in the work described by Turner & Barkus (1980) and against the statistical model of leaf production of Turner (1971) as modified by Allen (1978) (Fig. 2). Agreement using the apex model (A), was much closer to the observed pattern than the statistical model (M), because it accounted for changes in ontogeny as well as temperature, although the ontogenetic drift was too great later in the life of the plant. Refinements to the apex model are now possible since data on the ontogenetic changes in rate of leaf growth have been documented by Las-soudiere (1978) for 'Poyo' in Ivory Coast.

A prediction of the rate of leaf appearance is useful because it is a measure of the movement of the plant towards maturity. If the total leaf production is known, even empirically, an estimate of bunching date can be obtained.

Similar relationships may be established for leaf growth except that the leaf is a determinate organ, reaching a final size in a given environment. Its growth may be described using an autocatalytic relationship

$$W = A / (1 + W_0 e^{-kt}) \quad 3$$

where W is dry weight at time t , W_0 is $(A - W) / W$, A is the maximum value of W and k is a rate constant.

Flowering and bunch development

The nature of the flowering response in bananas is unknown, so we cannot define relationships for this. The Ts formula of Summerville (1944) does

not appear to have relevance for other varieties (Pillai & Shanmugavelu 1976, Turner 1979).

Some data are available on early bunch development. It is thought that the potential number of female hands is determined early in the life of the bunch but the actual number may be influenced during the 4 to 6 weeks before emergence (Summerville 1944; Simmonds 1966). However this idea fails to account for the positive correlation between fruit number per hand and hand number per bunch. An alternative approach is presented here.

The banana inflorescence consists of a number of nodes or hands each of which contains a number of fruit. The first few hands formed contain female flowers, the ovaries of which grow into the fruit of commercial importance while the subsequent hands contain male flowers, the ovaries of which do not grow to commercial size. Observations indicate that the total number of fruit in each hand decreases to a reasonably constant number in the male hands (Fig. 3). This number appears to be greater when the number of female hands is larger (Fig. 4). Conceptually observations of Figs 3 and 4 might be arrived at by a consideration of the rate of node production (dN/dt) and the rate of fruit production per bunch (dF/dt). In the vegetative phase a node (N_v) represents a leaf and in the reproductive phase a node (N_f) is a hand of fruit. The interaction between dN/dt and dF/dt then produces the type of data seen in Figs 3 and 4.

In the 'Williams' variety about 42 leaves (nodes) are produced during vegetative growth, whereas about 250 nodes

(hands) are produced in the reproductive phase, and these over similar time periods. dN_f/dt is therefore about six times dN_v/dt (where t represents a time period). In other varieties the difference between dN_f/dt and dN_v/dt may be greater or less than sixfold. This needs to be established under a range of conditions. The distribution of fruit numbers between hands may now be described. We may consider the vegetative and reproductive phases as stable states for the apex but the transition from the vegetative to the reproductive state is unstable (Fig. 5). During the transition dN/dt increases six-fold and stabilizes at dN_f/dt . If both dN_f/dt and dF/dt are constant in time then each hand will have a similar number of fruit - such as exists in the male phase of the inflorescence (Fig. 3). If dN/dt increases with time while dF/dt is constant then the number of fruit per hand (f_h) will decrease, as in the female phase of the bunch (Fig. 4). The number of female hands on a bunch will then be a function of rate at which dN/dt changes from dN_v/dt to dN_f/dt (i.e. d^2N/dt^2). If d^2N/dt^2 is large the number of female hands will be small and the number of fruit per hand will be small. Conversely if d^2N/dt^2 is small the male phase will be reached more slowly and the number of female hands and fruit per hand will be large. d^2N/dt^2 will change by a factor of 10 since as few as 2 or as many as 20 female hands can occur in the Cavendish varieties.

The magnitude of dF/dt will depend on the environment and it will have a response curve similar to equation 2. This would account for increased fruit numbers per hand in

Fig. 4. Mean number of female fruit per hand (f_h) according to the number of hand on the bunch (Cavendish group) — Poyo, ... Giant Cavendish, — Cavendish (from Champion 1967).

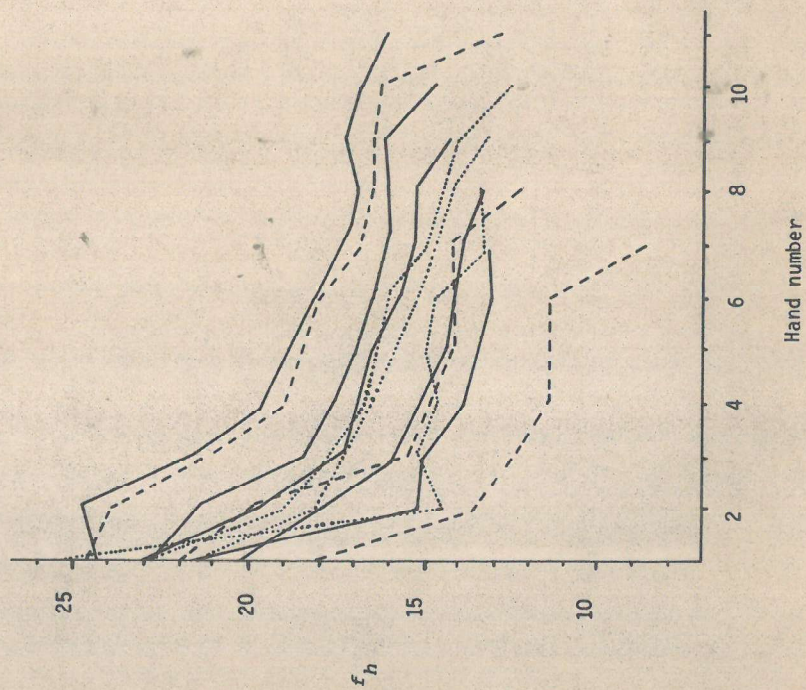


Fig. 5. Schematic representation of change of rate of node production from vegetative to male reproductive phase in relation to rate of fruit production (dF/dt).

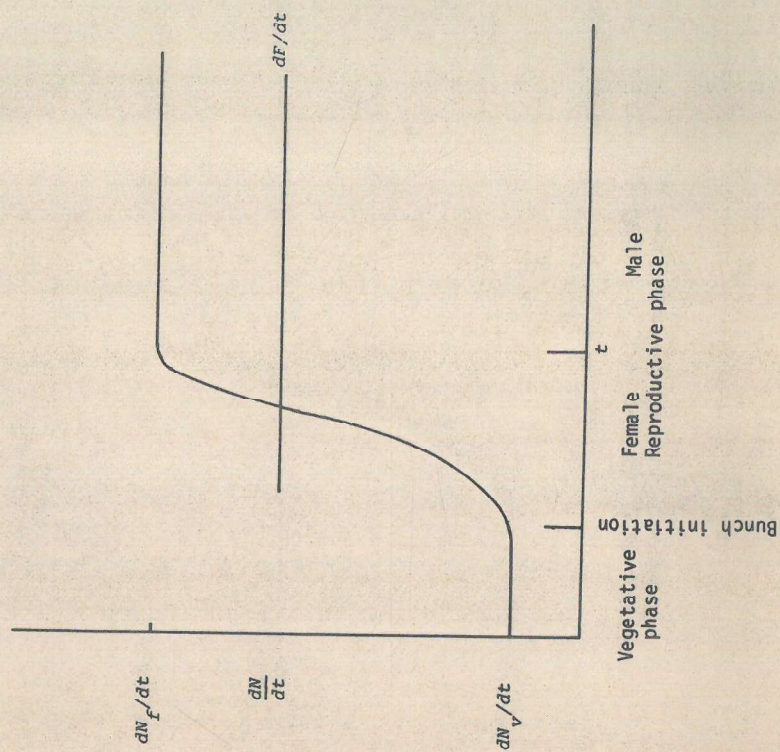


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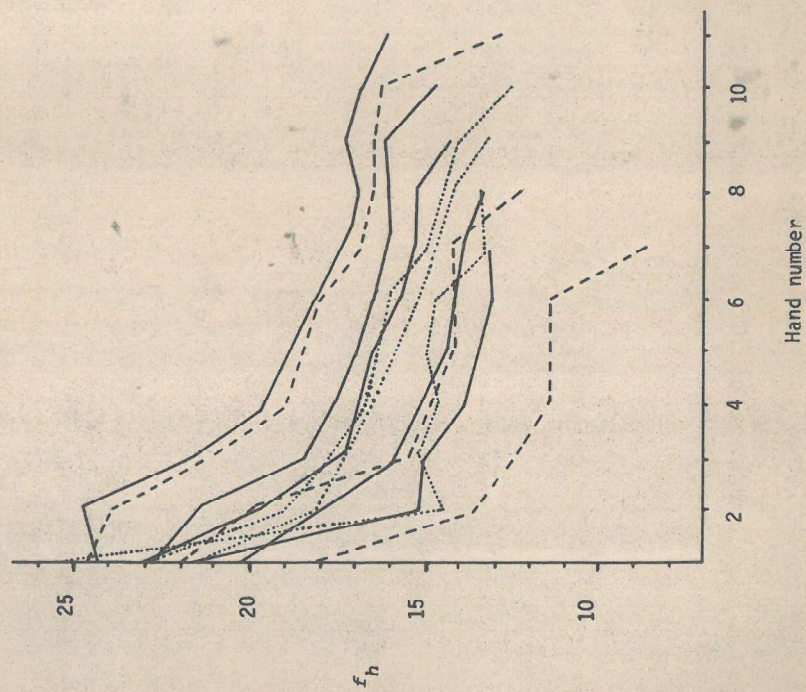


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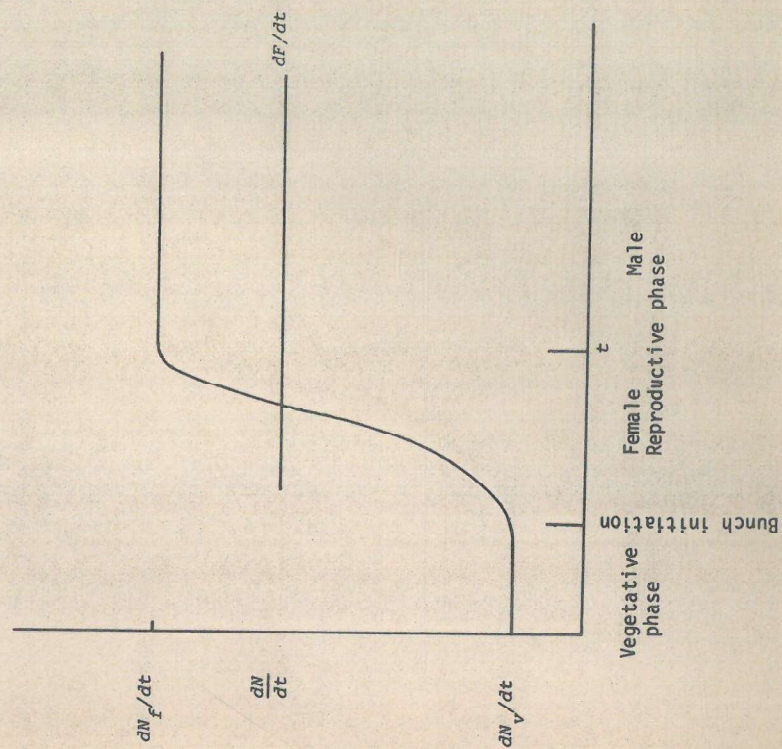


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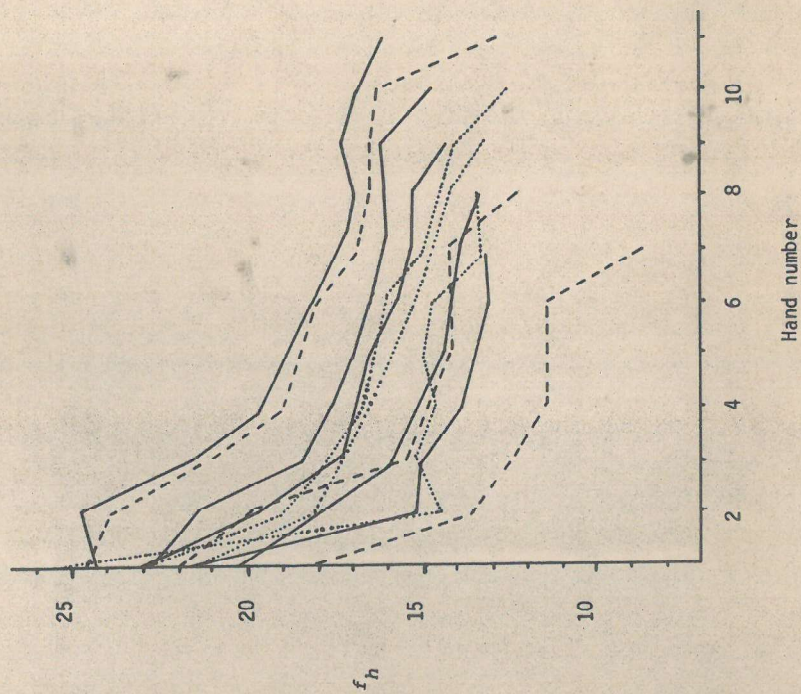


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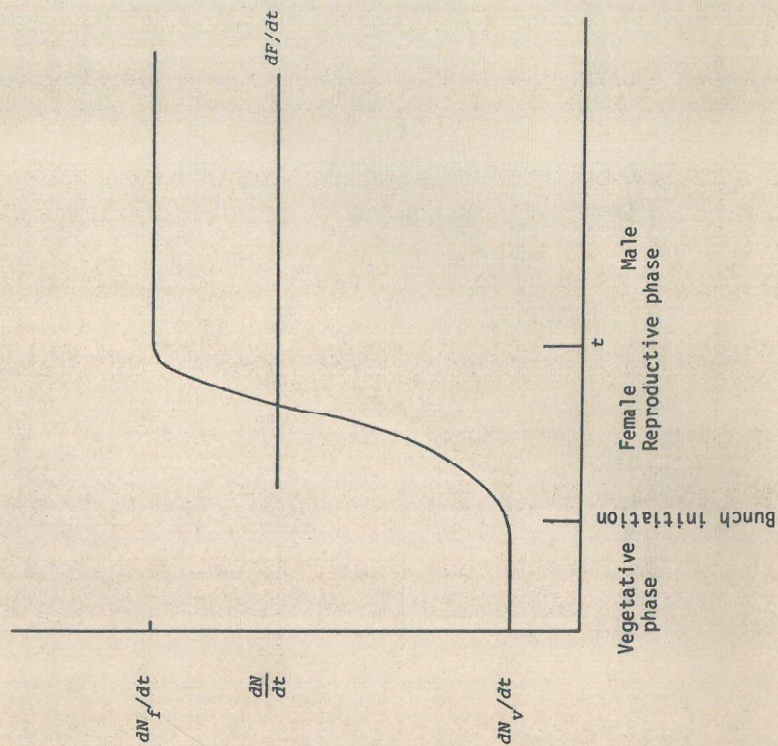
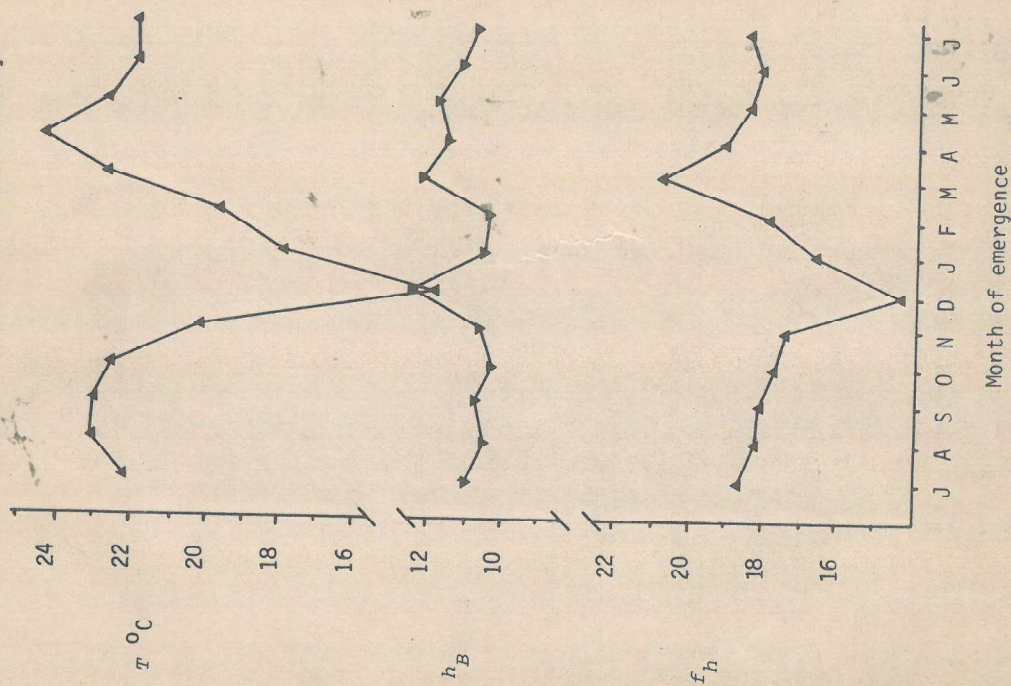


Fig. 6. Seasonal variation in mean fruit number per hand, f_h , and hand number per bunch, h_B , in relation to temperature 10 leaves before bunch emergence for 'Williams' bananas at Alstonville, NSW. [N. B. Scales do not start from zero].



Relative radiation flux in relation to flux at top of canopy.

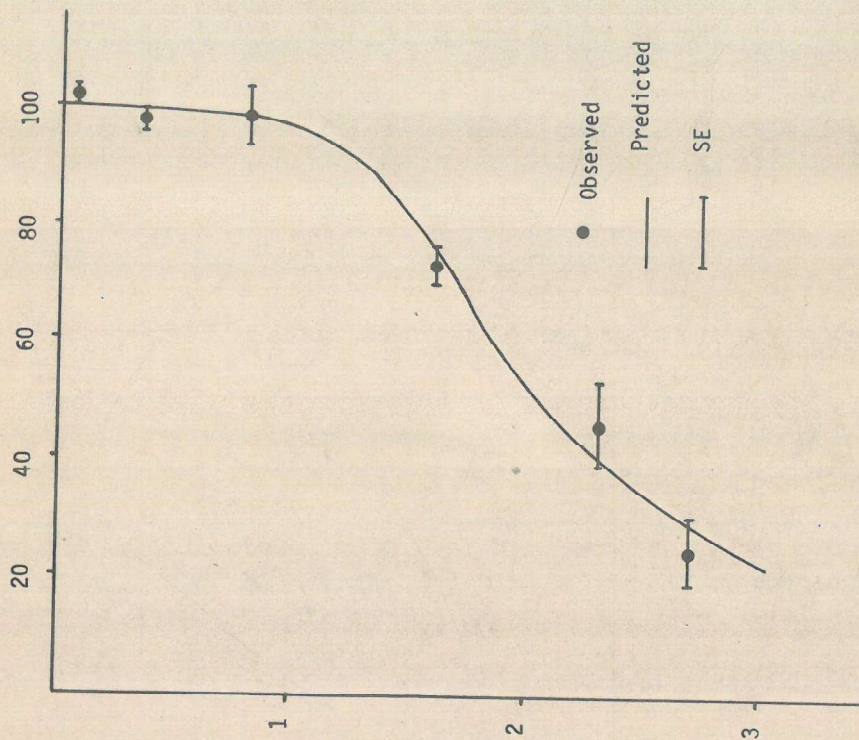


Fig. 7. Observed and predicted relative total radiation interception in ratoon crop bananas using the generalized canopy model based on Monteith (1968).

bunches with more female hands and also lower fruit per hand associated with cooler weather (Fig. 6). d^2N/dt^2 is likely to be influenced by internal and external factors. The internal factors may be regarded as concentrations of reserves in the plant and they will be inversely related to d^2N/dt^2 , thus large plants with large leaves will produce large bunches (Turner 1980). The external factor seems to be temperature which is positively correlated with d^2N/dt^2 .

A balance between the internal and external factors will produce more female hands on bunches growing in the cooler weather and the very warm weather, but not in between seasons (Fig. 6).

Summarizing, bunch development could be simulated using the following relations:

$$dN_v / dt = f(\text{environment, ontogeny}) \text{ cf equation 2}$$

$$dN_f / dt = f(\text{environment}) \text{ cf equation 2}$$

$$dF / dt = f(\text{environment}) \text{ cf equation 2}$$

$$\text{and } dN_f / dt = 6 (dN_v / dt).$$

In the transition period between vegetative phase and male reproductive

$d^2N/dt^2 = f[(\text{internal reserve concentration})^{-1}, \text{environment}]$ then hand number per bunch (h_B) will be

$$h_B = f(d^2N/dt^2) \quad 4$$

and fruit number per hand, f_h will be

$$f_h = f(dN/dt)/(dF/dt) \quad 5$$

The present difficulty with the method is to define an internal factor related to dF/dt and dN/dt and to place figures on the relationships described in equations 4 and 5.

Photosynthesis

In other crops considerable progress has been made in defining the light and radiation environment within the plant canopy (Setlik 1970). These studies give theoretical descriptions of light distribution and photosynthesis light response curves are available. They can be used to calculate the likely effects of altered plant density and arrangement on the utilization of light and potential productivity.

Following Monteith (1968) the usefulness of the generalized canopy model for bananas was explored at Alstonville N.S.W. (Turner 1979). The canopy was assumed to be continuous in relation to ground area - this is satisfactory for ratoon crop bananas planted 2m x 3m with a single sucker system - and was divided into layers of unit leaf area index (L). Within each layer leaves were assumed to be randomly oriented with respect to azimuth and to have a characteristic mean midrib angle (w) with horizontal. The relationship between w and depth within the canopy, measured as leaf area index from the top of the canopy, obtained from observations in N. S. W. and from those of Champion and Charpentier (1970) was taken as

$$w = (\pi/2) (1/L + 1) \text{ radians}$$

Radiation measurements within the canopy were made with 1 m long tube solarimeters. Within and between row radiation profiles were investigated as well as lateral variation between and within rows. Sampling problems were least with between row measurements taken hourly from 0900 to 1400 hrs. These data were compared with predicted radiation profiles using the modified Monteith (1968) model and agreement was satisfactory (Fig. 7).

To estimate photosynthesis within the canopy is only possible by extrapolating from the data of Brun (1961) who measured light response curves for banana leaves up to an illuminance of 32,000 lux. In the field leaves may experience up to 300,000 lux. No data are available on factors likely to influence to photosynthesis light response curve such as leaf age and temperature.

The supply of assimilates generated by such a description of the leaf canopy can be matched against the demand for assimilates generated by the various organs in the ontogeny section. Thus the growth of the plant can be assessed and factors limiting its growth can be identified.

At this time not a lot of data are available for the banana but descriptions of leaf geometry are needed within isolated plants, rows or where ground cover is complete. Combined with estimates of canopy photosynthesis the effect of planting arrangement can be investigated, at least in relation to its effect on potential photosynthesis.

Mineral Nutrition

There is a good deal of information available on the mineral nutrition of the banana, mostly from whole plant studies in the field (Martin-Prevel *et al.* 1965/66, Twyford & Walmsley 1973/74). Some of the relationships described in a general way by Martin-Prevel & Montagut (1966) may be used quantitatively. For example N uptake is directly proportional to whole plant dry matter production and this appears to hold for many varieties in diverse environments (Martin-Prevel *et al.* 1965/66, Twyford & Walmsley 1973/74, Marchal & Mallessard 1979). Estimates of N

uptake can be made provided dry matter production can be estimated. Or conversely the reduction in dry matter growth by low N supply in the soil may be estimated.

Relationships between growth and uptake of the other elements are less clear. Turner & Barkus (1980b) have estimated the apparent root transfer coefficient (α) for N, P, K, Ca, Mg, Mn, Cu and Zn, as influenced by K, Mg and Mn supply. These analyses show that α for K may be relatively constant, under a wide range of K concentrations in the solutions around the roots. This approach takes account of plant growth parameters (relative growth rates and top : root ratios) as well as nutrient concentration gradients from the plant to the soil solution. It offers the possibility of studying nutrient uptake in relation to plant growth and nutrient concentrations in the soil.

The recycling of nutrients is of considerable importance in bananas (Walmsley & Twyford 1968; Turner & Barkus 1973; Twyford & Walmsley 1974c). Relationships describing the distribution of nutrients between the plant parts, especially allocations to the bunch, need to be developed. These will be empirical at first but the whole plant studies of Martin-Prevel *et al.* (1965/66), Twyford & Walmsley (1973/74) and Marchal & Mallessard (1979) should provide a first approximation.

Armed with these relationships we will be in a much better position not only to interpret the response or lack of response to fertilizers in field experiments but to predict the effects of soil application of nutrients on production.

Water

The banana plant has a reputation for needing a plentiful supply of water for high production (Champion, 1963, Simmonds 1966) although few studies have been made of the factors affecting its water use or responses to water deficits.

Water use has been measured in a range of environments. In Israel (Shmueli 1953) and Ecuador (Aubert 1968) leaf discs were used to measure transpiration but this method has severe limitations (Slatyer, 1967). In Honduras (Ghavami, 1972) and the Antilles (Meyer and Schoch, 1976) drainage lysimeters were used to establish relationships between measured evaporation (E_p) and class A pan evaporation (E_a); E_p was 1.2 to 1.4 E_a for well watered soil where the canopy was complete. Arsott, Bhangoo and Karon (1965) measured changes in soil water in Honduras and estimated water use of between 6

and 9 mm d⁻¹. However no data on potential evaporation or net radiation were available.

The response of the plant to soil water deficits has been measured in terms of stomatal closure, reduction in transpiration and reduction in yield (Table 1). In general no response occurs down to -40 J kg⁻¹ soil water potential, while between -40 and -200 J kg⁻¹ a variety of responses occur, probably depending upon evaporative demand. Below -200 J kg⁻¹ a reduction in growth may be expected in all banana growing climates.

The supply of water is a major component of the variation in bunch weight from one harvest to another. There is a need to measure the actual water use of the crop and relate that to plant and environmental parameters as well as the supply in the soil. Evaporation from a crop can be described by:

TABLE 1. Summary of investigations relating soil water potential ψ to plant response in bananas.

No*	ψ (J kg ⁻¹)**	Response	Country	Author
1	-10 to -40	Nil	Honduras	Ghavami (1972)
2	-50	stomatal closure	Surinam	van Sloten and van der Weert (1972)
3	-50	reduced yield	New South Wales	Trochoulis (1973)
4	-60 to -80	reduced yield	Honduras	Ghavami (1974)
5	-100	reduced transpiration	Ecuador	Aubert (1968)
6	-100	reduced water use	Honduras	Arsott <i>et al.</i> (1965)
7	-115	stomatal closure	Israel	Shmueli (1953)
8	-200	stomatal closure	Taiwan	Chen (1971)

* Giant Cavendish clones used in all cases except Israel (Dwarf Cavendish) and Surinam (Robusta).

** All soil water potentials calculated from field capacity and permanent wilting point data, except in Ecuador (tensiometers), Surinam (water content-suction curve) and Ghavami's 1972 and 1974 experiments, where they represent treatments.

$$E = [(eQ_n R_a) / (\lambda + p(q' - q))] / [(1 + e) R_a + R_L] \quad 7$$

where $e = 1.515 \, de_s / dT$ (slope of saturation vapour pressure curve), p is the density of air, q is the specific humidity, Q_n is the net radiation received by the crop, R_a is a boundary layer resistance to water vapour diffusion and R_L is a leaf diffusion resistance for the whole plant.

The variety of responses to low soil water potentials (Table 1) shown by the banana will result from the interaction of the various components of equation 7, especially the R_L component which will influence the production of assimilates (photosynthesis section) and hence growth.

At Alstonville N.S.W. some preliminary field experiments on water use showed that the R_L component was very significant (Turner 1979). Relationships between R_L available soil water and environmental demand need to be established so that reasons for variable responses can be explored.

Environment

The environment section takes widely available meteorological data and converts them to quantities which can be used in other sections.

To estimate net radiation above the crop, temperature and hours of bright sunshine data can be used if instrumentation is not available (Linacre 1968). Mean day and night temperatures can be calculated from T_{max} and T_{min} data, making some assumptions about the sinusoidal variation of temperature between sunrise and sunset. Measurements of humidity, rainfall and

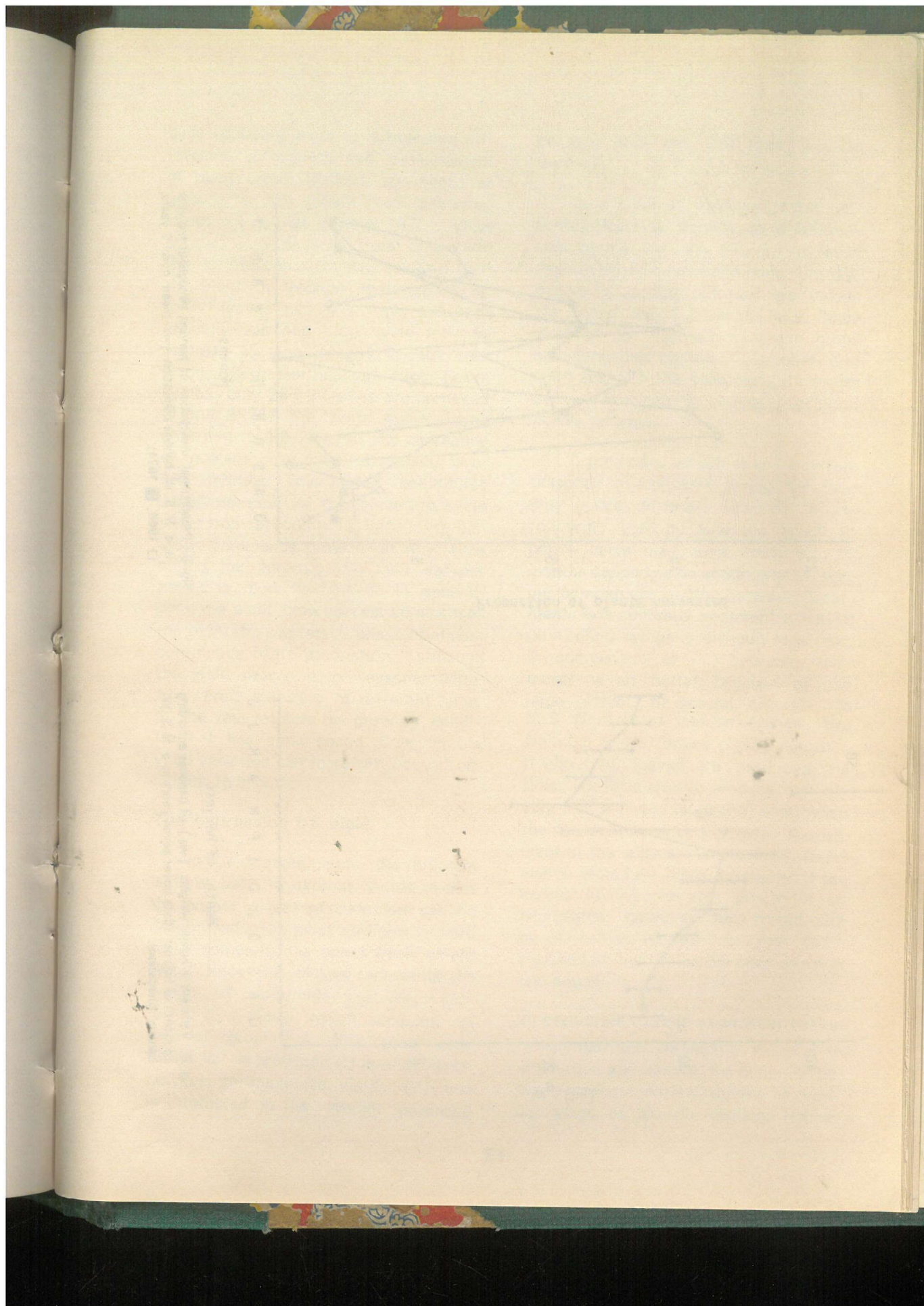
daily wind run are required. These climatic data influence the supply of water, mineral nutrients and photosynthate which in turn modify crop ontogeny and growth.

Some Alternatives

The outline I have given above is very brief and a good deal of detail has been omitted, nonetheless it provides a way in which the effect of climatic and cultural practices on growth can be assessed. Are there other alternatives? Let us briefly examine the nature of the banana plant.

Banana growth and climate

For the banana the ontogenetic sequence of vegetative growth, flowering and fruit growth is not set seasonally as in citrus, pome or stone fruits, for example. It consists of an underground rhizome (commonly a corm) which is surmounted by a growing point. Lateral buds produce suckers which, together with the parent corm, form the stool or mat. The stool consists of single-axis plants representing up to three visible generations. The first is the plant crop. Suckers arising from the plant crop form the second generation or first ratoon crop. This gives rise to the second ratoon crop and so the sequence is repeated for, say 50 or more generations. Each growing point produces about 40 ± 10 foliate leaves before it becomes re-productive. In the plant crop the growing point originates from a piece of planting material containing apical or lateral buds of another plant. The initial variation in the status of these



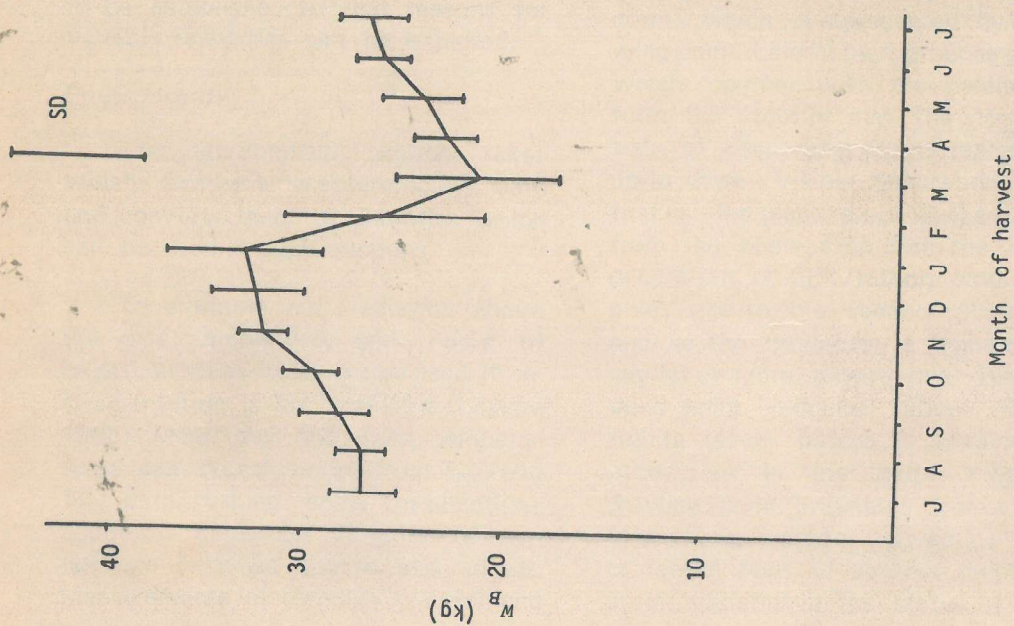


Fig. 8. Variation in bunch weights (w_b) of bananas according to month of harvest (data cover seven years in a N. S. W. banana plantation).

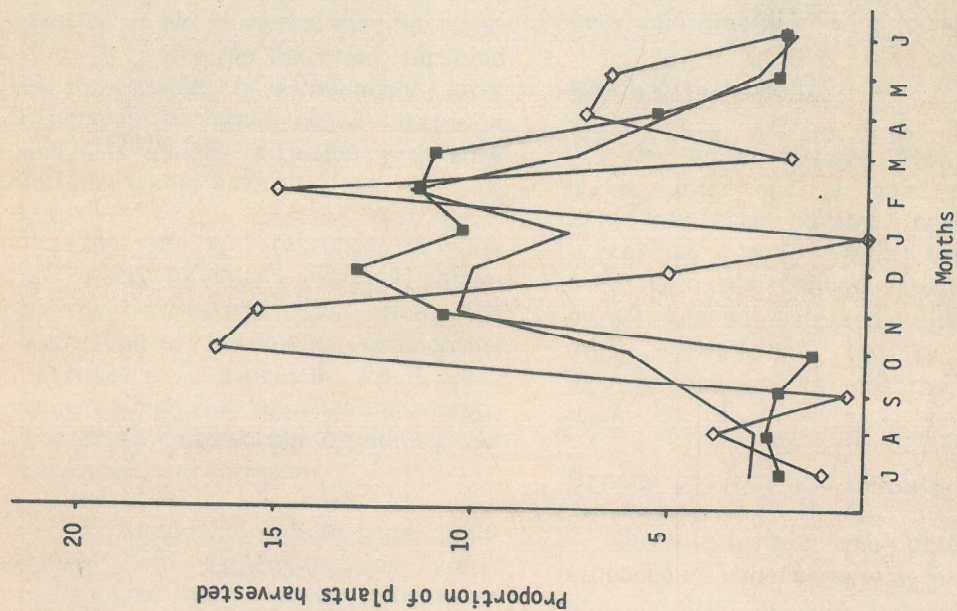


Fig. 9. Proportional distribution of harvest throughout the year in a N. S. W. banana plantation (—mean over 7 years, □ 1968, ■ 1974).

buds probably leads to subsequent differences in growth and development in plant crops. Suckers commence to grow after the parent has produced about 12 leaves (Turner 1972). New suckers may develop from then until the inflorescence (bunch) emerges from the plant. In tropical environments 40 to 50 leaves per axis are produced annually and one crop cycle may be as little as nine months. In the subtropics (e.g. Northeastern New South Wales) only 26 ± 2 leaves are produced (Turner 1971), the crop cycle being extended to 1.5-2 years. The harvesting of a plant crop may be spread over 3-4 months. This period constitutes 25-30 per cent of the whole life cycle under tropical conditions. Because ratoon crops commence growth at any time during the parent's life, their harvest period is more extended. In general, once the plant crop harvest commences the plantation enters a phase of almost continuous fruit production, although the yield shows large seasonal variation. Fruit maturing at different times of the year reflects the growing conditions it has experienced. Considerable yield variation can therefore occur from month to month.

The expression of yield

In field experiments the problem is how best to express yields so that the proper effect of treatment can be determined. The most straight-forward yield comparison is bunch fresh weight (W_B) since this closely represents the weight of marketable fruit. W_B is produced by a plant which occupies an area of ground, A . The time over which w is produced (t) is also important as, to maximise yields (Y) one is interested in the weight produced

per unit area per unit time, i.e. in $w_B A^{-1} t^{-1}$.

In a block of bananas treated uniformly W_B may vary by up to 100 per cent during the year (Fig. 8). In North eastern New South Wales maximum W_B occurs in January but minimum values are found only 1-2 months later. Since most of the bunches in ratoon crops are harvested between October and April (Fig. 9) the probability of results being influenced by seasonal variation in W_B is large.

A treatment which gives a certain response at one time during the year may give a different response in the following year because the bunch to bunch cycle may range from 9 to 18 months depending on conditions. A simple comparison of W_B between treatments will contain a treatment \times season interaction which is difficult to assess. A comparison of (Y) between treatments is no better because of the large effect of season on (t). In N. S. W. rates of leaf emergence vary from 0.5 to 4.5 leaves plant⁻¹ month⁻¹. If about 40 leaves are produced the time, (t), for a crop to produce marketable fruit will vary depending upon when the sucker commenced growth. Assessment of the effects of imposed treatments would be more tractable if the harvest distribution was similar for all treatments; however, there would still be difficulties in year - to - year comparisons of yield since the crop cycle is not annual.

Approaches to field experimentation

In nutrition research it has led to alternative approaches, the main one being to measure nutrient uptake at various stage of growth (Baillon, Holmes

and Lewis 1933, Martin-Prevel 1964, Montagut and Martin-Prevel 1965, and Twyford and Walmsley 1973, 1974^{a, b, c}). This method gives information on nutrient uptake during growth, on nutrient recycling in ratoon crops and it provides very useful information upon which a fertilizer rationale can be built. It fails to unravel the interaction of climate and nutrients. The importance of this is shown in Twyford and Walmsley's work in the Windward Is. They found three-fold differences in dry matter production and nutrient uptake related to "site factors". Similar results were obtained by Martin-Prevel *et al.* (1965-66) in the French Antilles. This approach is also of very limited use in experiments involving other cultural practices such as irrigation, desuckering, weedicides, disease control or varietal comparisons.

A less attractive alternative, which does cater for other cultural practices, is to use plots of at least 0.5 ha in size. This ensures that fruit will be harvested from all plots on most harvest dates and allows statistical analysis of results for each harvest. Bunches are comparable because they have experienced similar climatic conditions, although this is not strictly true if treatment alters (t). Such large plot sizes are impractical and expensive and do not normally allow satisfactory replication because of limits of land area. Also they do not increase understanding of the crop-climate-treatment interaction. Summerville (1944) analysed some of his results on a harvest date basis but found no improvement over standard techniques.

Twyford and Walmsley (1973) raised other problems with fertilizer field experimentation related to ratoon crop behaviour. Logically, ratoon crops will

require a lower fertilizer input than plant crops because of recycling and the nutrition of any given ratoon crop will be affected by the nutrition of the previous crop. The non-uniform setting of ratoons prevents accurate experimentation even if plant crops are treated uniformly; appreciable variation is introduced even in the first ratoon. These problems will always exist in field experiments with bananas.

We will continue on our present course of collecting more and more data on the physiology of the banana crop but we also need to give attention to making best use of the information we already have as well as new information

We need to assess the effects of climatic factors so that their contribution to yield and interactions with imposed treatments can be estimated. This would assist not only in the interpretation of banana field experiments but hopefully lead to an increasing understanding of the crop in a range of environments. The approach I have outlined requires a full knowledge and understanding of the various components involved and of how they relate to one another. Ontogenetic changes in the growth and development of the plant in time and the environmental factors which affect these are the main variables. Controlled environment experiments would undoubtedly help in this respect despite the well known difficulties of differing responses in growth rooms to those experienced in the field. In the absence of the large and costly facilities required for such studies with the banana, the effects of differing environmental factors have to be unravelled from partially controlled experiments and such isolated fragments of information

as may be available. We can make good use of this information if it is integrated into parts of a quantitative simulation model which can be gradually modified as more information becomes available and as it is tested under a wider and wider range of environments.

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