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STATISTICAL METHODS

FOR EXPERIMENTS WITH

PLANTATION CROPS

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CENTRAL PLANTATION CROPS RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
KASARAGOD - 671 124, KERALA, INDIA

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1. INTRODUCTION

1.1 Role of Statistics in Experiments

The purpose of statistical science is to provide an objective basis for the analysis of problems in which the data depart from the laws of exact causality. Statistics is universally accepted as an essential tool for all types of experiments. Experiments are conducted with the object of answering some question(s) in which the experimenter is interested and the results of an experiment, especially a biological experiment, commonly show the influence of many factors other than those whose investigation forms the reason of the research. Some of these disturbances may be traced to known or partially known causes, but the majorities are unaccountable and constitute sources of potential error in the interpretation of the results. At one time it was considered sufficient if an experiment evaluated the mean performance of each treatment, but Sir Ronald Fisher (1934) revolutionized the approach and nowadays it is required that each trial shall estimate its own error also. Variability is a characteristic of biological material and creates the problem of deciding whether differences between experimental units results from unaccounted variability or real treatment effects. Statistical science helps overcome this difficulty by requiring the collection of data to provide unbiased estimates of treatment effects and the evaluation of treatment differences by tests of significance based on measuring unaccountable variability.

The fundamental object of an agricultural experiment is to obtain data systematically and to make inferences or appropriate decisions based on the data. The most important principle of experimentation technique is to plan the experiment in such a way that the unexplained variation or the experimental error is minimized. The magnitude of experimental error is a matter of great concern in agricultural experiments. The experimental error occurs mainly due to the positional and genetic variations. By selecting genetically homogeneous planting materials such as clones or inbred seedlings, the errors due to the genetic variation can be controlled to a great extent. Major factors influencing the positional effect are soil fertility, spacing, competition from the neighboring plots, border effects, and other environmental changes. Blocking for soil heterogeneity and adopting appropriate experimental designs generally control experimental error due to positional variation. A well-conceived and properly designed experiment should be as simple as possible, have a high probability of achieving its objective(s) and avoid systematic and biased errors. Its conclusion should have a wide range of validity, and data collected from it must be analyzable by valid statistical procedures.

1.2 Problems in Experimentation with Plantation Crops

Plantation Crops, by definition, are commercial crops of perennial nature, cultivated in the tropics/sub tropics. Though the statistical techniques followed in experimentation with annual crops and perennial crops are essentially the same, the problems faced while experimenting with plantation crops are somewhat different from those of annual crops. The special feature of experiments with perennial crops is that because of the large area a tree occupies, individual trees assume importance in forming plots for experiments whereas in the case of annual crops aggregate of few hundreds of plants are considered together. Since the spacing is wider a relatively small number of plants can only be included in any experimental plot. If the plots are made too large the major soil fertility difference within blocks often nullify the advantage gained by increasing the number of trees per plot. Most of these crops are cross-pollinated and hence highly heterogeneous. However in some cases it may be possible to start the experiment with fresh plantations raised through vegetative propagation or by seedlings from the same parent stock obtained through *inter se* mating. But when an experiment is to be superimposed on an already existing plantation, formation of blocks by putting the experimental material is highly heterogeneous and of blocks by putting together adjoining plots may not give a satisfactory solution. Even when seedlings are planted together casualties in experimental plants adversely affect the uniformity of the plantations. When the gap filling is done at the appropriate time, the shade effect of the older trees on the gap filled plants and competition for nutrients and sunlight cannot be avoided. All these crops are having a long juvenile phase and the time taken for flowering differs between plants of a plot. Similarly differences are also prevalent for stabilization of yield and duration of bearing in the plant's life span. Since the crops are of perennial nature, the differential response of individual plants to the varying weather conditions from year to year introduces a further uncontrollable variation factor. The root spread of these plants is extensive and inclusion of non-experimental border trees becomes essential to avoid border effects, with the result the area required for the experimentation increases considerably. The effects of fertilizer application and other management practices cannot be immediately assessed as the effect manifest only after considerable time lag. This necessitates the continuation of these experiments for long period. During the juvenile phase of the plants due to lack of reliable parameters, the effects of the inputs cannot be assessed with certainty.

Some of these problems in experimentation with plantation crops had attracted the attention of statisticians in the past and the work done, and results obtained within and outside the country in fixing the size and shape of plots and blocks, number of replications, border effect and necessity or otherwise of guard rows, calibration and utility of covariance analysis, forecasting methods, estimation of pest population, quantifying the severity of disease symptoms etc, in coconut. arecanut, cocoa, cardamom, pepper, ginger, turmeric and oil palm are discussed in the following sections. Some references of similar studies conducted in other plantation crops like tea , coffee and rubber have also been given.

2. FIELD EXPERIMENTATION TECHNIQUES

Field experimentation techniques in fruit trees and other perennial plants have been discussed in detail by Pearce (1976), Chaudhary *et. al* (1979) and Anon.(1986). Daniel (1984a, b) and Daniel and Bonnat (1987) have also specifically dealt about field experimentation techniques in oil palm and coconut. Jacob Mathew (1991) has also discussed in detail the statistical techniques for experiments with coconut.

2.1 Size, shape and orientation of plots and blocks and number of replications.

The primary objective in any field experimentation technique is to minimize the error variance. In any field experiment, proper selection of the size, shape and orientation of plots and blocks will reduce the experimental error considerably. Compact block with uniform plots is a prerequisite for field experimentation.

Smith (1938) gave an empirical relation between variance and the size of the plot. He defined the variance law as $Y=ax^{-b}$ where Y is variance of yield per unit area based on plots of x units, a is the variance per plot of unit area and b is a characteristic of soil and measure of correlation among contiguous units. In the case of trees and bushes Pearce (1955), modified this relationship as $Y=V1/x + V2\,x^{-b}$ where, V1 and V2 correspond to the genetic and environmental components of total variation. Singh et.al.(1975) have summarized the various methods for fixing the size and shapes of plots. While the CV of plots decreases with increase in plot size, this decrease is not proportionate. Consequently, an increase in the number of replications, with a reduced plot size, if necessary leads to a more precise comparison of treatments. In perennial crops, size of plot has to be considered in the light of possible losses of experimental plants due to mortality. If losses are expected, it is better to use either large plots that can stand a few losses, or small ones that can be completely eliminated from analysis but not the medium sized ones. Blocks may be arranged in such a way as to maximize differences between blocks, whereas plots are arranged within blocks, so as to minimize the differences among them. In many of the tree crops, genetical component of variation is of sizable magnitude, compared to the environmental component. Care has to be taken to control the former component of variation while forming blocks. When the experiment is laid out in slopy and uneven area, orientation of plots also assumes importance. Number of replication is generally decided on the basis of available experimental area, the residual degrees of freedom required, the possibility of losing some of the plots due to mishaps and the efficiency required for the estimates. Some results of studies conducted have been presented below crop-wise.

Coconut: The earliest report regarding plot size for coconuts is from Sri Lanka. Based on the uniformity trial, Joachim (1931) found 18-20 trees per plot as the optimum for field trials under plantation condition. The C.V. of these plots was around 14%. For treatment differences of 15% to be considered significant, six replications were required. Pieris and Salgado(1937) also arrived at more or less similar conclusion. In India, Shrikhande(1957) found that there was no marked reduction in C.V. beyond eight trees per plot. He found that the genetic and the environmental components are in the ratio 1:2 or 3:2, though Pankajakshan (1960) has later shown that environmental component is more important when the data are considered in blocks of four or more years. For smaller plots the genetical component was more important and therefore when the plot size is four or less, it is advantageous to give importance to the genetic component. Working out the serial correlations of varying orders, Seena and Prabhakaran (1997) has estimated the percentage of genetical variability as 83.4. Shrikhande (1957) had also tried alternative method of reducing variation and increasing between block variation, by controlling environmental and genetic components of variation separately and in combination.

With the increased plot size, Abeywardena (1964) observed, that the effect of bienniality was nullified. He has suggested that six palms should be the minimum plot size for avoiding any significant bias in the interpretation of single years data. Even with six palm plots, the C.V. could be kept within 10% with the aid of calibration, indicating further reduction in plot size in. coconut experiments (Abeywardena, 1970). Alforja *et. al.* (1978) have shown that for fertilizer experiments with polybagged coconut seedlings, significant results were obtained with 12 seedling plots.

In the absence of uniformity trials, data from other experimental plots have also been used, after eliminating the treatment effect, by the method suggested by Ray *et al.* (1973). Data from two locations in the west coast have shown that for D x T palms, the per unit decrease in CV was minimum when the plot size exceeded eight palms (Nambiar, 1986). Similar results were obtained for WC Tall palms also (Nambiar, 1989). Analysis of data for T x D palms for four years has shown that a plot size of six palms is optimum, when the data are considered for individual years, and 3 to 4 when the data are considered for four years together (Anon., 1986).

Alternative methodologies have been proposed by Peiris and Thattil (1997) to determine the most efficient plot size for tree crops, using data from experiments based on randomized complete block design. They suggested that efficient plot size for field experiments in coconut, for a wide range of agro-ecological vigours is four or six palms.

Arecanut: C. V. decreased with increase in plot size (Agarwal *et. al.* 1968). In general, beyond the plot of eight palms, the reduction in C.V. was not appreciable in both four plot and eight plot blocks and rectangular plots were more efficient. Six palm plots with single guard row were found to be the optimum. With this plot size, the number of replications required was 4-6 in four plot blocks and 5-6 in eight plot blocks, for 10% S.E. of mean. For arecanut nursery experiments Bavappa (1959) found 24 seedling/plot as the optimum.

Cocoa: From uniformity trials, conducted at Trinidad, Cheesman and Pound(1932) concluded that when the plants are reasonably uniform with respect to age, field experiments on a latin square layout with 12-18 trees per plot are expected to demonstrate differences due to treatments of the order of 30%. Based on similar trials at Grenada, Jolly(1942) recommended plots of 0.05 acre in size, if sufficient replicates were used. Pearce and Thom(1951) reported, from Nigeria, that the plots should be as small as practicable and correction by covariance of preceding two or four years yield to reduce the error. By this way, if plots are not more than 0. 025 acre in area, about 0.15 acre per treatment is needed for a reasonably accurate experiment. In Ghana, Gunningham and Burridge(1959) suggested 16 tree plots for uniformly spaced cacao. With this plot size, about 12 replications were required for 20% difference between treatment means to be significant at 5% level. Paez and Siller (1963) recommended eight tree plots.. Paez(1964) further brought down the size to 4-6 plants and recommended square plots of four or nine plants when using borders and in the absence of borders, rectangular planting may be preferred. However, further studies have shown nine tree plots and five replications as optimum for detecting yield differences of 20% when spacing is uniform and under regular shade canopy (Pereira 1972). A trial in less evenly planted commercial field shaded by several tree species was found to require at least 14 tree plot and six replications, to detect yield differences of 30%.

Cardamom: Heterogeneity between rows was found to be significantly more than that of columns and as such formation of plot with more number of rows will give more homogeneous blocks for experiments (George *et. al.* 1979). A plot size of 12 plants arranged in four rows of three plants each for smaller blocks and 18 plants in six rows of three plants each for larger blocks has been recommended as the optimum.

Pepper: Abraham et. al. (1969) examined the data of pepper wines and concluded that, on the basis of cost factor, single standard plot was the optimum. A plot size of two standards was optimum with a single guard row and 6-8 standards with double guard rows. The minimum number of standards per treatment required to achieve a given level of accuracy of the means (5% standard error) increased progressively from 67 to 200 standards, with the increase in plot size from one standard to 50 standards, when 4-plot blocks were used. Larger plots in compact blocks were better than oblong plots. However, these differences were not appreciable for smaller plots.

Oil palm: Webster(1939) recommended a plot size of 12-32 palms, considering single year yield. Ollagnier(1951) recommended small plots of 6-12 palms and high degree of replication. Study at Nigeria has revealed that optimum plot size was around 16 and plot shape do not affect plot variability(Chapas 1961). In the study conducted by Nambiar et al (1992) based on the yield data from NPK fertilizer experiment it was concluded that the optimum plot size is around 8 palm/plot. The coefficient of variation was less for plots of shape 4 rows x 2 columns, the rows being across the slope. Smaller blocks were found to be more efficient. In another study, using data from a uniformly treated plot, a plot size of about 10 palms was found to be optimum (Anon., 1997). C.V. was comparatively less in the plot shape of 10 rows x 1 column (10x1) compared to 1x10, 2x5 and 5x2 shapes.

Cashew: Analysis of uniformity trial data revealed that the percentage information in maximum in single tree plots (Nair and Prabhakaran, 1983). To avoid the chance of loss of information with single tree plants, they suggested the use of two tree plots. In another study, George et. al. (1991) found that a plot size of 6 rows of 2 trees each, and forming plots across the fertility lines as the optimum.

Tea: Eden(1931) found plot size of 0.056 acre as the most suitable, with latin square design. Dutta and Heath (1960) suggested 30-45 bushes as the optimum and recommended long and narrow plots to square ones. Sen and Biswas(1966) also found long and narrow plots with longer side extending along the contour lines as the most suitable one. The C.V. showed a declining tendency with age. Therefore more replications would be required for experiments with young tea than with mature tea.

Coffee: The earliest recommendation was 20 bushes per plot (Gilbert, 1938). Gonagin and Fraga Jr.(1955) tried two plot sizes of nine and four plants and found that smaller plots were efficient in eleminating differences in soil fertility. Butters (1964) found nine tree plots (3x3) as the most suitable and between 12 and 22 replications would be required to give a 90% probability of detecting 20% yield difference in a randomised block experiment with four treatments. Awatramani (1965) critically examined the results of the past experiments and confirmed the findings of Gilbert (1938) that the C.V. was low for experiments conducted on old trees. In the case of cultural experiments, where treatment differences are expected to be small an increase in the number of replications to eight and use of other methods of improving accuracy of the experiments (like analysis of covariance using pre-treatment data, etc.) were suggested. In manurial experiments where treatment differences are generally high, it is desirable to have minimum six replications. For pot experiments, total number of plants per pot should be as high as possible and long and narrow plots are preferred to those tending towards a square shape(Castillo and Parra, 1960)

Rubber: Narayanan (1965) found that, about 35-40 recorded trees per plot would permit estimation of plot mean with a standard error of 6% of the mean for girth and 12% for girth increment, for experiments with young trees. Iyer (1968) also assessed the effect of plot size on the precision of measurement of girth, girth increment and yield with the data of mature and immature trees. Neither the plot size as area nor the trees per plot (stand) have any effect on the C.V. of girth and girth increment.

Paardekooper(1973) stated that smaller plots with more replications are always more efficient than larger plots with fewer replications. Single tree plots are always the most efficient and preferably should be used for all experiments not requiring guard rows. For girth, when trees are grouped into plots, as opposed to single tree plots, the loss in efficiency is about 30% for plots of 12 trees, 50% for plots of 24 trees and 65% for plots of 36 trees. This meant that the total number of trees required in an experiment with 24-trees plots is twice that of a single tree plot design, to achieve the same sensitivity. Even though there is loss in efficiency in a six to eight tree plots as against single tree plots, the former were preferred as, it is more convenient to determine the bulk yield of the plot, than that of individual trees. Another advantage of plots of eight trees is that the, skewed distribution of yield will be corrected to near normal (Narayanan, 1967). Paardekooper (1966) has cautioned that the marked advantage in efficiency of very small plots can only be realized in experiments where no guard trees are required. With a single guard row around the recording plot the optimum size is 20-49 trees giving 6-25 recording trees in the centre.

Ginger & Turmeric: In ginger, plot size consisting of 3-4 rows of one column in the case of ultimate unit of plants in 1mx1m. bed, and plot size of 6 rows of one column in the case of ultimate unit of one row of 5 plants each, were found to be optimum (George et al. 1984).

In the case of turmeric, plot consisting of 3 beds of size 1m.x1m. along the fertility gradient was found to be optimum (George *et al.*, 1984).

2.2 Border effects and guard rows.

Owing to the border effect, the yield or other characters of the plants near borders differ from those at the centre of the plot. In varietal trials, the border plants of a more vigorous variety gain in competition with plants of neighboring plots with less vigorous variety whereas this advantage is not available to the plants in inner portions of the plot or under normal field conditions. To a certain extent this anomaly can be avoided by proper orientation of plots. Similarly, in manurial trials, the manure from manured plots might seep into the adjoining plots and may vitiate the treatment effect. Apart from the possible introduction of a bias on the comparison of treatments, these border effects would lead to an inflation of error variation by increasing the heterogeneity among plots. To overcome those problems non-experimental guard rows are suggested.

Govinda Iyer (1957) examined the yield data from coconut manurial experiment laid out in a randomized block design with three treatments, five replications and nine-tree plots. The mean yields of central trees and border trees did not differ. Hence it was suggested that the data obtained from all the 9-trees in each plot may be used with advantage for analysis instead of the data from the two central trees only. This is not unexpected in the light of results (Kushwah *et.al.*1977) from root studies where it was noticed that 75% of the roots are confined to an area of 2m radius around the bole of the palm. Maheswarappa *et. al*, (2000) have also reported that the effective root zone lies within 1m radius in six year old coconut palms and within 2m radius in 26 year old palms, in littoral sandy soil. But analysis of field data from a varietal-cum-manurial-cum-irrigation experiment in sandy loam soil indicated that the experimental palms in the border rows behave differently from the palms in the inner rows (Jacob Mathew et al., unpublished). Similarly the border palms in the rainfed plots are greatly benefited by irrigation received from the adjoining irrigated plots. This points out the need of guard rows, in some experiments.

In arecanut, Bhat and Leela(1969) has observed that 60-67% of all roots and 51-56% of fine roots are concentrated within a 50cm radius of the palm and more than 80% of all roots are within 1-1.25m from the trunk. Therefore, edge effects may not be very much appreciable in manurial experiments, where the spacing adopted is 2.7m x 2.7m or more.

Vernon (1968) had made separate recordings of the "edges" and "cores" of the plots of cacao shade and manurial experiment at Ghana and found that the gross plot yield exceeded the guarded plot yield by about 17%.

In the case of coffee, Castillo and Parra(1960) found that guard rows are needed for pot experiment.

For rubber, Watson and Narayanan(1963) have suggested one boundary row on either side and two trees at either end of the recorded rows, as guard rows, for normal planting distances to protect the experimental trees from poaching, when the trees are 5-6 years old.

2.3 Calibration

Calibration is defined as the use of prime information pertaining to a given experimental material to control (by statistical means) its variability during the experimental phase. In many tree crops, genetic component of variation is of sizable magnitude compared to the environmental component (Shrikhande, 1958). Pankajakshan (1960) has shown that environmental component is more important when the data are considered in blocks of four or more years. Pearce (1976) has suggested that calibration bv a suitable auxiliarv variable for reducing this variability. Another interesting approach of using auxiliary variable is to use stratified random designs instead of the usual randomized block designs. In this case, the uniformity as revealed by auxiliary variable instead of geographical contiguity is taken as guideline for forming blocks.

The idea of calibration for reduction of experimental errors have been in vogue since 1930. Eden (1931) appears to be the first to advocate calibration trials with perennial plants (see Pearce and Taylor, 1950). He has cited a trial, which was conducted "blank" for three, years with treatments added in the fourth year. Calibration is intended to control the genetic variation, which is of greater magnitude in many of the plantation crops.

Coconut : The advantages of calibration and covariance analysis has been compared by Shrikhande, (1958) and the different methods used are (1) control of environmental variation alone by dividing the land into compact blocks and within each block the adjacent trees are grouped to form plots, (2) control of genetic component of variation alone by grouping the trees on the basis of past yield records and blocks are formed with palms of similar yields, (3) combination of methods 1&2, that is, the land is divided into compact blocks and trees arranged within blocks according to their yields. Reduction of variability in experiment could be achieved through methods 2 and 3 , which aim at controlling the genetic variability. However, this can also be achieved through method I, through covariance analysis. The use of covariance technique with methods 2 and 3, did not reveal a substantial improvement, which was not unexpected, because it meant a two-fold use of the previous records.

Saraswathi and Krishnan (1989) suggested an alternate method of grouping of palms, having marked yield differences. This method is based on the principle of negative intra-class correlation present among the experimental units within a plot. This method is found to reduce the within block variation, by increasing the within plot variation.

Cocoa: Based on the uniformity trial data, Cheeseman and Pound (1932) has suggested that, with plants heterogeneous for age, field experiments should not be recommended unless previous records of natural yield are available. The use of records for three years previous to the experiment may increase precision by as much as eight fold. However, the value of previous records varies with circumstances, and cannot be stated in general terms, because the inclusion of an abnormally good or bad year may result in a loss, rather than a gain in precision. Gunningham and Burridge (1959) also found satisfactory reduction in variability, decrease in the required number of replications and increase in precision by calibration and adjustment. Single season calibration was unsatisfactory. He suggested adjustment of paired seasons by paired seasons and any experiment will, therefore, cover four seasons. Jolly (1942) has also suggested obtaining yields for at least one control year, since the physical appearance of field is evidently a poor guide to its variability. Longworth and Freeman(1963) recommended trunk girth as a calibrating variate for yields in the case of (i) young trees(ii) as a supplement to pre-treatment yield on mature trees and (iii) where it is essential to begin a trial immediately on previously unrecorded trees. Vernon and Morris(1964) studied 18 years data for nearly 2500 trees, and found that one year pre-experimental data reduces the error variance of the first experimental year, on an average in the ratio 0.5:1.0. The decrease was less for subsequent experimental years, the ratio being 0.9:1.0 for an 8-year interval. Gain in accuracy from two years prerecording was greater than from one, the difference more than justifying the cost of the extra years recording. However, the extra prerecording which delays the start of an experiment by one year may not be worthwhile.

2.4 Plant competition in mixed crop trials

Mixed cropping experiments or growing more than one crop in a garden are intended for the optimum utilization of the land. They are also very important in the case of perennial crops where during the pre bearing period of the main crop some inter crops can be grown. It is necessary to study the intra and inter component competition between plants to choose proper combination and spacing of crops. There have been many investigations to study the plant competition both in pure and mixed cropping system in several crop species.

In the case of cocoa + arecanut mixed cropping system Jose *et al.* (1995) studied intra and inter component competition using inverse polynomial model of the form $W_c^{-1}=A_c+B_{cc}P_c+B_{ca}P_a$, where Pa , Pc are plant densities of two crops 'a' and 'c', Wc is the mean yield per plant of crop c, Bcc and Bca are intra and inter component competition coefficient and Ac is the intercept. The analysis of pooled yield data of cocoa and arecanut for different growth periods showed that in the case of cocoa, the main source of competition is intra component competition and the inter component competition was significant only during 3rd to 6th year of planting whereas in arecanut inter component competition was significant during 11th to 14th year of planting and in other periods both intra and inter competition coefficients were not significant.

Interplot competition was noticed in mixed cropping trials with arecanut in small plots. To avoid this, provision of adequate border rows or increasing the plot size has been recommended. In mixed farming trials where grass is grown in arecanut gardens in bigger plots , intra class correlation was positive showing absence of competition between plots (Anon., 1977).

2.5 Duration of experiments

Duration of the experiment generally depends on the objective of the study. In the case of varietal evaluation studies, the trial may have to continue for 15-20 years. In the case of fertilizer experiments, it may have to run for at least 10 years. Mathes (1980) studied the yield data obtained over 20 consecutive years, from a fertilizer trial carried out in a mature coconut plantation and found that the inter-annual correlation coefficients between successive pairs of years first increased, then reached a plateau, increased again and ended in an asymptote. From the eighth year onwards, these correlations remained stationary. On the basis of these results, an 8 to 10 year experimental period has been recommended to be sufficient to determine the full response of fertilizers. This is not unexpected, because in a fertilizer trial, Muliar and Nelliat (1971) had found that the effect of phosphorous treatment was visible in coconut after ninth year only.

3. ANALYSIS OF DATA

3.1 Normality in the distribution of yield data

In the usual statistical techniques adopted in agricultural data analysis, it is assumed that the data follows normal distribution. It is observed that in experiments with perennial crops, this assumption may not be true in many situations. In such situations the normality can be obtained by proper transformation of the data.

Jacob Mathew and Vijayakumar (1984) observed that the distribution of the yield of coconut for individual years is always positively skewed and leptokurtic. They found that pooling the data for consecutive years as well as consideration of palms in groups did not improve the distribution. Among the different transformations tried, $\sqrt{x+10}$ transformation was found to bring the data to a near normal distribution in most cases. Bhagavan (1985) has shown that, in the case of arecanut, $\sqrt{x+3/8}$ transformation changed the data on number of nuts and Öx the weight of nuts to a normal distribution in most of the years. In the case of FFB weight of oil palm also, the distribution was found to be positively skewed and lepto kurtic for most of the years, indicating that low yielders are more. In the years of bumper yield, the distribution tended to be normal. By pooling the data for adjacent years, the skewness was found to get reduced and kurtosis was found to improve. Therefore while analysing oil palm yield data, it is desirable to pool data over years, for reduction in variance and to satisfy the assumption involved in analysis of variance. (Anon. 1986)

3.2 Compilation of annual yield data

In many of the perennial crops, yield is obtained during a specific period of the year only. But in the case of coconut, nuts are harvested throughout the year, about 60% of the total yield being obtained in the first half of the calendar year. Two different methods of compilation of annual yield data have been noticed - one based on calendar years (January to December) and the other based on crop year (July to June). Studies by Jacob Mathew et al. (1989) have shown that the year to year variation is more pronounced in the case of calendar year tabulation, as compared to crop years. This is because, when the yield data are considered on the basis of crop years, one half year of high yield is combined with a preceding or succeeding half year of low yield, or vice- versa, or the two half years coming together are of medium yield, thus reducing the year to year fluctuations. But in the case of calendar years, two half years of high yield, or two half years of low yield are coming together, thereby increasing the year to year variations. With the help of experimental data, it has been shown that conclusions drawn can be different, depending upon the method of compilation of yield data. Whatever be the method of compilation, since the differences narrow down when two year averages are taken, they have recommended the analysis of mean yield for two consecutive years, over the analysis of annual yield.

3.3 Covariance analysis

The use of pre-treatment data in the analysis of covariance for reduction of experimental error was in vogue since the 30's. This method of analysis is intended to control the genetic variation, which is usually of greater magnitude in tree crops.

Coconut: The advantages of covariance analysis has been compared by Shrikhande (1958). Govinda Iyer (1957) observed that the consideration of experimental years in sets(of two or more years) and use of the last three pre-experimental years' data as the concomitant variate will help in detecting treatment differences most efficiently. Abraham and Kulkarni (1963) have also examined the period of pre-experimental data to be used for covariance analysis. Their study of the yield of coconut trees for 20 years showed that the correlation between any two years yields decrease, as the number of years separating the two years, increases. They found out that about two years data immediately prior to the experimental period was sufficient for covariance analysis. Abeywardena (1970) has also observed 30-50% reduction in experimental error by using two years pre-experimental yield as calibrating variable. Studies conducted at CPCRI have also confirmed the above findings (Jacob Mathew and Vijayakumar, 1984). They had studied the inter-relationship between the yields obtained in different years. Though the yields obtained in different years were highly correlated, the relationship was comparatively weak when the annual data for immediately preceding and succeeding years were considered, due to the alternate bearing tendency shown by some of the palms. Compared to this, the correlation was much higher, when there was a gap of one year, between the two years under consideration. When data for groups of years were considered, the coefficients of correlation were found to go up to 0.9. Only marginal decreases in values were noticed when the gap separating the. earlier and later periods was increasing. They also reported substantial reduction in variance and consequent improvement in efficiency, when pre-experimental yield data were used in covariance analysis. Use of two years' pre-experimental data was found to almost double the efficiency, compared to what was obtained with single years data. Based on this, they have suggested the use of progressive average yields for analysis, instead of analysing the annual yield data every year. Similar study by Abeysinghe (1986) has also shown that two-year pooled pre-experimental yield on four tree plot produces consistent calibration and reduces the experimental error mean square by about 73%. This brings down the mean coefficient of variation to 9.7% from its pre-calibration levels of 36 on one-tree plots and 18 on four-tree plots.

Arecanut: Covariance.analysis was found to reduce the error variance by 13 to 34%. The maximum reduction was indicated by considering the pre-experimental yield of two years(Agarwal et. al., 1968).

Oilpalm: The use of not more than four years pre-treatment yield data as a calibrating variable in the analysis of covariance was found to result in considerable gain in precision (Chapas, 1961)

Cashew: Analysis of covariance performed with pre-experimental yield, trunk girth and selection index (identification of superior trees) as concomitant variables, and the relative efficiency of covariance analysis over ordinary analysis of variance was estimated by Prabhakaran and Nair (1983). Among the three calibrating variables, the selection index served as a better covariate, than four years' average annual pre-experimental yield or trunk girth.

Tea: Sen(1963) found that adjustment by covariance for the previous years yield resulted in considerable reduction in error, However, in latin square design, where row classification was based on previous year's yield, no appreciable reduction in error can be achieved through covariance. Adjustment of yield due to covariance generally ceased to be efficient after four years experimentation in manurial trials and after two years in pruning trials (Sen and Biswas, 1966). Adjustment based on average yield over a period of four to six years resulted in an increase in efficiency. They found pre-treatment yield is more efficient than pruning weight as an ancillary variable. When cost of operation was also considered, the latter was more economical and, therefore, preferable. Under the condition prevailing in northeast India, using the pre-treatment last crop (Sept.-Dec.) was generally more efficient than using the whole season's crop.

Coffee: Butters (1964) tried stem diameter, measured at the first-internodes on bearing stems as a calibrating variable and found-it to be of limited use.

Rubber: Murray(1934) reported from Sumatra that when pre-experimental and "experimental" years are consecutive, there was nearly four fold increase in precision by covariance analysis. When they were three years apart the error variance of adjusted yield reduced to about a half. Narayanan (1966) also found that for yield, covariance analysis reduced experimental error at least in the first three years when pre-treatment yields are considered. In the case of girth increment, it was restricted to the first year of post- treatment data. For girth records, greater precision of treatment comparisons was obtained at least during the first six years. Subsequent studies (Narayanan, 1968) revealed the value of girth as a calibrating variate for improving precision of post-treatment yield comparison. Covariance analysis reduced the experimental error at least in the initial 3-4 years of the experiment. He has also, suggested the use of both pre-treatment yield and girth for double covariance analysis(Narayanan, 1970).

3.4 Pooled analysis of data

The performance of the crop generally depends on the genotype, the environment and the interaction between the genotype and the environment. The effect of the uncontrollable environmental factors on crop performance is as important as that of the controllable factors and the evaluation and the quantification of their effects are essential. The uncontrollable factors are expected to change with season and location and since these changes are measurable their effects on treatment performance can be evaluated. The most common way to evaluate the effects of the uncontrollable environmental factors on crop performance is to repeat the experiment at several sites, or over several crop seasons or both. Pooled analysis of variance technique is generally used in such situations. In perennial crops, repeating the experiment at several seasons or years is impractical. Experiments with perennial crops are continued for many years and the observations are taken periodically (seasonally/yearly). In such situations experimenter may be interested to see the variation of the study variable under different seasons or years and their interactions with various treatments.

Shrikhande (1958) and Jacob Mathew and Jose (1988) have pointed out that coconut trees show a marked biennial bearing habit, giving high and low yields over successive years. Since all the trees are not usually in the same phase of yield in a year, the analysis of yearly records of individual trees of any experiment may be misleading. The average yield of a coconut tree, over an even number of consecutive years represents a good index of its performance and should be utilized in the analysis of data on coconut trees. Jacob Mathew and Vijayakumar (1984) have also pointed out that pooling the data for consecutive years reduces the experimental error by over 60%. They have suggested using the progressive average yields for analysis, instead of analysing the annual yield data every year.

Patterson (1939) has given the methodology for the pooled analysis of data, when the experiment has run for a certain number of years. Since the yields in the same plot in successive years are usually correlated, the experimental error in one season is not independent of that in another season. In comparing the over all yields of treatments, this difficulty is overcome by first finding for each plot the total yield over all the years. These totals are analysed by the method appropriate to the design that was used. This method provides a valid error for testing the overall treatment effects. Thus the analysis of variance table will be of error (a) error (b) type, in which the former is used 'to assess the aggregate difference between treatments for the whole period covered by the experiment, and the latter to measure any differential response of the treatments of the varying seasonal condition.

Muralidharan *et al.*(1998) studied the appropriateness of split-block and multivariate analysis for testing treatment-by-time interaction in coconut experiments. It was shown that inference drawn through these procedures not necessarily be the same. The split-block analysis is suggested whenever the assumption of equal variances and equal covariances hold good. In other situations, multivariate analysis is preferred.

4. FORECAST OF YIELD

Reliable forecasting of crop production before the harvest is needed by the Government, agro-industries, traders and agriculturist alike. Additive linear regression with biometrical characters, partial harvest data or weather variables are generally used to forecast the crop yield.

4.1 Based on biometrical characters

In tree crops, the yield and biometrical characters are related. This relationship is utilized to forecast the yield of various tree crops/perennial crops. In general, additive linear regression with yield as response variable and the selected biometrical characters as independent variables is used to get a functional relationship. Once the relationship is established, that can be used to forecast the yield.

Coconuts are generally harvested about 8-12 times a year. In research institutes and other well maintained farms, while it may be possible to monitor each of the harvests and get data on the annual yield, this may not be easy in the case of crop cutting experiments and trials in cultivator's gardens. From Philippines it has been reported (Anon., 1973) that by counting every single nut, mature as well as young ones, hanging on the tree, one can get a fair idea about the number of nuts that can be expected from the tree in a year's time.

Observations on some of the biometrical characters recorded during different months of year, and their relationship with the nuts harvested during the next r calendar year has been studied by Arulraj et al. (1979). The coefficient. of determination of the regression showed progressive increase from January to December and regression based on December observations were found to be identified over the years. A combined regression of the form $y=6.58+0.86x1+0.46x2$, where x1 is the number of nuts more than four months age after the spathe opening (above fist size) and x2 is the no. of buttons less than four months age after the spathe opening (below fist size), has been proposed to use as a reliable estimate of the coconut yield of the succeeding calendar year of WC Tall palms under Kasaragod conditions, with an $R^2=0.80$.

Reynolds (1979) has suggested selecting 10% of the palms in an area and counting (using binoculars) all large nuts (more than 10.0 to 12.5 cm in length) to obtain a mean figure for large nuts and multiplying the same by the number of palms/ha and increasing it by a percentage factor of 35% to compensate for not counting the smaller nuts, to get a fairly accurate estimate of annual coconut production per hectare.

By applying Box-Jenkins methodology for time series analysis, Peiris(1989) showed that a multiplicative seasonal ARIMA process of (0,1,2) x (0,1,1) x 6 gave good fit to a particular set of data from an estate in Sri Lanka. This model is useful in forecasting both annual and harvest-wise yield. The model is also flexible because the forecast can be done without any physical variables like rainfall and temperature . The percentage error in prediction was reasonably low also.

Jacob Mathew et al. (1991) have conducted detailed studies for four years on .the number of nuts present on the crown at any time of the year and the yield of nuts in the coming one year, under rainfed Kerala conditions, for WC Tall palms. At Kasaragod, November- December was found to be the best period for estimating the annual yield and have suggested the regression equation $Y = -0.527 + 0.914 X$, where Y is the estimated annual yield and X is the count of nuts in the different stages of maturity, on the crown, at the time of' observation. Under Kayamkulam condition, the best period was found to be January to March, and the corresponding equation was $Y = -3.0804 + 0.8879 X$. Subsequent studies (Jacob Mathew *et al.* , unpublished) conducted for palms growing under irrigated and rain fed conditions at Kasaragod, the following prediction models have been proposed to forecast the yield (Y) based on total count of nuts above first size (X1) and below first size (X2) using observations recorded during different periods

Rain fed :	Sept. to Feb.	Y=1.09X1 +0.44X2 (R^2=0.92)
	Mar. to May	Y=1.02X1 +0.52X2 (R^2=0.88)
Irrigated:	Sept. to Feb.	Y=1.09X1 +0.42X2 (R^2=0.89)
	Mar. to May	Y=1.08X1 +0.42X2 (R^2=0.82)

In the other months, the regression coefficients were not homogeneous over the years. The above relationship holds for W.C.Tall, TXD and DXT palms. With one single observation, it is possible to estimate the yield expected during the next one year.

Magat *et al.* (1997) have suggested that by taking the average of total nut count of three oldest bunches and multiplying by 4 or 4.8, an estimate the annual yield can be obtained in Tall and Hybrid varieties respectively.

A study taken up in arecanut has shown that 90% of the variation in arecanut yield can be explained using the regression model $Y=1.415X_1^{0.546}X_2^{1.068}$, where Y is the annual yield (wt. of nuts) of the plot, X_1 is the average bunch weight during the first harvest and X_2 is the total no. of bunches (Annon., 1994).

In the case of oil palm, the following relationship has been suggested for estimating the annual yield (wt. of FFB in kg./plam) : $Y=1.73X_1+19.31X_2-21.61$ (R^2=0.81), where X_1 is the average bunch wt. of the previous year and X_2 is the number of bunches available at the time of observation (Annon., 1994b). In another study, Jacob Mathew *et al.* (1993) have reported that 96% of the changes in annual yield is explained by the variation in bunch number and mean bunch weight.

Parameswaran *et al.* (1984) have pointed out percentage of flowered shoots per unit area of tree canopy, total tree canopy area, percentage of hermaphrodite flower opened and percentage fruit drops as the important characters influencing yield in cashew. Another systematic study conducted by George *et al.* (1984) revealed that estimate of yield of individual plots can be made, with reasonable precision (R^2=0.61), about 4-5 months before completion of the harvest , by a single spot observation, using the relationship $Y=1.459+0.0094x_1+0.3314x_2+0.0082x_3$, where Y is the estimated yield in kg, x_1 is no. of nuts on the tree, x_2 is the condition of the tree flowering (graded 0 to 5) and x_3 is canopy area in m^2. Based on this a methodology has been given by George *et al.* (1989) for estimating the yield at plantation level. They have suggested a double sampling procedure, in which a small sample is used for detailed observation on canopy area and no. of nuts at all stages of maturity and a large sample is used for recording condition of flowering.

Analysis of data on biometrical characters and yield attributes of cardamom collected from two plots one each at Appangala and Sakleshpur showed that the yield forecast is possible with R^2 varying from 81 to 86% in the different locations, using the count of no. of capsules alone. Inclusion of additional characters like number of panicles, effective length of panicles, leaf area etc. were found to only marginally increase R^2. The annual production of cardamom plants can be estimated during August, using the prediction equation Y = 8.59 + 1.03C (R^2 = 0.84) where Y is the yield (gm) and C is the count of capsules

Balakrishnan and Jose Abraham (1986) found that the yield of pepper plants (Y) could be estimated based on the visual yield score (X) as a predictor variable using the regression model Y=0.32X (R^2=0.80). The visual score was obtained by adding together the scores assigned (1, 2 and 4, respectively for poor, moderate and high yielding) for each meter of the plant from bottom to top depending upon the judgment of the spike density in the canopy of the plant.

4.2 Based on partial harvest data

Many perennial trees are multiharvesting type and studies are conducted to forecast or estimate the annual yield based on a particular periods harvest data.

Based on the correlation between partial harvest data and annual yield, Balakrishnan et al. (unpublished) have suggested that a technique known as component sampling, in coconut. It was found that by component sampling, the precision of yield estimates can be greatly improved, compared to simple random sampling and double sampling procedures.

Data collected from Vittal, Palode and Kannara have showed that the forecast of annual yield in Arecanut is possible (R^2 >0.7) by using the November harvest (No. of nuts or weight of nuts) and number of bunches remaining in the crown as independent variables.

Month-wise harvest data of oil palm from Palode revealed that the yield obtained in June and August have significant positive correlation with annual yield and can be made use for forecasting.

4.3 Based on juvenile characters

Correlation and path coefficient analysis of various growth characters of young coconut palms of the age group of 4-7 years, with long term yield of coconut (Prabhkaran *et al.* 1991) revealed that no. of leaves was the major contributor towards variation in nut yield. Selection of palms for nut yield could be done effectively on the basis of number of functioning leaves, as early as on the sixth year after planting. For predicting yield, the following relationship has been suggested : Y=4.42X2 - 23.24X (R^2=0.78) where X is the no. of functional leaves at the sixth year.

4.4 Based on foliar nutrient values

Attempts have been made to estimate the yield of coconuts, based on foliar nutrient values. Considering leaf no. 10 as the index leaf, a multiple regression model has been worked by Jose et al. (1991) to estimate the yield of nuts (Y) from the values of nitrogen (N), Phosporous (P) and Pottasium (K) per cent of the leaf and the no., of leaves retained by palm (L.). The relationship was of the form

$$\begin{aligned}Y=-92.924 &+44.682\ N-0.0004\ P\\ &+49.397\ K+6.292\ L-6.970N\ P\\ &+30.729\ NK-2.218\ LN\\ &+17.449\ PK-0.205\ LK \qquad (R^2=0.85).\end{aligned}$$

The quadratic form of the above regression model was

$$\begin{aligned}Y=-34.619 &+29.594\ N-3.827\ P+51.279\ K\\ &+6.547\ L+23.646\ N^2-0.932\ NP\\ &+10.044\ NK-2.493\ LN\\ &+20.294\ PK-54.968\ K^2+0.379\ LK\\ &\qquad (R^2=0.86).\end{aligned}$$

4.5 Based on weather parameters

Weather is a major factor influencing the yield. In perennial crops, yield is dependent not only on the current year weather, but is related to one or more of the preceding years. Attempts have been made during the past many decades to study crop-weather relationship and to predict the yield based on one or more weather parameters. Some studies on yield prediction models for coconut, based on weather variables has been presented below:

Abeyawardena (1968) developed a crop forecasting model based on 12 rainfall parameters using data from 1935 to 1966 and obtained yield predictions close to the observed values. However, the validity of the model for anticipating yields has not been tested. Abeyawardena (1983) later developed an empirical statistical model to forecast yields in Sri Lanka. This was based on eight variables, defined as 'drought indices' for eight different agro-ecological regions derived from the monthly rainfall figures from 1963 to 1976 and taking into consideration of the minimum requirement of soil moisture for optimum prediction. The errors of the estimated values for some years were very large, but no alternative methods have been developed and the use of drought indices is more meaningful and useful than actual cumulative rainfall.

Saraswathi and Mathew (1988) used 15 years data on total monthly rainfall as 12 independent variables to predict yields in each of the ten districts in the state of Kerala. Though the coefficients of determination of these models were reasonably high, there were two degrees of freedom for error and few of the parameters were significant at 5% level. Pillai et al. (1988) also attempted to forecast yield using a linear regression model Y=f(X1,X2), where X1 is the total rainfall for the five months period from the six variables derived from monthly rainfall, distribution one year earlier. The validity of the model was tested for seven different 15-year yield groups. The models were flexible to use, but the percentage of error for the seven groups varied from 1.9 to 40.0. A predictive model (R^2 = 0.91) with six climatic variables (maximum relative humidity, sunshine duration, vapor pressure, and minimum air temperature at different periods) was developed by Vijaya Kumar et al. (1988). From this model, yield for a given year could be predicted by the middle of May in the year before harvest, but its use is limited by the paucity of such climatic data.

The following are the model proposed for prediction of coconut yield , in the studies described earlier

Sl. No.	Model		Reference
	Yield =f (JF, MA, MA-MJ, ND^2, JF_n) JF : Rainfall during Jan-Feb MA : Rainfall during Mar-Apl MA-MJ : Product of rainfall during Mar-Apr and May-Jun ND^2 : Square of rainfall during Nov-Dec. JF_n : No. of rainy days during Jan-Feb.	(R^2=0.89)	Peiris and Peries (1991)
2a	$Y=52.46+0.9509x_0-2.3953x_1-3.889x_2-1.3969x_3$ $Y=48.98-2.6086x_1+3.9662x_2$ where x_i (I=0 to 3) stands for the number of weeks with $\leq$ 2 rainy days during March-May, during i^{th} lag peiod (year).	(R^2=0.65) (R^2=0.59)	Jacob Mathew *et al.* (1988)
b	$Y=68.83+0.7815x_0-3.7815x_1+3.6684x_2-1.2851x_3$ $Y=63.23-3.5350x_1+3.6569x_2$ where x_i(i=0 to 3) stands for number of weeks with $\leq$ 50mm rainfall during March-May, during i^{th} lag period.	(R^2=0.67) (R^2=0.62)	,,
3	$Y=-15.51+0.524x_1+4.046x_2+1.384x_3+3.881x_4-0.600x_5-3.101x_6$ where x_1, x_2,x_3 stand for relative humidity (FN), hours of sunshine and vapor pressure respectively, of the previous year, x_4 and x_5 stands temp. (max) and relative humidity (FN) of two years earlier and x6 stands for temp. (min.) of three years earlier.	(R^2=0.91)	Vijayakumar *et al.* (1989)

Effect of weather parameters on arecanut yield under the Bengal conditions also has been studied. The following is the regression equation developed for this purpose :

$Y=2.30+2.73X_1+13.52X_2+10.95X_3$ (R^2 = 0.97), where X_1 is relative humidity of November of previous year, X_2 is the minimum temperature of December of previous year and X_3 is max. temperature of April, two years earlier. Forecast is possible by the end of December, which is 3-4 months before the beginning of harvesting season.

5. GENERAL

5.1 LEAF AREA ESTIMATION

Leaf area gives a simple and an approximate measure of plant's photosynthetic potential and therefore is an important character contributing towards yield. It is also an important factor for the foliar spray of fertilizers, plant hormones, insecticides and fungicides .

Coconut : Marar and Papachan(1964) were the first to work out leaf area in coconut seedlings. Based on the correlation between leaf area and length & width they proposed a coefficient of 0.0878 to be multiplied to the product of Length and width of leaf to estimate the leaf area

Satheesan *et al* (1983) developed equations to estimate leaf area of one year old coconut seedlings using lamina length and width of the leaf .They also gave regression equation for estimating total functional leaf area of the seedling. Shivashankar *et al* (1986) developed linear regression equations to estimate leaf area and shoot dry mass of seedlings of 5 hybrids coconut varieties. The area of bifurcate leaves was best estimated by using leaf length and width in the equation in the young pinnate leaves; the linear measurements of 4 leaflets in the bifurcate portion and the whole leaf were necessary to obtain precise estimate of leaf area($r^2 > 0.90$) . Ramadasan and Jacob Mathew(1987) developed regression equations for non destructive estimation of leaf area and dry matter production in adult palms of coconut by using suitable sampling techniques.

Arecanut : Yadava and Vijayakumar(1973) were the first to estimate the leaf area. They worked out the leaf area using the ratio of actual leaf area obtained through planimeter to the apparent leaf area (got by summing length x breadth measurement of all the leaflets). They also worked out a regression equation based on the relationship between apparent leaf area with actual leaf area to estimate the leaf area of a single leaf as well as total leaf area of a palm.

Cashew : Murthy *et al* (1979) suggested an exponential model using length and breadth measurements which gave high R^2(0.99) in the case of adult trees. They also suggested that with simple linear regression equations using the product of linear measurement, the leaf area can be estimated but with slightly lesser R^2. Bhagavan and Subbiah (1983) did a similar work in 3 month old cashew seedlings based on length and product of length and breadth using in a regression equation.. They also gave a exponential equation to estimate total leaf area of the plant using linear measurement of the median leaf and total number of leaves.

Pepper : Mohan Kumar and Prabhakaran (1980) developed a regression equation to estimate leaf area using leaf length and breadth . Shivashankar *et al* (1986) did a similar work, but took into account the variation in size and shape of the leaves at different age groups of the seedlings while developing regression equations.

Cardamom : George *et al* (1984) gave regression equations for estimating leaf area of one year old Malabar cultivar of cardamom plants based on length and breadth measurement of individuals leaves. They also gave equations to predict the total leaf area of a tiller/clump with the knowledge of length and breadth measurement of the median leaf the tiller with maximum leaves and total number of leaves in the tiller/clump

Turmeric : Reddy *et al* (1989) developed regression equation using product of maximum length and breadth of individual leaves as an independent variable and got a high R^2 (0.99). Satheesan *et al* (1994) while trying to work out leaf area for the plants grown under two agroecological conditions (under coconut and as pure crop) found that though it is possible to estimate the leaf area under each condition separately with good precision, common regression equations for the two conditions are not possible.

Rao and Sebastian (1994) derived constants for computing leaf area in tree crops, using Li-3000 portable leaf area meter. Constants have been worked out for coconut, arecanut, cocoa, cardamom and pepper.

In cocoa, separate models have been suggested for estimation of leaf area of fresh leaves , young leaves and mature leaves, based on dry matter weight (Reynolds, 1971).

Methodologies have been developed for estimating the surface area of areca fruits. Anadraj and Bhagavan (1983) worked out two separate regression models for large and small nuts, based on the weight of nut. Padmanabhan *et al.* (1997) suggested a non-0destructive method, based on the length and breadth measurements of the fruit.

5.2 Indexing the Severity of Diseases

The necessity for quantifying the severity of disease symptoms is., felt when comparing the intensity of the disease in different genotypes and locations, and when field control trials are laid out, which may involve evaluation of different treatments.

Root (wilt) disease of coconut: In the case of root (wilt) disease of coconut attempts were first made to quantify the disease incidence by George and Radha (1973). They suggested a method involving the scoring of all the leaves in the crown, for flaccidity, necrosis and yellowing. On the basis of their frequency of occurrence and intensity, due weightage and grade points were assigned to each symptom. The disease index I was worked out as follows , for adults palm and , for young palms, where, F, Y and N are the grade points assigned to a leaf for flaccidity (0-5), yellowing (0-3) and necrosis (0-2) respectively and L is the number of leaves. Nambiar and Pillai (1985) tried to simplify this procedure and suggested that scoring the leaves in any one of the five spirals can be adopted without loss of information. Since in majority of the root(wilt) affected coconut palms, leaf rot is also seen associated with, this method of indexing was further modified by incorporating a score for leaf rot also. The resultant index is of the form $I=8.1F+5.5Y+5.3N+1.1LR$, where F, Y, N and LR denote the score for flaccidity, yellowing, necrosis and leaf rot, all in a 0-5 scale (Jacob Mathew, 1999).

Tatipaka disease: Ramapandu and Rajamannar (1983) suggested an Index based on score for L: reduction in leaf size (0-4), A: atropy of nuts (0-4), P: paling of leaves (0-3), R: round nuts (0-3), F: fasciation (0-4) C: Chlorotic spots (0-4) and T: abrupt tapering (0-4). The index was of the form $I=5(L+A+P+R)+2.5(F+C+T)$.

Stem bleeding disease of coconut: The characteristic symptom of disease is the exudation of a dark brown gummy fluid from the growth cracks in the trunk, mostly at the base. The lesions traverse upwards and sometimes many lesions coalesce together forming larger patches. The tissues lying beneath the affected bark also shows decay. Jacob Mathew et. al. (1989) have developed a methodology for indexing the disease severity in stem bleeding affected coconut palms, based on lesion size and score for tapering. The index is worked out using the formula $I=1.8l+4.3t$, where l is the lesion size expressed in 100 cm2 and t is the score for tapering (0-4). This will be useful in comparing the disease severity in different locations/cultivars as well as for a meaningful comparison of the efficacy of treatments.

Basal stem rot: An index of the form $23.6+17.7h+3.6r-0.6\,l$, where h is the height (in m.) upto which bleeding has spread in the stem, r is the reduction in leaf size (0-4) and l is the number of functioning leaves has been developed by Bhaskaran and Karthikeyan (1994)

Yellow leaf disease of arecanut: The symptoms generally associated with this disease are foliar yellowing, necrosis, reduction of crown size, shedding of mature and immature nuts, discoloration of kernel and blackening of root tips. George *et al.* (1980) proposed an index to quantify the severity of YLD based on three easily recognizable foliar symptoms, yellowing necrosis and reduction in crown size. The disease index I for a palm was worked out using the formula, $I = \left(\frac{Y+N}{L} + R\right)10$, where Y and N are the sum of grade points for yellowing and necrosis, L is 50% number of leaves in the crown, and R is the grade point for the reduction in crown size for the palm as a whole. The grade points assigned to the symptoms varied from 0-7 for yellowing, 0-2 for necrosis according to the intensity and number of leaflets showing the symptom, and 0-1 for reduction in crown size.

5.3 Non parametric methods

Most widely used tests of significance like 't ' and 'F' are based on an assumption that the populations from which the samples are drawn are distributed normally. While moderate deviation from normality will not distort the conclusions drawn from the tests, a departure more than moderate from the normality is bound to affect the conclusions. In coconut and arecanut it had been already proved that the distribution of yield data is far from normal for individual trees. Suitable transformations have been suggested (see Section 3.1) to normalize the distribution, but in years, where the yield is extremely poor, these transformations are not of much help. It was in this context the use of nonparametric tests where no assumption of parent population is made, are considered useful. They also have the added advantage that it is enough to have ordinal measurements like ranks rather than the exact value of observation- the property which will be extremely useful when experiments are laid out in cultivator's fields where it is difficult to get the exact data. Asymptotic Relative Efficiency (ARE) of these tests compared to corresponding parametric tests are generally more than 0.85. But the ARE of the parametric tests like 't' and 'F' are as small as zero or 'infinitely bad' compared to the corresponding nonparametric tests when the assumptions of the tests are not met. So, it is safer to go for these tests under these circumstances.

It was shown using data for coconut experiments that Kruskal-Wallis and Mann whitney tests can be used in place of CRD analysis or t-tests(Anon 1993). Friedmans test, Quade test(Anon 1995) and Van der Waerden's Normal Score tests(Anon 1996) could be used in place of RBD especially when the experiments are carried out in cultivators fields where normally we do not get the exact yield data .

5.4 Measurement of bienniality

Year to year fluctuation in the annual yield is a common feature in most of the perennial crops. These variations are generally attributed to genetical as well as environmental factors. In any large population it is possible to see large number of trees which are biennial in their bearing habits, whereas in the case of many others the year to year variation may be highly irregular. Also a small proportion of trees give somewhat steady yield over the years.

Jacob Mathew and Jose (1991) has worked out an index to measure the bienniality in coconut yields based on the rank correlation coefficients for yield obtained in consecutive years and adjacent years. It was found to be significant in W.C. Tall population of different age group under rainfed conditions. In low yielding palms biennial rhythm was found to be less. This methodology can be used in other perennial crop species also.

5.5 Estimation of Pest Population

Assessment of pest population is important for adoption of suitable and timely control measures. Not much systematic work has been done in this area in plantation crops.

Mathen *et al* (1973) projected the total population of Stephanitis typicus Dist. A pest of coconut foliage based on sampling studies. From the count of insects in different portions of the leaflets and leaves, they found that the population of the pest in a group of not less than 10 palms can be estimated by counting the pest in 20% of the leaflets in the middle region of 20% leaves. The innermost leaves were taken for sample in each palm. The sample population multiplied by a constant 3.76 gave the estimated population within 5% error on groups of palms.

George *et al* (1982) did a similar study for standardizing a technique to estimate the population of coconut leaf eating caterpillar Opisina arenosella Walker . They found that the middle leaves and leaflets lodge more number of caterpillars(with minimum CV%) than the other parts of coconut palms. They came out with regression equations to predict the total population of the pest by using middle leaflets of the first 20% of leaves on the crown of a palm. The equations were different for different seasons.

Chandrika Mohan *et al* (1997) standardized a sampling technique for the population estimation of root grub (Leucopholis coenophora) around the palm basin in irrigated coconut gardens. According to them the total number of white grubs present in the root zone of a palm can be estimated by the regression equation Y = 3.78 + 1.7938 X where Y is the total population of white grubs found around a palm and X is the number of insects found upto a depth of 40cm at a distance of 50 to 100cm away from the trunk of the palm.

5.6 Selection Index

In this method selection is made for all the traits simultaneously by using some kind of a total score or Index of the net merit of an individual. Constructed by combining together the scores for each component character. The individuals with the highest score are kept for breeding purpose .The amount of weight given to each trait depends on its relative economic value,its heritability, and the genotypic and phenotypic correlations between different traits. Naturally, this method is more efficient than either the 'Tandem Selection' where the selection is restricted on a single trait or 'Independent Culling level' where selection is made simultaneously for all the traits independantly rejecting all individuals that fail to meet the minimum standard for any one trait.

Ramachander and Bavappa (1972) worked out selection indices for arecanut taking 17 growth characters at different stages of the palms with 12 yield components taken as a single group and combination of certain of them in seven other groups . As against an expected genetic advance of 57.1 due to straight selection, the advance was 498% based on all the characters. A simple index using the number of leaves and height of the plant alone at the time of transplanting gave a relative improvement of 332%.

For South Kanara variety of aecanut, a vogour index, based on characters like palm height, girth at permanent mark, internodal distance at permanent mark and maximum length of leaf sheath has been have been worked out for selection elite palms.

In view of the significant positive correlation of no. of leaves and negative correlation of the height at the time of transplanting, with subsequent yield, Bavappa (1970) has suggested a selection index, I = 40 x no. of leaves - height in cm. He has suggested that seedlings with a high Index value alone be selected for planting in arecanut.

Rao and Jacob Mathew (1981) made an attempt to evaluate the coconut germplasm material at the nursery stage, by working out an index based on the cumulative scores for mean and CV of each character.

Discriminant function has been constructed by Vijayakumar et al. (1991) based on seedling characters, to classify W.C. Tall palms as future high yielders or low yielders.

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