SELECTION PARAMETERS IN TAPIOCA
(*Manihot esculenta* Crantz)

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THESIS
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1980

DECLARATION

I hereby declare that this thesis entitled "Selection parameters in Tapioca (*Manihot esculenta* Crantz)", is a bonafide record of research work done by me during the course of research and that the thesis has not formed previously the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani,
25-7-1980.

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CERTIFICATE

Certified that this thesis, entitled "Selection parameters in Tapioca (Manihot esculenta Crantz)", is a record of research work done independently by Shri. V.V. RADHAKRISHNAN under my guidance and supervision and that it has not formed previously the basis for the award of any degree, fellowship or associateship to him.

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INTRODUCTION

INTRODUCTION

Tapioca which is otherwise known as cassava or manioc (Manihot esculenta Crantz), belongs to the family Euphorbiaceae, and is cultivated extensively in almost all the districts of Kerala as a major crop. Its native home is in the lowlands of tropical America (Rogers, 1963), and it was introduced into India by the Portuguese during the last decade of the 18th century. The crop is cultivated for the root tuber which is a rich source of starch that is used both for edible and industrial purposes.

The crop is second only to rice in importance as far as the area under which it is cultivated in the State is concerned. However, it ranks first when the per hectare production of carbohydrate is considered, and it is reported to yield four times more of starch than rice, the most important food crop of the state.

Yet compared to other tapioca growing regions, the yield of tuber from the crop in this part of the country is deplorably low, probably due to the routine practice of using inherently inferior varieties with low productivity for cultivation.

The species exhibit considerable genetic diversity and a large number of varieties and stabilized complexes exist, which are presumed to have evolved in nature at different places through gene mutation followed by hybridization, recombination and selection, somatic mutation, and introgression involving other diverse forms. Hence it is felt, that there is considerable scope for effecting selection in favour of desirable genotypes with relatively high yield potential and appreciable degree of adaptability, which could be developed eventually into stable communities having their own indentity coupled with reasonable degree of adaptation to normally expected changes in the environment.

Manifestation of yield in this crop, as that in other crops, is of a highly complex nature, the inheritance of which in turn is influenced primarily by the functioning of an intrincically aligned polygenic system. Further, this character is governed by several other equally complex polygenically controlled component characters as well. The number of such component variables is invariably large, and each is found to affect the main character in its own characteristic way and in different magnitude. Further, being a crop cultivated essentially for the tuber, the yield factor is concealed till the time of harvest is over. Because of this reason, tapioca introduces unique problems for effecting selection, which may not be exactly the same as that in the case of crops in which the produce is borne aerially. Here again, a good number of the components that bear a significant direct influence on the yield of tuber are too of similar concealed nature making direct reading practically not possible and selection for particular desirable types extremely difficult. Hence it is all the while important and desirable to identify accurately and preferably components that lend themselves amenable for direct and easy reading. In the event of such components being discovered, they could be made use of successfully in the estimation of reliable parameters and in the formulation of appropriate selection criteria in this crop. Further, an understanding of the interrelationship of the identified variables and their individual attributes like heritability, genetic gain, genetic advance etc. is believed to be of immense value in making such attempts additionally more fruitful.

The practical usefulness of making such estimates for selection in the breeding of crop plants has been recommended by several authors (Fisher, 1918; Wright, 1921; and Lush, 1949).

Researches carried out in this crop at the Central Tuber Crops Research Institute at Trivandrum and other centres have enabled the identification of a few dependable biometrical parameters that have helped in the formulation of relatively better criteria for effecting selection in favour of desirable genotypes from among others constituting a genetically heterogeneous base population.

It is definite that more number of such reliable parameters could be identified yet that could be made use of for making selection procedures more accurate and sound in this crop.

The present study was undertaken with a view to introduce supplementary information in this regard.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Present investigation in tapioca envisages two distinct lines of biometrical study.

The first relates to the understanding of the correlated components of yield of tuber and their relative importance on the basis of the statistically computed parameters. Heritability in the broad sense, and Genetic Advance and Genetic Gain at different intensities of selection.

The second involves the assessment of the magnitude of the relative direct and indirect influence of these variables, and also that of the residual factor, on yield of tuber. Here the theory of causation is made applicable and the path coefficient analysis method was resorted to.

(1) Correlation of variables

Galton (1889) conceived the idea of correlation of variables for the first instance.

Fisher (1918, 1954) developed the method of applying the theory of correlation of variables, in the understanding of their influence in biologic systems.

Snedecor and Cochran (1967), improvised the mathematical computation of the coefficient of correlation.

The expression of inherited characters is often influenced by the genotype, the environment, and the genotypic environmental interaction.

Burton (1952), introduced a convenient procedure for the calculation of the phenotypic and genotypic coefficients of correlation.

Genetic parameters like heritability and genetic advance and genetic gain under different probability levels of selection have been often found to be of great use for assessing the relative importance of these inherited and correlated variables.

Hanson et al. (1956), proposed the mathematical relationship of various estimates on computation of heritability. This attribute is generally expressed as the percentage, and in the broad sense it refers to the relative proportion of variance due to genotype over the variance due to the phenotype.

Johnson et al. (1955) introduced the methodology for partitioning the total variance into that due to genotype, phenotype and error, in the analysis of variance. Error, in this context refers to genotypic-environmental interaction.

Lush (1949), and Johnson et al. (1955) devised an accurate and easily manageable procedure for the calculation of the genetic advance under specified intensities of selection.

Johnson et al. (1955), further, substantiated the advantage of computing the genetic gain under selection and its usefulness in relative comparison of variables.

These two parameters, genetic advance and genetic gain, are of great value to the plant breeder in understanding to what extent they could be possessed, and made advantage of, in respect of certain desired polygenic characters under specified probability levels of discrimination in favour of particular genotypes during selection.

Biometrical researches were conducted in different crops by several workers and many could make out useful guide lines which eventually proved to be of immense value in the improvement of respective crops through breeding.

This review is confined to reports made in the three tuber yielding crops - tapioca, potato and sweet potato.

Correlated variables in tapioca

Jones (1959) reported that yield of tuber in tapioca was associated positively with relatively larger leaves, duration, and higher values for the leaf area index.

Magoon (1972) reported that the number of tubers per plant was significantly and positively correlated with tuber yield per plant. Further, the yield was significantly and directly correlated with tuber length, tuber circumference, plant height and rind thickness. Length of tuber was, however, positively associated with girth.

Estevao et al. (1972) reported that varieties with high root yield had a low fresh weight in the aerial parts, although an occurrence in the contrary need not be necessarily overlooked.

Muthukrishnan et al. (1973) reported that tuber yield in tapioca is positively and significantly correlated with number of nodes per plant and negatively with leaf breadth. Accordingly, tuber yield could be predicted on the basis of number of nodes, plant height, length and breadth of leaves, and length and girth of individual tubers.

Enyi (1973) reported high yields could be achieved with a low leaf production cultivar, provided that high harvest indices are realised.

C.I.A.T. (1973) suggested that harvest indices might be used as a means of assessing the yield potential of a collection of cultivars grown under similar conditions.

Holmes and Wilson (1974) recommended that harvest indices could be made use of as a measure of assessing the yield potential in a collection of cultivars grown under similar conditions. They reported existence of significant association between leaf production parameters (node number, leaf number and leaf area) and total dry weight of the plant. Correlations between these parameters and tuber yield indicated that leaf production and leaf abscission were important determinants of total dry matter production and tuber yield. The values for correlation coefficients were, however, higher with total dry matter production than with tuber yield.

Williams and Gazali (1974) found that tuber size is the major component of yield in cassava.

Hunt (1974) observed that cultivars producing leaves rapidly were better in that they were able to replace damaged leaves so that no significant reduction in yield was realised.

Wilson (1976), while conducting detailed studies on the effect of yield components on yield in cassava, obtained significant values for correlation coefficients among node number, leaf number, leaf area and total dry weight. Number of leaves was directly proportional to the area, and dry matter production.

Kawano et al. (1977) stated that varietal variation in yield and harvest index were sufficient for making efficient visual selection in cassava. He observed that harvest index is highly associated with root yield. The correlation between harvest index and root yield was significant. It was concluded that in the selection for root yield harvest index is a better criteria to be relied upon.

Ribeiro (1977) suggested that root production was related to plant height, stem diameter, number of shoots and number of leaves. He recommended that the relationship - root fresh weight/dry weight of plant, could be considered as valid criterion in the selection of cultivars for high productivity.

Kawano et al. (1978) observed that harvest index is highly heritable and suggested that it was an excellent selection character for high tuber yield.

Biradar et al. (1978) conducted detailed investigations with twelve varieties of cassava to estimate genetic variability and correlation coefficients for seven quantitative characters. In general, phenotypic coefficient of variation was higher than that for the genotype for all the characters studied. Phenotypic and genotypic coefficients of variation, heritability and genetic advance estimates were high for number of nodes and tuber yield per plant indicating considerable scope for improvement of economic trait like tuber yield. Genotypic correlation coefficients were higher in magnitude than phenotypic correlation coefficients. Harvest index, number of tubers per plant and mean tuber weight showed strong positive correlation with tuber yield, while number of nodes per plant had significant negative correlation. They suggested that for the identification of high yielding genotypes more emphasis had to be laid on characters like harvest index and number of tubers per plant.

Kamalam et al. (1978) conducted correlation studies in 71 selfed progeny lines of cassava for tuber yield and its five components, viz., harvest index, number of tubers, number of nodes, weight of vegetative part and plant height. The tuber yield was positively and significantly associated with all the above characters. Harvest index showed significantly negative correlation with number of nodes, weight of vegetative part and plant height through it had a non-significant positive correlation with number of tubers. Tuber yield was mainly dependent on harvest index, number of tubers and to a certain extent on weight of vegetative part.

<u>Correlated variables of potato</u>

Tai (1975) during a study on yield and yield components in 7 potato cultivars, established a causal relationship between environmental resources, component traits and yield based on the concept that yield components were determined sequentially at different stages in the ontology of plants and the hypothesis that the environmental resources could be separated into independent groups with each contributing to the development of a component trait. These components were estimated using the method of path coefficient analysis based on the postulated causal relationship.

Meister and Thompson (1976) studied the phenotypic correlations among the yield components of potato, such as, number, size, specific gravity of tubers and number of leaves. A model for yield formation, as affected by the above components was proposed and analysed by the path-coefficient method, and the effects of genotypic and environmental correlations were separated.

Maity and Chatterjee (1977) in a study with 50 varieties of potato for 5 characters, found that yield was positively correlated with height and number of tubers per plant. There was significant partial correlation coefficient between yield and leaflet size, and multiple correlations indicated that leaflet size had the greatest influence on yield followed by tubers per plant and height.

Segura moreno and Fuentecuidad (1978) while estimating the phenotypic correlations in potato cultivars found that height and tuber number had the maximum direct influence on yield. Average leaf length was of importance in inter-specific crosses. In some of the cultivars stem number and average leaf were also of importance. All these characters gave high heritability estimates.

Kaminski (1978) examined 11 characters in 120 varieties of potato for three years. He found that the more variable and the least heritable characters were tuber number per plant and mean tuber weight. Morphological characteristics of the aerial parts displayed low variability and differed in heritability.

Challaiah and Kulkarni (1978) in a study on the growth and yield attributes in potato found that fresh weight of top and tubers had significant association with the tuber yield in the beginning, whereas both had significant correlation at later stages. Largest size had higher significant correlations with the yield compared to lesser significant value of total tuber number and insignificant correlation of grade tubers. Total tuber weight had significant association with the tuber yield. Average and gradewise specific gravity had no significant correlation with the yield.

Correlation of variables in sweet potato

Thamburaj and Muthukrishnan (1976) in an investigation of association of metric traits by path analysis indicated that the genotypic coefficient of variation was in general lower than the phenotypic one indicating the larger measure of the environmental influence. The weight of tubers per vine, the number of leaves per vine and the weight of foliage exhibited a high degree of both phenotypic and genotypic coefficient of variations while girth of stem had the least value for the coefficient of variation. High heritability and low genetic advance were observed for all the characters except girth of tuber and number of tubers per vine in which the genetic advance was very high. Except length of vine and girth of stem all the characters had positive association with tuber yield. The path analysis indicated that the weight of foliage, girth of tubers and number of tubers per vine contributed maximum direct effects on tuber yield indicating the importance of these three characters as selection indices for sweet potato and the number of leaves, length of petiole and length of tuber had negative direct effects on tuber yield.

Pushkaran et al. (1976) in an analysis of yield and its components in sweet potato, the simple and mutual correlations and path at the levels of the first and second order of components reveals that an increase in the length of vine caused significant increase in tuber yield. But at the same time, the overall area of leaf should not be allowed to increase, because this character carried negative relationship with yield.

Kamalam et al. (1977) conducted a study in ten varieties of sweet potato and estimated phenotypic and genotypic coefficients of variation, heritability, genetic advance, correlation and path coefficients for six characters. Genotypic coefficient of variation was lower than the phenotypic one for all the characters studied. Length of vine and number of tubers showed very high degree of phenotypic and genotypic coefficients of variation associated with high heritability estimates and genetic advance. In general, genotypic correlations were higher than the phenotypic correlations. Number of tubers had positive significant correlations with yield. Length as well as weight of vine showed significant negative correlations with yield. Number of tubers, showed the maximum positive direct as well as indirect effects on yield. It is suggested that number of tubers per plant, length of petiole and to a lesser extent weight of vine should be the criteria for selection of a high yielding plant type in sweet potato.

MATERIALS AND METHODS

MATERIALS AND METHODS

MATERIALS.

Twenty varieties of tapioca, which exhibited identifiable diversity in morphology and performance, constituted the material in the experiment. The selection of the varieties was made from the germplasm maintained at the Central Tuber Crops Research Institute, Trivandrum.

The varieties belonged to five categories, each consisting of four. Excepting one, the groups represented ecogeographically different adaptation and the fifth included elite strains which were evolved through breeding at the Institute.

The particulars of the material were as follows:

Sl. No.	Group	Variety	Treatment
1	I. Columbia	CIAT 1	T1
2		CIAT 15	T2
3		CIAT 17	T3
4		CIAT 18	T4
5	II. India	CI 567	T5
		CI 740	T6
		CI 784	T7
		CI 1413	T8

9	III. Madagascar	CE 29	T9
10		CE 61	T10
11		CE 107	T11
12		CE 114	T12
13	IV. Nigeria	TMS 30444	T13
14		TMS 30757	T14
15		TMS 30930	T15
16		TMS 301024	T16
17	V. Evolved varieties (India)	H 97	T17
18		H 165	T18
19		H 226	T19
20		H 2304	T20

(It was established during earlier observation trials that these varieties performed reasonably well in the condition under which this experiment was carried out).

METHODS.

The field experiment was conducted during June 1979 - March 1980 in the premises of the C.T.C.R.I., Trivandrum.

Experimental Design and Layout

The experiment, incorporating the 20 treatments, was laid out in a Randomised Block Design with three replications. Thus each block (replication) consisted of 20 treatments (plots) and the total number of plots in the layout was 60.

<u>The crop</u>

Each plot (size 7 m x 4 m), representing a treatment, was planted with 28 stem cuttings arranged in 4 rows of 7. Cuttings of uniform size and length obtained from the middle portion of the preserved stems were planted with 90 cm^2 spacing.

The crop was given timely management care as per recommendation given in the Package of Practices of the C.T.C.R.I. (1979).

<u>Collection of data.</u>

Data were collected from a sample consisting of the middlemost ten plants in each plot and the remaining eighteen constituted the border. Measurements were taken and recorded for the following variables.

1. <u>Yield of tuber per plant</u>

The tuber harvested from each plant was weighed and the weight was expressed in kilograms.

2. <u>Number of tubers per plant</u>

The total number of tubers in each plant was counted.

3. <u>Mean weight of tuber</u>

This was estimated by dividing the per plant yield of tuber by their number.

4. <u>Mean length of tuber</u>

The sum of the length of all the tubers from the same plant was divided by their number and the value for the variable was expressed in centimetres.

5. <u>Mean girth of tuber</u>

The mean girth of tuber was estimated and recorded. For this, three separate measurements were taken in respect of individual tubers - one around the middle, and the remaining two about the proximal and distal ends. The average of these three measurements was calculated. The procedure was repeated for all the tubers obtained from the same plant. The sum of the mean values was further divided by the number of tubers.

6. <u>Harvest index</u>

Nichiporovic (1960) defined "Harvest Index" as the ratio of economic yield to biological yield. The value was computed on the basis of the following relationship.

$$\text{Harvest Index} = \frac{\text{Yield of fresh tuber per plant}}{\text{Total weight of the plant including the tuber}}$$

7. <u>Length of stem at harvest</u>

The total length of the stem including that of branches was measured and the value expressed in centimetre.

8. <u>Number of nodes at harvest</u>

The total number of nodes in the stem including that of branches was counted.

9. <u>Number of branches</u>

The number of branches in a plant at the time of harvest gave the value for the variable.

10. Number of leaves retained at harvest

The number of green leaves present in the plant was recorded.

11. Leaf Area Index (LAI)

During the third month after planting

12. Leaf Area Index (LAI)

During the fourth month after planting

13. Leaf Area Index (LAI)

During the fifth month after planting

14. Leaf Area Index (LAI)

During the sixth month after planting

15. Number of leaves abscissed during the 4th month after planting

16. Number of leaves abscissed during the 5th month after planting

17. Number of leaves abscissed during the 6th month after planting.

Leaf Area Index (LAI)

Three different types of leaves were identified in cassava varieties (Jose and Hrishi, 1976) - Broad, Medium and Narrow. The classification was made on the basis of the value for the length/breadth ratio. Accordingly, leaves were classified as broad for values 3.1 and below, medium for range 3.1 to 5.3 and narrow for those with values 5.3 and above.

Ramanujam and Indira (1978) proposed "the linear measurement and dry weight method" for the estimation of leaf area in the crop. Fifteen leaves were chosen at random from each plant. The following measurements were taken for each leaf

(i) length of middle lobe,

(ii) its maximum width, and

(iii) the number of lobes.

The product of the three values was eventually multiplied by the appropriate constant (leaf factor) =0.44 for broad and medium, and 0.62 for narrow. This estimate is presumed to give the area of the particular leaf from which measurements were taken. The area of all the 15 leaves in the sample was calculated. From this the mean leaf area was worked out, which in turn multiplied by 15 gave the total leaf area** or the net photosynthetic area in a plant.

** TLA = 1 x b x n x k x N

where TLA is the total leaf area per plant.

1 = length of the middle lobe

b = maximum width of the middle lobe

n = number of lobes per leaf

k = leaf factor

N = number of leaves per plant

"Leaf Area Index"@@ is defined as the ratio of the total leaf area to the area occupied by the plant (Watson, 1937).

The spacing under which planting was done represented the area occupied by a single plant. In this case it is 90 cm^2.

@@ LAI = $\frac{TLA}{s^2}$

where LAI = the leaf area index

TLA = Total leaf area per plant

s^2 = Spacing in square

During the course of the experiment the leaf area index was computed at four stages of the growth period as given under items 11, 12, 13 and 14 mentioned above.

Number of leaves abscissed

As far as tuber yielding crops are concerned this phenomenon has been recognised to be of importance in connection with initiation and development of tuber.

The variable was estimated by counting the number of nodes from where leaves have dropped off.

Counting was made at three critical stages as already pointed out earlier (Items 15, 16 and 17).

For the sake of operational convenience the seventeen variables were given the following symbols.

Sl.No.	Variable	Symbol
1	Yield of tuber per plant	Y
2	Number of tubers per plant	x1
3	Mean weight of a single tuber	x2

4	Mean length of tuber	x3
5	Mean girth of tuber	x4
6	Harvest index	x5
7	Total length of stem at the time of harvest	x6
8	Number of nodes at harvest	x7
9	Number of leaves retained at harvest	x8
10	Number of leaves abscissed during the fourth month	x9
11	Number of branches	x10
12	Leaf Area Index on third month	x11
13	Leaf Area Index on fourth month	x12
14	Leaf Area Index on fifth month	x13
15	Leaf Area Index on sixth month	x14
16	Number of leaves abscissed during the fifth month	x15
17	Number of leaves abscissed during the sixth month	x16

Statistical analysis

The data collected in respect of the seventeen metric traits were tabulated and analysed statistically.

For estimating the measures of central tendency and dispersion, and for the analysis of variance (ANOVA), the methods proposed by Panse and Sukhatme (1957) were adopted.

ANOVA

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F.ratio
Replication (Blocks)	(r-1)	S.S.R.	S^2_R	$\frac{S^2_R}{S^2_E}$
Treatment (Varieties)	(v-1)	S.S.V.	S^2_V	$\frac{S^2_V}{S^2_E}$
Error	(r-1) (v-1)	S.S.V.R.	S^2_E	

Where

r = the number of replication,

v = the number of varieties,

S.S.R. = replication sum of squares,

S.S.V. = variety sum of squares,

S.S.V.R. = error sum of squares,

S^2_R = replication mean square,

S^2_V = variety mean square, and

S^2_E = error mean square.

The significance of the computed value for 'F' was tested against the appropriate value in the 'F' table (Panse and Sukhatme, 1957).

Phenotypic variance (Johnson et al., 1955)

$$V_P = \frac{V}{N}$$

Where

V_p = Phenotypic variance

V = type mean square, and

N = number of replications

Genotypic variance (Johnson et al., 1955)

$$V_g = \frac{V-E}{N}$$

Where

V_g = Genotypic variance,

E = Error mean square, and

N = Number of replications

Phenotypic coefficient of variation (Burton, 1952)

$$P.C.V. = \frac{V_p \times 100}{Mean}$$

Where

P.C.V. = Phenotypic coefficient of variation, and

V_p = Phenotypic variance

Genotypic coefficient of variation (Burton, 1952)

$$G.C.V. = \frac{V_g \times 100}{Mean}$$

Where

G.C.V. = Genotypic coefficient of variation, and

V_g = Genotypic variance

Heritability in the broad sense (Hanson et al., 1956)

$$h^2 = \frac{V_g}{V_p} \times 100$$

Where

h^2 = heritability expressed in percentage,

V_g = Genotypic variance, and

V_p = Phenotypic variance.

Expected Genetic Advance under selection (Lush, 1949, and Johnson et al., 1955).

$$G.A. = \frac{V_g}{V_p} \times \sqrt{V_p} \times k$$

Where

G.A. = Genetic Advance,

V_g = Genotypic variance,

V_p = Phenotypic variance,

k = Selection differential expressed in phenotypic standard deviation, and

k = 2.06 in the case 5% selection in large samples (Miller et al., 1958 and Allard, 1960).

Expected Genetic Gain under selection (Johnson et al., 1955)

$$G.G. = \frac{G.A.}{\bar{x}} \times 100$$

Where

G.G.	=	Genetic Gain,
G.A.	=	Genetic Advance, and
$\bar{x}$	=	mean

Correlation coefficients (Snedecor and Cochran, 1967)

$$r = \frac{SP\ xy}{\sqrt{S.S.x \times S.S.Y}}$$

Where

r	=	Correlation coefficient,
x and y	=	variables under study,
S.P.xy	=	sum of products of xy,
S.S.x	=	sum of squares of x, and
S.S.Y	=	sum of squares of Y.

Simple correlations between yield of tuber and each of the sixteen components as listed earlier, and the mutal correlations among the components were worked out.

Genotypic correlations (Al-jibourin et al., 1958)

$$rg = \frac{V_g 12}{\sqrt{V_g 1 \times V_g 2}}$$

Where

rg	=	genotypic correlation coefficient,
$V_g 12$	=	genotypic covariance of variables 1 and 2,
$V_g 1$	=	genotypic variance of variable 1, and

E = represents the Effect

Y = Yield of tubers per plant

TE = represents the transitory effect

x5 = Harvest Index

CC = represents the concealed causal components

x1 = Number of tubers per plant,

x2 = Mean weight of a single tuber,

x3 = Mean tuber length, and

x4 = Mean girth of a tuber.

RC = Represents the readable causal components

x6 = Total length of stem at the time of harvest

x7 = Number of nodes at harvest

x8 = Number of leaves retained at harvest

x9 = Number of leaves abscissed on fourth month.

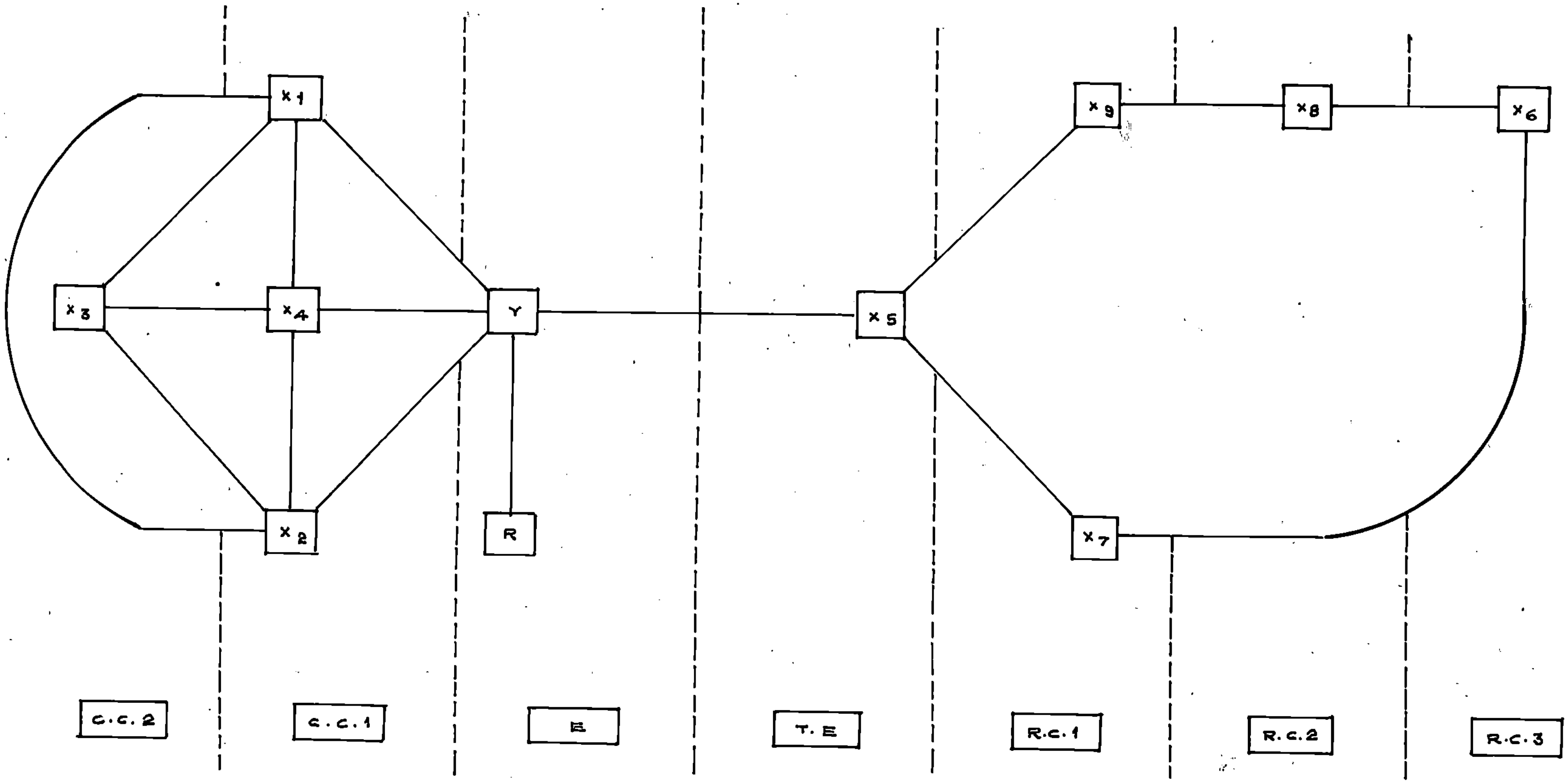


FIG: 1 CAUSAL DIAGRAM FOR PATH ANALYSIS IN TAPIOCA

V_g2 = genotypic variance of variable 2.

The significance of rg is tested using the 't' test.

Path coefficient analysis (Wright, 1921, 1923, 1934, 1954, and Dewey and Lu, 1959)

An attempt was made, during the course of investigation to understand the nature and magnitude of cause effect relationship in a hypothetically formulated system of correlated variables.

Accordingly, variable Y was recognised as the effect, x5 as the transient effect (which in all other respects was considered as one of the causal components), and the fifteen variables x1........x16 (excepting x5) as the causal variables.

A causal scheme was formulated (as shown in Figure 1) incorporating nine out of the total sixteen causes listed above. The elemination of the six variables (x10.....x16) from the scheme was made after a thorough scrutiny of the relative degree of the association of each of these variable with the effect (Y).

Further, in the causal diagram (path diagram the causes were identified to be belonging to the different orders of involvement the I, the II and the III.

The proposed scheme, being one for a tuber yielding crop, in which the yield factor (effect) is totally concealed, the four causal components (x1......x4) were identified as absolutely concealed or hidden causes, one (x5) which represent the Harvest Index as the transitory effect since part of this component is hidden and readily not readable, and the the remaining four (x6......x9) as readable causes since this category includes characters that relate to parts of the plant that are above the soil and hence directly measurable.

For calculating the value for the path coefficient in a causal scheme as that proposed above, the equation developed and recommended by Dewey and Lu (1959) was used.

$$Y = a1x1 + a2x2 + a3x3 + a4x4 + e$$

Conclusions were drawn on the basis of these findings.

RESULTS

RESULTS

The analysis of variance for yield (Y) and the sixteen proposed yield components (x1......x16) reveal that the treatments (varieties) differed significantly among themselves for all the seventeen variables included in the study (Table 1).

Presented in Table 2 the following for the seven variables.

(i) Range,

(ii) Mean,

(iii) Percentage magnitude of range over the mean,

(iv) Variance, and

(v) Coefficient of variation.

From Table 2, it appears that x4 (girth of tuber) and x5 (Harvest Index) exhibited the maximum and minimum degree of variation among the seventeen variables studied respecively Y(Yield of tuber), however, occupied an intermediate position.

The variables could be arranged in descending order on the basis of the relative degree of variability as follows:

1. x4
2. x8
3. x14
4. x6
5. x12
6. x16

7. x9
8. x15
9. x12
10. x7
11. x11
12. x13
13. Y
14. x1
15. x10
16. x3, and
17. x5

Figure 2, indicates the relative degree of the magnitude of the ten variables included for making the causal diagram (Fig.1) which were selected on the basis of the degree of their significant association with other variables. Further, the variables are identified to belong to the following categories.

(i) Concealed variables - (Y, x1,x2,x3, & x4),

(ii) Readable variables - (x6,x7,x8, & x9), and

(iii) Partly readable variable - (x5)

The mean values for the seventeen variables for the twenty treatments are given in Table 3.

As is evident from Table 4, the value for heritability in the broad sense (h^2) ranges from as low as 8.12 for x9 (number of leaves retained at harvest) to as high as 60.22

Table 1. Anova for yield and its components in tapioca

Source of variation	df	Y	x1	x2	x3	x4
Block	2	0.0273	2.1372	3.4722	9.9238	4.2659
Treatment	19	0.8110**	6.4559**	0.0281**	31.1309**	12.1760**
Error	38	0.3047	1.3145	0.0069	7.1172	9.0170

**Significant at 1%

continued.....

Table 1 continued

x5	x6	x7	x8	x9	x10
0.0019	10732.34	635.34	479.51	20.01	0.1315
0.0105**	102816.89**	14885.72**	267.34**	974.32**	0.6384**
0.0053	30060.62	6682.35	211.29	274.71	0.1229

continued.....

Table 1 continued

x11	x12	x13	x14	x15	x16
0.0630	0.4827	1.6193	8.5547	180.89	1900.45
0.9548**	2.6295**	1.9268**	4.3807**	4073.71**	11856.38**
0.3815	1.3521	0.6588	1.2328	735.11	2538.46

Table 2. Range (R), Mean (M), Percentage of magnitude of the range over mean (%), Variance (V) and Coefficient of Variation (CV) for 17 variables (Y, and x1......x16) in tapioca.

Variable	R	M	%	V	CV
Y	1.04 - 5.00	2.659	148.87	0.4734	25.88
x1	3.60 - 11.60	7.389	108.26	3.0283	23.55
x2	0.123- 0.767	0.375	171.64	0.0140	31.55
x3	16.30 - 37.21	23.821	87.77	151.1217	16.33
x4	10.92 - 33.46	17.007	132.18	77.9200	51.91
x5	0.445- 0.792	0.636	54.53	0.0069	13.05
x6	274.80 - 1186	565.950	161.00	54312.7000	41.18
x7	153.80 - 598.400	314.25	141.03	9406.8000	30.77
x8	12.00 - 111.000	34.40	287.82	229.9700	44.09
x9	32.50 - 132.75	65.69	152.62	507.9200	34.31
x10	1.20 - 3.60	2.35	194.04	0.2947	23.08
x11	0.48 - 4.74	1.94	219.47	0.5725	29.49
x12	1.39 - 8.82	3.30	225.22	1.7779	40.42
x13	1.45 - 6.04	3.75	122.47	1.0813	27.74
x14	1.47 - 7.89	3.49	183.79	2.2821	43.25
x15	63.00 - 294.00	133.27	173.34	1847.9800	32.26
x16	98.00 - 565.74	214.08	218.49	5647.7700	35.10

Table 3. Table showing the mean values for the seventeen variables for the twenty treatments in tapioca.

Sl. No.	Treatments*	Y	x5	x1	x2
1	T15	3.68	0.63	9.40	0.3916
2	T13	3.35	0.69	5.93	0.6083
3	T2	3.32	0.67	6.07	0.4973
4	T16	3.24	0.65	7.53	0.4356
5	T18	3.09	0.72	8.67	0.3536
6	T17	2.93	0.63	6.27	0.5286
7	T4	2.85	0.67	6.44	0.4450
8	T7	2.79	0.64	7.00	0.3660
9	T20	2.79	0.72	9.80	0.2890
10	T5	2.75	0.64	9.13	0.2740
11	T19	2.71	0.71	6.47	0.4193
12	T12	2.61	0.66	8.47	0.3070
13	T1	2.55	0.69	5.87	0.4340
14	T8	2.44	0.57	9.13	0.2760
15	T10	2.43	0.72	6.73	0.3605
16	T3	2.31	0.66	6.87	0.3363
17	T14	2.23	0.58	6.73	0.3336
18	T6	1.94	0.62	6.77	0.2826
19	T11	1.78	0.49	8.58	0.2156
20	T9	1.76	0.59	5.00	0.3480
Critical Difference (C.D.)		0.9109	0.1197	1.8919	0.1379

*On the basis of the value for C.D. the first nine treatments formed a group in which the constituent varieties showed no significances for (Y) and the remaining eleven formed a second group.

Table 3 continued

x3	x4	x6	x7	x8	x9
22.67	16.36	1027.53	312.13	35.67	64.62
27.79	18.81	560.00	356.20	28.60	61.83
23.09	18.32	428.73	266.20	40.63	58.20
24.19	17.39	840.33	249.33	32.67	78.25
19.64	17.58	367.42	474.67	30.07	54.58
23.24	17.14	464.80	255.20	37.20	58.67
26.40	16.68	523.68	296.53	55.77	37.75
23.93	16.53	522.27	430.80	32.33	76.67
21.27	13.79	438.67	246.20	33.27	64.50
19.72	36.51	413.67	218.53	15.00	73.83
23.02	16.82	391.47	277.27	27.73	102.75
20.86	15.33	680.13	260.87	33.40	66.17
30.56	15.29	635.40	281.10	43.60	45.20
24.38	13.81	561.27	271.40	17.87	89.50
28.10	15.11	695.80	358.30	47.87	86.92
20.34	15.42	482.60	325.33	30.33	74.08
25.68	11.59	958.40	428.13	42.07	47.08
22.55	14.27	424.39	271.80	26.90	58.83
20.02	13.36	562.31	350.07	38.52	111.66
28.98	20.03	487.73	374.33	38.60	44.83
4.4023	8.7262	286.10	134.89	23.98	27.35

continued..

Table 3 continued

x10	x11	x12	x13	x14	x15	x16
2.60	2.60	3.65	4.41	4.03	153.58	283.08
2.53	1.95	2.76	3.19	3.93	125.83	216.08
2.20	1.59	2.14	2.87	2.40	114.33	200.75
2.26	1.58	2.55	3.19	3.09	213.33	377.08
2.10	2.95	5.52	5.19	4.91	95.83	145.00
2.07	1.79	3.41	3.16	3.34	100.58	154.67
1.64	0.92	2.13	3.20	2.48	84.92	174.08
2.53	3.03	4.64	5.30	6.49	137.75	224.33
2.53	1.91	2.99	3.41	3.18	140.08	191.92
2.33	1.67	2.53	2.59	2.27	139.08	206.00
2.20	1.26	2.57	3.71	2.84	102.75	158.08
3.33	1.35	3.39	3.82	4.32	141.08	215.17
1.40	1.85	3.29	4.11	4.18	91.12	160.17
2.60	1.53	2.46	3.13	2.20	154.83	231.42
3.06	1.97	3.50	4.17	3.82	195.25	324.08
2.53	2.93	4.23	5.03	4.03	132.17	188.42
2.00	1.93	5.01	3.54	3.15	131.92	243.92
2.01	1.98	3.22	3.66	2.56	103.00	149.58
2.98	2.05	3.36	4.45	5.68	203.00	285.50
2.10	1.94	2.64	2.81	2.86	104.58	152.25
0.58	1.02	1.92	1.34	1.83	44.74	83.14

Table 4. Phenotypic Variance (Vp), Genotypic Variance (Vg), Heritability (broad sense (h^2), Genetic advance (G.A), under selection and expected Genetic Gain (G.G) for seventeen variable in tapioca (Y and x1............x16).

Variable	Vp	Vg	h^2	G.A	G.G
Y	0.4734	0.1688	35.64	0.5051	18.99
x1	3.0283	1.7138	56.59	2.0286	27.45
x2	0.0140	0.0070	49.96	0.1219	32.48
x3	151.1217	8.0050	52.93	4.2400	17.80
x4	77.9200	7.5000	10.45	0.6831	4.02
x5	0.0069	0.0017	24.63	0.0421	6.62
x6	54312.7000	24252.0900	44.65	214.3600	37.88
x7	9406.8000	2724.4500	28.96	57.8600	18.35
x8	229.9700	18.6800	8.12	2.5400	7.37
x9	507.9200	233.2000	45.91	0.9458	1.44
x10	0.2947	0.1719	58.31	0.6521	27.72
x11	5.7257	1.9112	33.37	1.6450	84.74
x12	1.7790	0.4258	23.94	0.6576	19.93
x13	1.0813	0.4226	39.08	0.8370	22.34
x14	2.2821	1.0490	45.97	1.4300	40.96
x15	1847.9800	1112.8700	60.22	53.3300	40.02
x16	5647.7700	3109.3100	55.05	85.2200	39.81

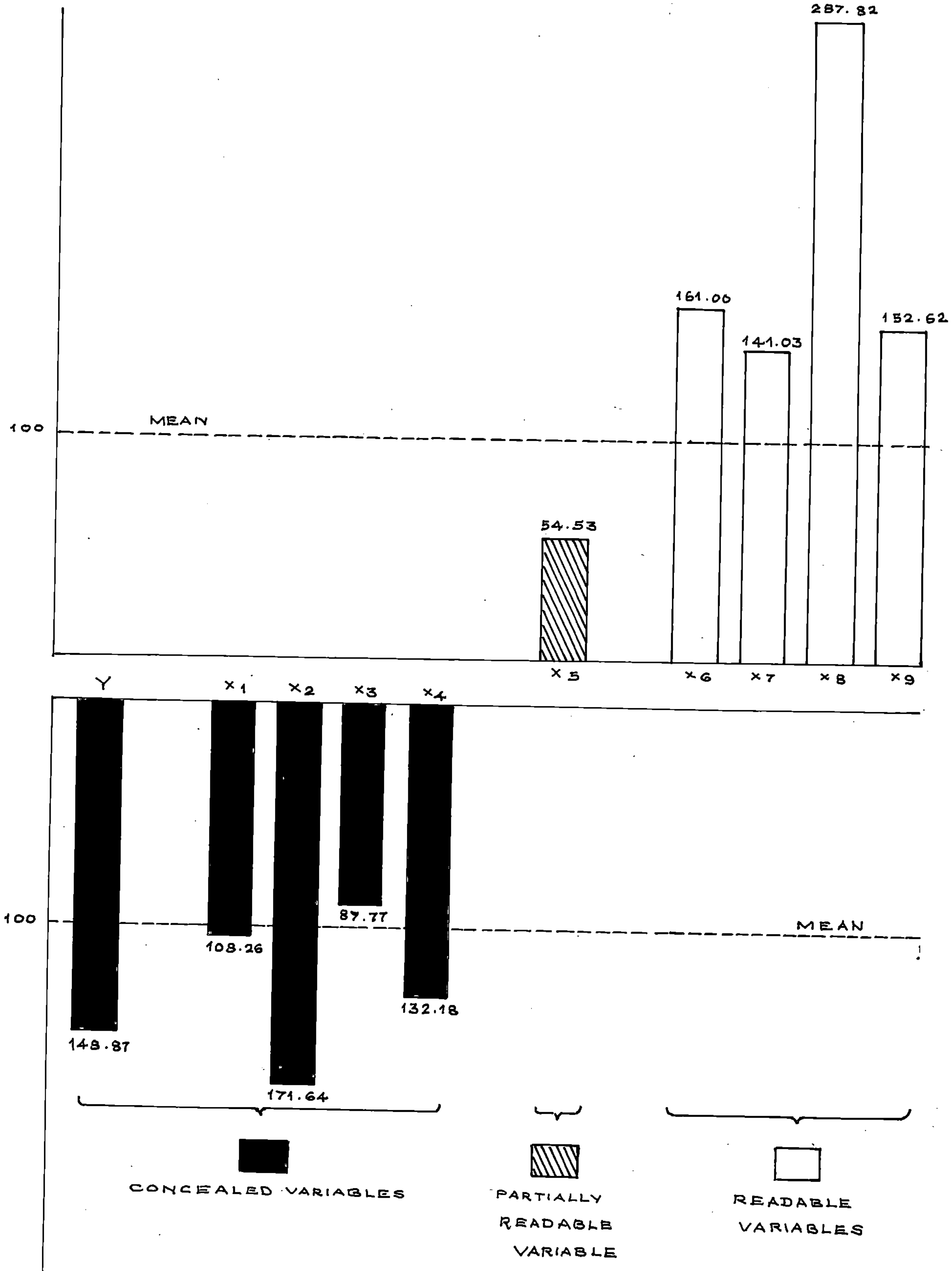


FIG: 2 DIAGRAMMATIC ILLUSTRATION OF THE RELATIVE DEGREE OF MAGNITUDE OF THE RANGE FOR TEN VARIABLES IN TAPIOCA for x15 (number of leaves abscissed on the 5th month). The value corresponding to Y (yield) is 35.64. But x5 (Harvest Index) appears to record a relatively lower value than Y (24.63).

The interrelationship -- phenotypic and genotypics, for the seventeen variables was estimated and the results tabulated (Table 5 and Table 6).

The final selection of variables for making the causal diagram was confined to ten of the seventeen variables only. The values that are included in Tables 5 and 6 were the criteria adopted for the exclusion of these seven variables in this connection. Less associated ones were rejected whereas the more associated ones were retained, yet a logical assessment of the relative importance of the variables were not over looked.

Table 7 presents the results of path coefficient analysis.

The trend of the change in the mean value in respect of leaf area index (LAI) estimated on the third, fourth, fifth and sixth months is represented graphically in Figure 3.

It appears that the value for the attribute progressively increases from the third month, reaching the peak by the fourth, and then declining.

The observation in respect of the number of leaves abscissed from the fourth through the sixth months is

Table 5. Phenotypic correlation of seventeen variables in tapioca.

Variable	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10
Y	0.273**	0.6076**	0.079	0.0935	0.3250**	0.1479	-.1378	-.1233	0.0063	0.0544
x1		-.5175**	-.4913**	0.0860	-.1699	0.0702	-.1064	-.2415	0.3828**	0.3203**
x2			0.2890**	0.0270	0.3461**	0.0419	-.0515	0.0529	-.2566**	-.2058
x3				-.0008	0.1676	0.2892**	0.0863	0.1969	-.1933	-.2628**
x4					-.0820	-.0063	-.1205	-.0672	0.0609	-.0584
x5						-.1220	-.0140	-.0330	-.3070**	-.1630
x6							-.0667	0.3310**	0.1337	0.2328
x7								0.0133	0.0300	0.0725
x8									-.2108	-.0760
x9										0.5277**

**Significant at 1%

continued....

Table continued

	x11	x12	x13	x14	x15	x16
Y	0.0480	-.0260	-.1258	-.0760	0.0560	0.2870**
x1	0.2113	0.1205	0.1114	0.1539	0.3103**	0.2570**
x2	-.2076	-.1948	-.2198	-.2507**	-.1950	.0057
x3	-.1601	-.1486	-.2386	-.2412	-.0226	0.0655
x4	-.1974	-.1640	-.1740	-.1224	0.0309	-.0109
x5	-.0280	0.0945	-.0240	-.1750	-.2470	-.1540
x6	0.0371	0.0865	-0.139	0.0143	-.3525**	0.5483**
x7	0.3355**	0.3873**	0.3465**	0.2813**	-.0036	0.0233
x8	-.0704	0.0089	0.0003	0.1043	-.1308	-.0389
x9	0.1618	-.0138	0.1238	0.2797**	-.0800	-.0668

continued

Table continued

	x11	x12	x13	x14	x15	x16
x10	0.0638	-.0034	0.1257	0.1103	0.4831**	0.3728**
x11		0.7262**	0.5681**	0.6067**	0.0657	0.2480
x12			0.6002**	0.6068**	-.0159	-.0574
x13				0.6744**	-.0011	0.0146
x14					0.1699	0.1258
x15						-.8390**
x16						1.0000

Table 6. Genotypic correlation of seventeen variables in tapioca

Variable	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10
Y	0.4673**	0.6562**	0.0929	0.8806**	0.5594**	-.4332**	0.1694	0.3293*	-.4363**	-.1576
x1		-.6622*	-.8676**	-1.1035**	0.2699	0.9338**	-.3536	1.1379	0.5570**	0.5346**
x2			0.6388**	0.0191	0.3461	-.0006	-.3312	0.8892**	-.6638**	-.5631**
x3				0.6810**	0.1676	0.3598	0.2104	1.0197**	-.5962**	-.4771**
x4					0.5527**	0.2540	1.0090	0.9640**	-.9490**	-.9460**
x5						0.6467**	-.4094	0.1782	-1.1734**	-.3607
x6							0.3795	0.2991	0.0285	0.1010
x7								0.9610**	-.1657	0.1286
x8									-.6728**	-.7257**
x9										0.9081**

*Significant at 5%

**Significant at 1%

Table continued

	x11	x12	x13	x14	x15	x16
Y	-.0079	-.2518	-.0706	-.2161	-.1168	0.0702
x1	0.0292	0.0828	0.1121	0.1874	0.4845**	0.2665
x2	-.3312	-.2565	0.1691	-.3768	-.4506**	-.1832
x3	-.1078	-.3068	-.2385	-.2896	0.2830	-.0147
x4	0.5009**	-.0654	0.4849**	0.7589**	-.9190**	-.6612**
x5	-.0155	.8778**	0.4936**	-.0932	-.2791	-.0719
x6	0.0356	0.3617	-.1953	0.2398	0.6047**	0.8140**
x7	1.1046**	1.0247**	0.9698**	0.8396**	-.1102	-.0448
x8	-.1407	0.2002	0.3780	0.5904**	-.0563	0.4117
x9	0.2487	-.0273	0.4026	0.4432	0.8505**	0.5560**

continued....

Table continued

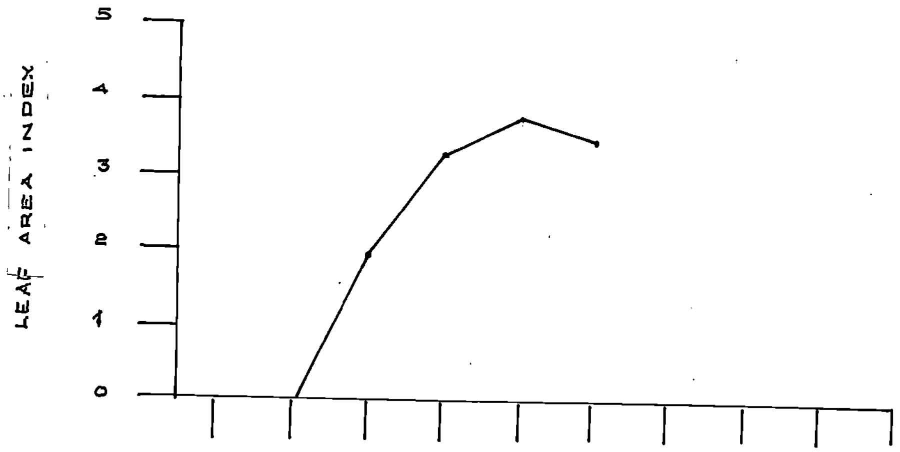
	x11	x12	x13	x14	x15	x16
x10	1.1394**	0.1499**	0.3405**	0.4921**	0.8396**	0.6212**
x11		0.8412**	1.0099**	0.6595**	0.9730**	0.0065
x12			1.0394**	0.7539**	-.0536	-.0204
x13				1.0491**	0.2054	0.1079
x14					0.3094	0.1773
x15						1.0040**
x16						1.000

Table 7. Path coefficients for the proposedc cause effect relationship scheme involving the effect E (Y) and nine components (x1.......x9)

	x1	x2	x3	x4	x5	x6	x7	x8	x9	Total corre- lation on (Y)
x1	0.16766	-.56294	-.04019	1.56819	-.17805	0.51665	0.02140	-.19026	-.61244	0.68939
x2	0.07835	0.85012	0.05153	-1.15470	0.00308	-.00035	0.00038	0.14868	0.72992	0.60395
x3	0.04526	0.29423	-.14888	-.30294	0.08916	-.35780	0.02477	0.02980	1.29020	0.96376
x4	-.14546	0.54309	-.02495	-1.80750	0.10986	0.19908	-.01273	0.17051	0.65550	-.31260
x5	-.18501	0.01624	-.08229	-1.23090	0.16131	0.14054	-.06105	0.16119	1.04346	-.03651
x6	-.26281	-.00054	-.09627	0.65030	0.04097	0.55331	0.05000	0.05008	-.03136	-.41996
x7	-.05928	-.00539	0.06095	-.38030	0.16276	0.20998	0.06510	0.16069	0.18219	0.27109
x8	-.19070	0.75591	-.02653	1.84316	0.15550	0.16548	-.05815	0.16720	0.73980	-.13464
x9	0.09339	-.56430	0.17469	1.07756	-.15308	0.01578	0.01003	-.11250	-1.09950	-.55793

Residual effect = 0.4346

FIG: 3 DIAGRAMMATIC REPRESENTATION OF MONTHWAR VARIATION IN LEAF AREA INDEX (L.A.I) IN TWENTY VARIETIES OF TAPIOCA



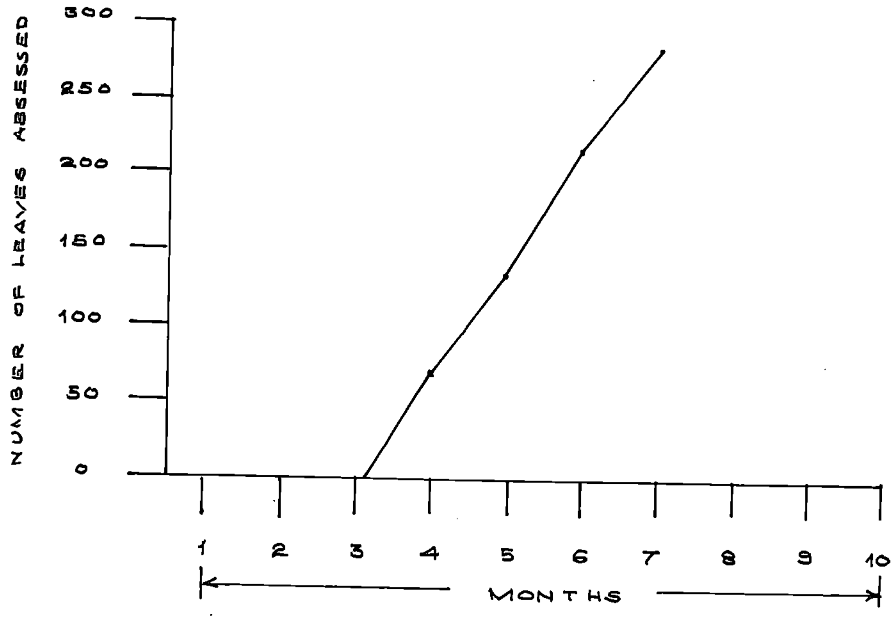


FIG: 4 DIAGRAMMATIC REPRESENTATION OF MONTHWAR VARIATION IN NUMBER OF LEAVES ABSESSED diagramatically presented in Figure 4.

The illustration is suggestive that the value exhibits signs of progressive ascend only, i.e. more number of leaves get abscissed in advancing months.

DISCUSSION

DISCUSSION

The material used in the study consisted of 20 varieties of tapioca, which exhibited significant divergence for all the 17 characters analysed (Table 1).

Variability among the variables

Considerable variation was noticed in this regard. It is evident from Table 2 that harvest index (x5) recorded the lowest value for the coefficient of variation, probably because this is the only attribute among the seventeen that might have become appreciably stabilized. Yield of tuber (Y), the most important character, recorded a relatively higher value (25.88), and the finding seems to suggest that between the two variables referred to above, the latter manifests relatively more variability. Further, with regards to the remaining 15 variables the extent of variability differed remarkably. It was maximum for girth of tuber (x4) and the value for the coefficient was 51.91. From the table it is seen that the value for the estimate ranged from 13.05 for harvest index (x5) to 51.91 for girth of tuber (x4).

Variability in respect of quantitative characters is not a strange phenomenon. Further, for effecting selection it is an essential requirement. More the variation better will be the response to selection. In the light of findings made on the basis of Table 2 it is proposed that there is scope for effecting selection in favour of all these 17 characters. But such a programme incorporating the manipulation of a large number of variables will be more than obtruse from the practical point of view. Therefore, an alternate programme which is sufficiently simple and preferably with the involvement of a conveniently fewer number of variables having adequate response to selection will have to be searched. This necessitates further identification of the more important ones from others in this respect.

Identification of different types of variables

Tapioca being a crop cultivated for the root tubers, imposes problems different from crops in which the produce is borne serially. For the sake of operational convenience the variables are classified as follows.

a) Concealed variables

Five out of the 17 variables do not lend themselves suitable to direct reading because of their concealed nature, which is maintained till the time of harvest. They are

1) Yield of tuber - (Y)
2) Number of tubers per plant - (x1)
3) Mean weight of tuber - (x2)
4) Mean length of tuber - (x3), and
5) Mean girth of tuber - (x4)

These 5 characters pertain strictly to the tubers.

b) Readable variables

The following 11 variables are included:

1) Length of stem - (x6)

2) Number of nodes - (x7)

3) Number of leaves retained - (x8)

4) Number of leaves abscissed on the 4th month - (x9)

5) Number of branches - (x10)

6) L.A.I. on the 3rd month - (x11)

7) L.A.I. on the 4th month - (x12)

8) L.A.I. on the 5th month - (x13)

9) L.A.I. on the 6th month - (x14)

10) Number of leaves abscissed on the 5th month - (x15), and

11) Number of leaves abscissed on the 6th month - (x16)

Partly readable variable

The remaining single variable - Harvest index (x5) necessitates inclusion of measurements of both concealed and exposed variables for computation.

Dependence of variables

When two or more variables are included in a particular study, one has to think about whether the variables by themselves are independent or dependent on other variables. Accordingly, the association or interrelationship of variables, was estimated at the levels of the phenotype as well as the genotype.

Based on the information 10 variables out of the total 17 were identified to be relatively more important then the rest and these 10 variables for the purpose of easy understanding were eventually made use of for making diagrammatic representations as given under Figures 5, 6, 7, 8 and 9. These variables are:

1)	Yield of tuber	-	(Y)
2)	Number of tubers per plant	-	(x1)
3)	Mean weight of tuber	-	(x2)
4)	Mean length of tuber	-	(x3)
5)	Mean girth of tuber	-	(x4)
6)	Harvest index	-	(x5)
7)	Length of stem	-	(x6)
8)	Number of nodes	-	(x7)
9)	Number of leaves retained (harvest)	-	(x8), and
10)	Number of leaves abscissed (4th month)	-	(x9)

The following conclusions were drawn.

<u>Association of yield and harvest index</u>

Yield of tuber (Y) is the most important character as far as the crop of the study is concerned. It bears significant positive association in phenotype as well as genotype with harvest index (x5). Harvest index (x5), as already mentioned earlier is computed by dividing the gravimetric yield of fresh tuber by the weight of the plant including the tuber. Hence it is presumed that the increase in the value for yield (Y) coupled with a corresponding

CC	=	represents the concealed causal components		
		x1	=	Number of tubers per plant,
		x2	=	Mean weight of a single tuber,
		x3	=	Mean tuber length, and
		x4	=	Mean girth of a tuber.
E	=	represents the Effect		
		Y	=	Yield of tubers per plant
TE	=	represents the transitory effect		
		x5	=	Harvest Index
RC	=	represents the readable causal components		
		x6	=	Total length of stem at the time of harvest
		x7	=	Number of nodes at harvest
		x8	=	Number of leaves retained at harvest
		x9	=	Number of leaves abscissed on fourth month.

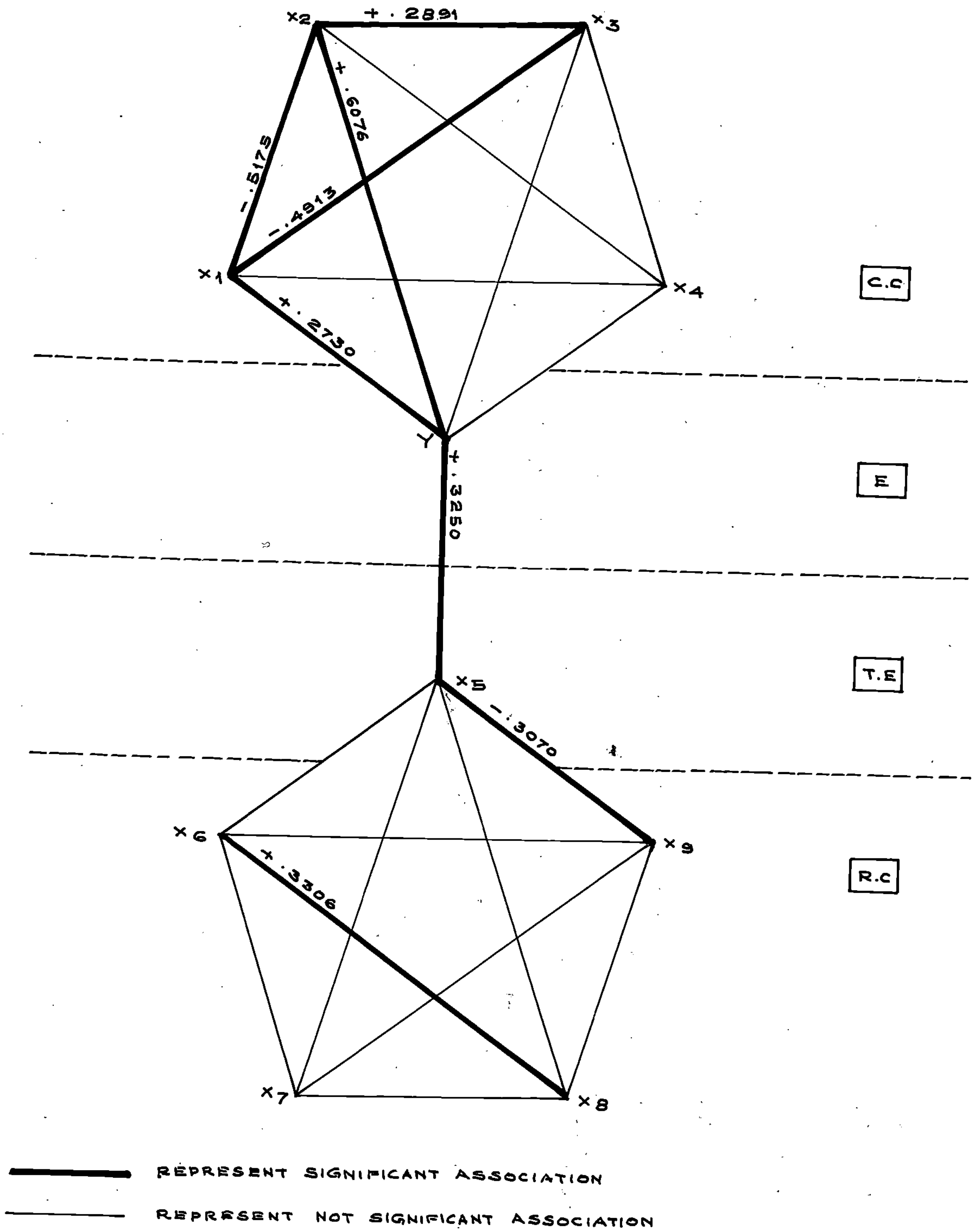


FIG: 5 DIAGRAMMATIC REPRESENTATION OF PHENOTYPIC ASSOCIATION OF TEN VARIABLES IN TAPIOCA

CC = represents the concealed causal components

x1 = Number of tubers per plant,

x2 = Mean weight of a single tuber,

x3 = Mean tuber length, and

x4 = Mean girth of a tuber.

E = represents the Effect

Y = Yield of tubers per plant

TE = represents the transitory effect

x5 = Harvest Index

RC = represents the readable causal components

x6 = Total length of stem at the time of harvest

x7 = Number of nodes at harvest

x8 = Number of leaves retained at harvest

x9 = Number of leaves abscissed on fourth month.

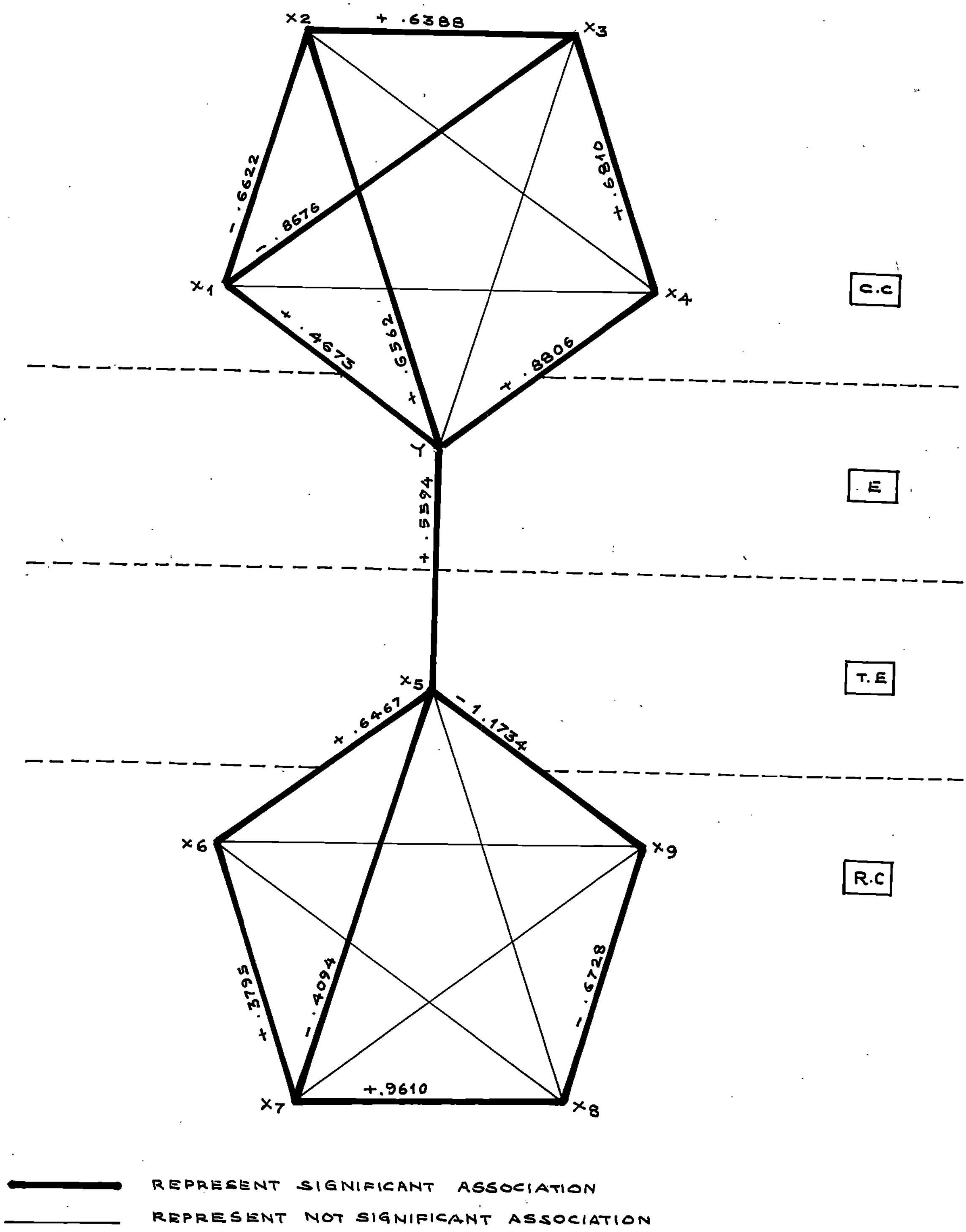


FIG: 6 DIAGRAMMATIC REPRESENTATION OF GENOTYPIC ASSOCIATION OF TEN VARIABLES IN TAPIOCA

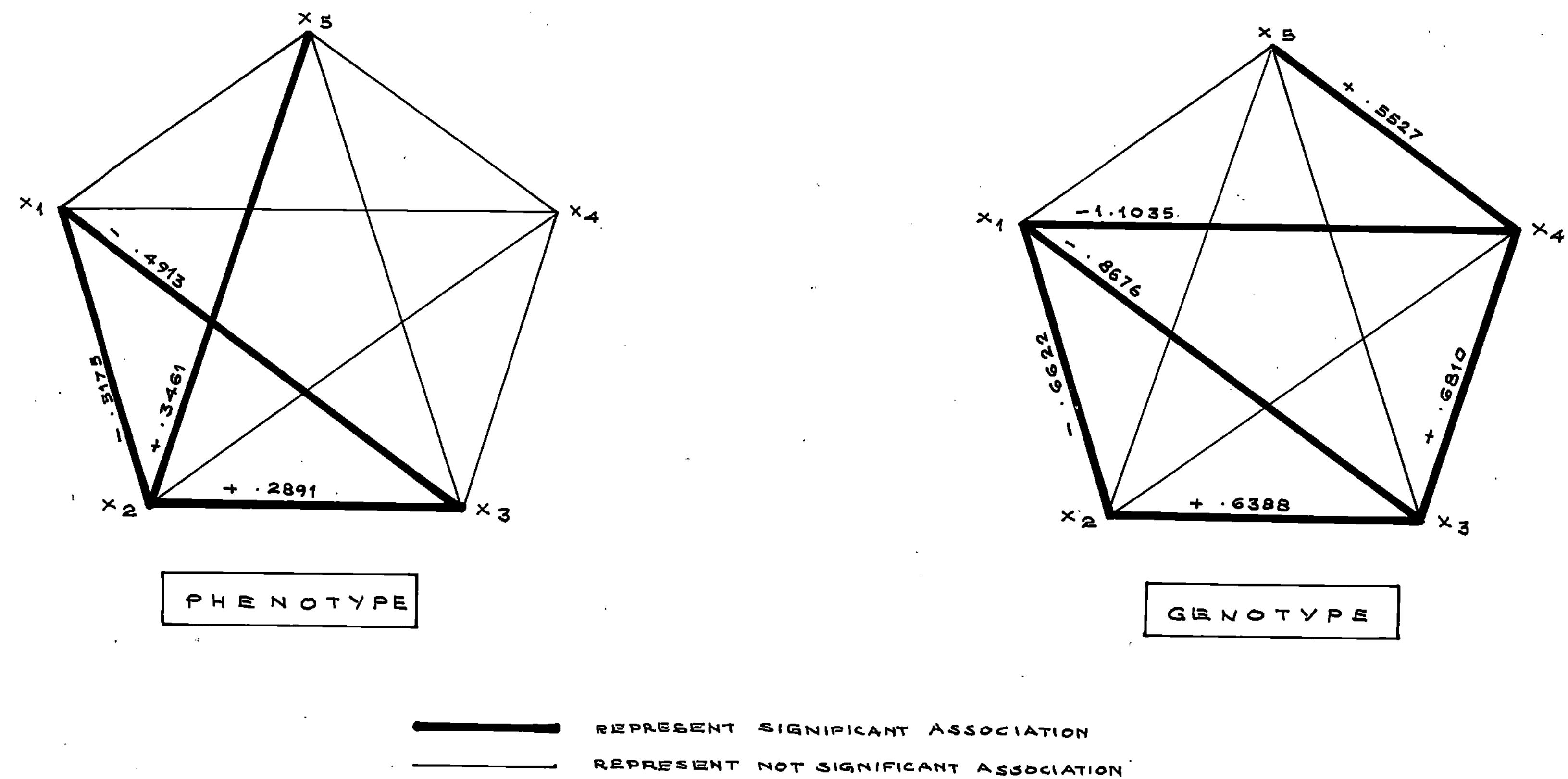


FIG: 7 DIAGRAMMATIC REPRESENTATION OF ASSOCIATION OF FIVE VARIABLES IN TAPIOCA

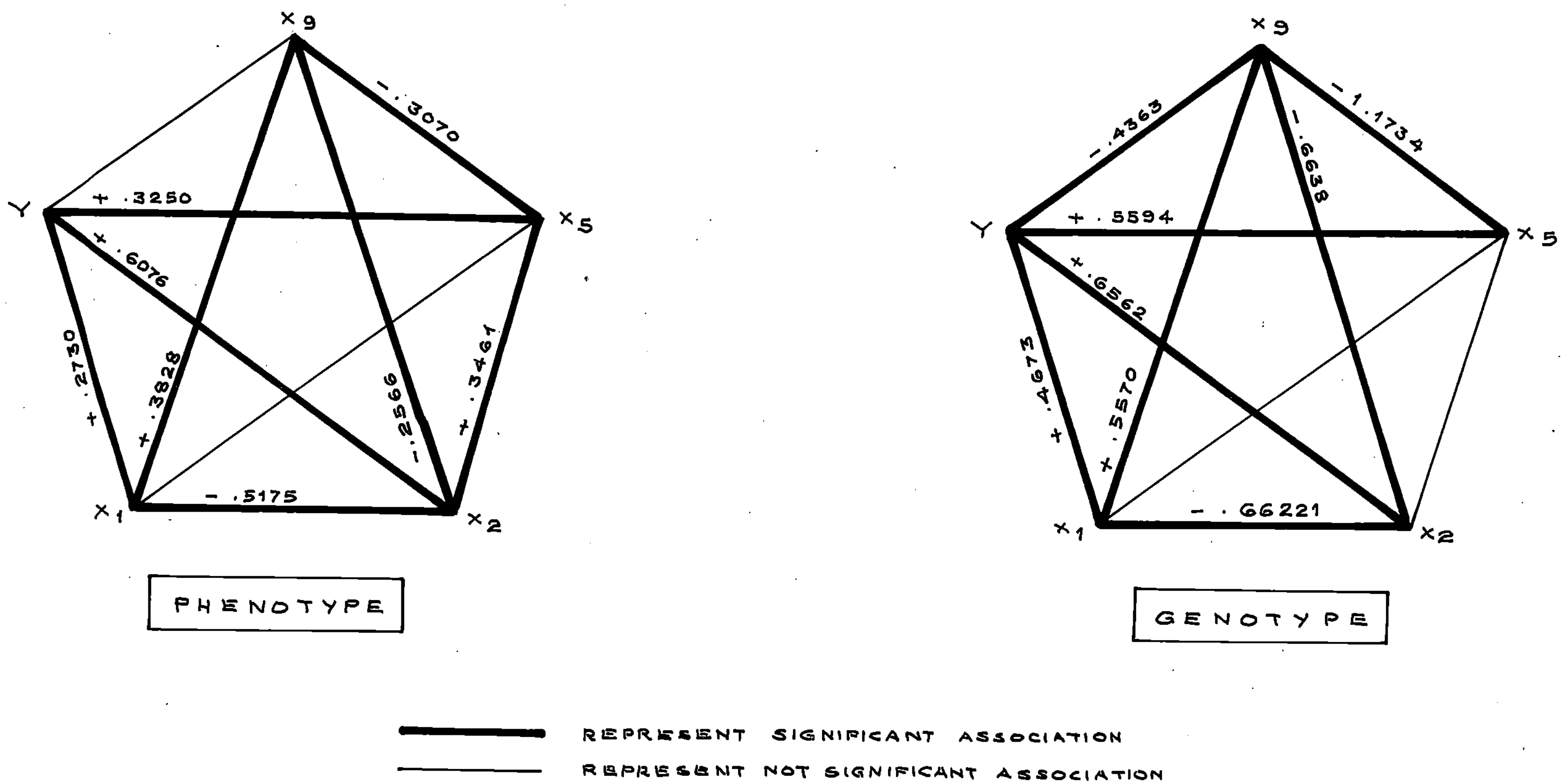


FIG: 8 DIAGRAMMATIC REPRESENTATION OF ASSOCIATION OF FIVE VARIABLES IN TAPIOCA

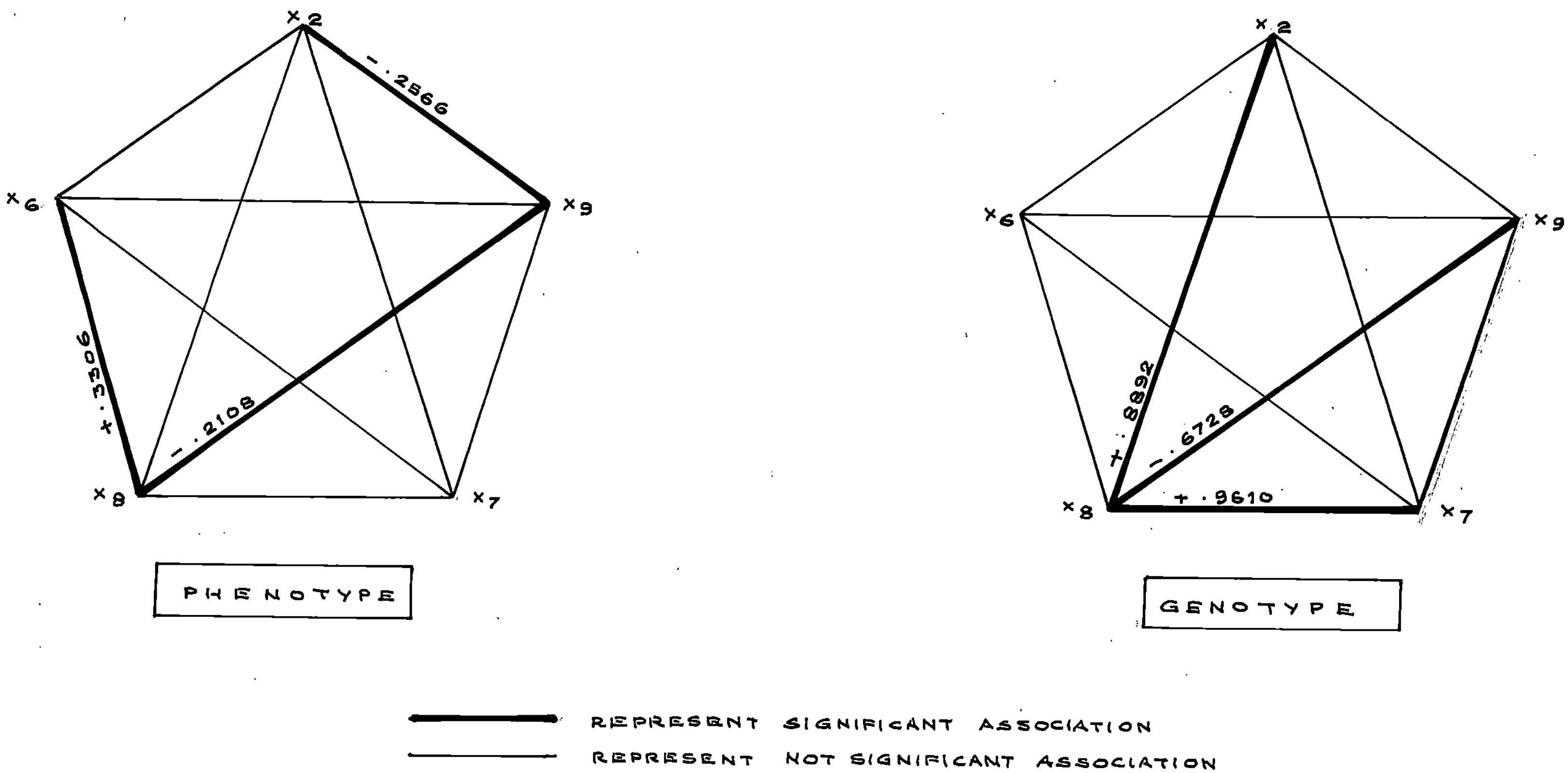


FIG: 9 DIAGRAMMATIC REPRESENTATION OF ASSOCIATION OF FIVE VARIABLES IN TAPIOCA

decrease in the mass of vegetative part is a must for resolving an economically advantageous value for the index. Similar positive significant association between yield and harvest index has been reported earlier by Biradar et al. (1978), Holmes (1974), Kamalam et al. (1978), and Kawano et al. (1978).

<u>Association of yield and tuber characters</u>

Phenotypic and genotypic association are represented in Figures 5 & 6 respectively. Positive as well as negative, significant and negligible relationships can be read distinctly.

Yield (Y) bears phenotypically and genotypically significant positive associations with number (x1) and mean weight (x2). Biradar et al. (1978) has reported earlier the occurrence of significant positive association between yield and number of tubers, and yield and mean weight of single tuber. Similar association in the case of yield and number of tubers has been reported by Kamalam et al. (1978) also. Here again the association of yield with weight seems to be comparatively stronger than that between yield and number.

Girth seems to be associated with yield (Y & x4) only in the genotype and the relationship exhibited a positive trend. Magoon (1972), Muthukrishnan (1973), and William (1974) also observed significant positive association between girth of tubers and yield.

Association among tuber characters

As already mentioned earlier yield is significantly associated with number (y & x1) and mean weight (Y & x2). But number bears significant phenotypic and genotypic relationships with mean weight (x1 & x2) and length (x1 & x3).

Magoon (1972) reported the presence of positive association between mean length of tuber and mean girth of tuber.

Further, mean weight exhibits significant associations with number and length (x2 & x1) and (x2 & x3) respectively. In addition the length is genotypically associated with girth (x3 & x4) and girth with yield (x4 & Y).

The influence of weight (x2), number (x1) and girth (x4) on yield (Y) appears to be direct. The most intense relationship is that between yield and mean weight (Y & x2).

Association between harvest index and tuber characters

Harvest index is positively and significantly related to mean weight only (x5 & x2) and the sign is positive. Further, the character is genotypically related to girth (x5 & x4). This relationship also appears to be direct.

Association of harvest index and readable variables

Four readable variables were tested in this regard.

1) Length of stem - (x6)
2) Number of nodes - (x7)
3) Number of leaves retained - (x8), and
4) Number of leaves abscissed on the 4th month - (x9)

Harvest index is significantly and negatively related to number of leaves abscissed during the 4th month alone (x5 & x9). This relationship is significant at the levels of the phenotypic and genotype. That between harvest index and length of stem was significant and direct in genotype alone (x5 & x6). Number of nodes was significantly and inversely associated with the harvest index genotypically (x7 & x5).

Association among readable variables

The relationship between length of stem and number of nodes (x6 & x7) was direct and significant and confined to the genotype only. The character is found to be directly associated with number of leaves retained at harvest in respect of phenotype (x6 & x8).

The number of leaves retained, in addition, bears genotypic significant association with number of nodes and the number of leaves abscissed during the 4th month (x8 & x7; and x8 & x9 respectively). Between the two relationships the former is positive and later negative.

Among the 4 readable variables mentioned in the above discussion number of leaves abscissed during the 4th month alone bears an intense relationship with harvest index (x9 & x5).

Association of number of leaves abscissed on the 4th month against yield, harvest index and number and weight of tuber

The readable character x9 bears genotypic significant relationship with the other 4 variables i.e. (x9 & x4), (x9 & x5), (x9 & x1), (x9 & x2). However, phenotypically significant relationship existed only in respect of x8 & x5, x9 & x2 and x9 & x1.

Association between mean weight and the four readable characters

Phenotypically the mean weight is significantly associated with number of leaves abscissed during the 4th month (x2 & x9) which, in turn, possesses significant association with number of leaves retained at harvest (x9 & x8). This character and length of stem are related (x8 & x6).

In genotype the mean weight of tuber seems to bear significant relationship only with a single readable variable i.e. number of leaves retained at harvest (x2 & x8). Further, the character x8 is related to number of nodes at harvest x7 and number of leaves abscissed during the 4th month (x9).

A close scrutiny of Table 6 brings out the following additional information in respect of genotypic associations between number of tubers and length of stem (x1 & x6), and number of tubers and leaves retained at harvest (x1 & x8).

In the light of the above findings it is gathered that

1) Tuber yield in tapioca is directly influenced by the mean weight of tuber and the number of tubers
2) A higher value for the harvest index is always indicative of a correspondingly higher yield of tuber
3) Harvest index is further inversely influenced by the number of leaves abscissed during the 4th month

4) A lesser number of leaves abscissed during the 4th month therefore is presumed to increase the yield of tuber
5) Increase in length of stem has a negative influence on yield
6) Increase in girth of tuber will have a corresponding increase in yield.

<u>More important Vs Less important component variables</u>

The interrelationship of the selected 10 variables including yield (Y) and harvest index (x5) were discussed at length as given above. It seems that some of the variables deserve preferential recognition over others based on relative importance. Further, it is emphasised that all the dependent variables need not necessarily function in the same manner. Each one may influence another either directly, or indirectly through one or more other variables. In addition, the characteristic features of these variables in terms of heritability, genetic advance and genetic gain under specified intensities of selection too will have to be taken into consideration before a final commitment is proposed as to their relative importance in this context. As is evident from Table 4, the value for heritability in the broad sense is highest (56.51) for number of tubers (x1) and the lowest (8.12) for the number of leaves retained at harvest (x8) among the 10 specially chosen variables. Heritability in the broad sense alone was computed during the course of study because tapioca being a highly cross pollinated crop does not promise added advantage by making an estimate of the parameter in the narrow sense. For yield the heritability value is 35.64, a figure that suggests prospects in effecting genetic improvement through selection. Harvest index, the attribute which is to a largest extent associated with yield record a lower figure (24.63), probably because selection would have been more operative for this character as compared to yield. Leaving apart the concealed component namely number (x1), mean weight (x2) length (x3) and girth (x4), in a consideration in which confinement was purposefully restricted to readily readable characters as the length of stem (x6), number of nodes (x7), number of leaves retained at harvest (x8) and number of leaves abscissed on 4th month (x9), the values for the heritability estimate are 44.65, 28.96, 8.12, and 45.91 respectively. Under this circumstance it is apparent that there is considerable scope for selection in favour of length of stem and number of leaves abscissed during the 4th month. Number of nodes does not seem to exclude completely the possibility of any gain being realised through selection. Further, the number of leaves retained at harvest, since it records the lowest value for the estimate (8.12), it is all the while wise to consider it as a character that is influenced more by the environment than the genotype.

In a comparison of the values obtained in respect of genetic advance and genetic gain under specified probability levels of selection it is seen that the number of leaves abscissed during the 4th month (x9), which bears an inverse relation to yield of tubers (Y) as already referred to earlier, seems to promise the maximum scope for resolving genetic improvement through selection.

With the above points in mind a scheme for the probable cause-effect relationship for yield of tuber in tapioca has been proposed.

<u>Cause-effect relationship</u>

The theory of causation proposed by Wright (1921) has proved itself already to be of immense worth in the hands of practical breeder. In this relevance the yield of fresh tuber in tapioca is identified as the effect and the remaining 8 variables, in a more generalised manner, as the causes. For the sake of operational convenience, during the course of study a few modifications are being proposed. Harvest index has been given the status of a transitory effect since the computation of the parameter necessitates the inclusion of information pertaining to the effect for its computation. Being a crop in which the yield factor is concealed till the time of harvest is over, four of the causes viz., number (x1), mean weight (x2), length (x3) and girth (x4) of tuber are classed as hidden causes, and four, length of stem (x6), number of nodes (x7), number of leaves retained at harvest (x8) and number of leaves abscissed during the 4th month (x9) as the readable causal components. Further, in the formulation of the causal scheme a distinction of the causes to different orders of importance have been introduced.

Accordingly, the causal diagram was made as shown in Figure 1.

An analysis of the path coefficients which was conducted during the course of study reveals interesting information which is presented in Table 7. Reference is made to Figure 10, also in this context.

Among the readily readable or observational components, the maximum degree of correlation effect was expressed by number of leaves abscissed during the 4th month (x9), followed by the total length of stem (x6), and the number of nodes (x7). The lowest value was that corresponding to number of leaves retained at harvest. The observation seems to indicate that yield is increased as and when the values for x9, x6 and finally x8 decrease and that for x7 increase. In other terms a potentially high tuber yielding tapioca can be identified among the short statured genotypes with more number of nodes, i.e. one with relatively shorter internodes, with fewer number of leaves getting abscissed during the 4th month and consequently retaining relatively more number of leaves at harvest time. The results of the path coefficient analysis seems to assist to make the concept more accurate.

The respective values for direct and total effect of the four concealed causal components, the single transitory effect, and the 4 readable causes are given below.

E = represents the Effect

Y = Yield of tubers per plant

TE = represents the transitory effect

x5 = Harvest Index

CC = represents the concealed causal components

x1 = Number of tubers per plant,

x2 = Mean weight of a single tuber,

x3 = Mean tuber length, and

x4 = Mean girth of a tuber.

RC = represents the readable causal components

x6 = Total length of stem at the time of harvest

x7 = Number of nodes at harvest

x8 = Number of leaves retained at harvest

x9 = Number of leaves abscissed on fourth month

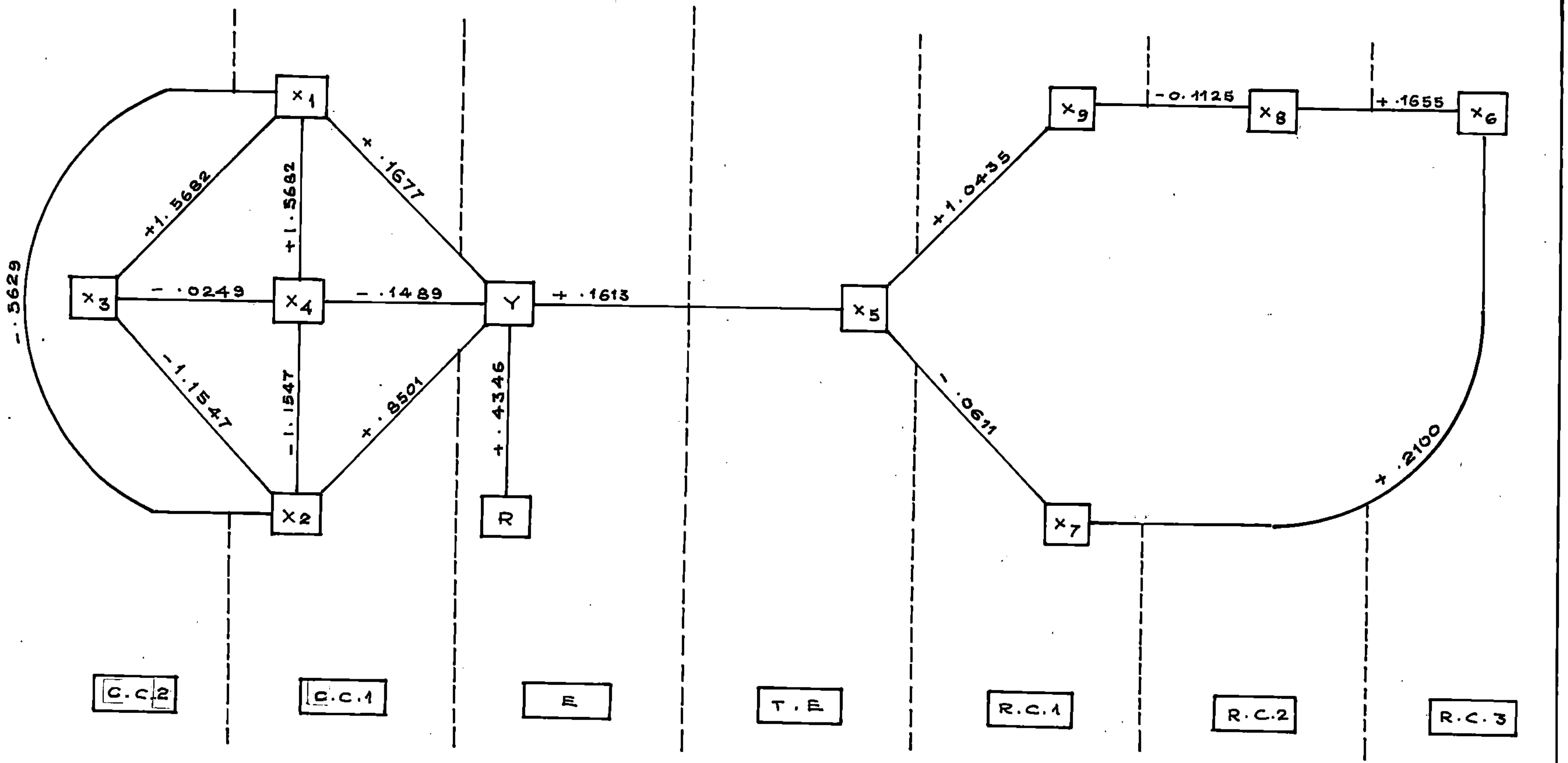


FIG: 10 CAUSE EFFECT RELATIONSHIP IN TAPIOCA
BASED ON PATH COEFFICIENT ANALYSIS

Concealed causes	Component	Direct effect	Total effect
	x1	+0.1677	+0.6894
	x2	+0.8501	+0.6040
	x3	-0.1489	+0.9638
	x4	-1.8075	-0.3126
Transitory effect	x5	+0.1613	-0.0365
Readable causes	x6	+0.5533	-0.4199
	x7	+0.0651	+0.2711
	x8	+0.1672	-0.1346
	x9	-1.0995	-0.5579

The information in the light of the causal scheme Figure 10 reveal the following features.

1. Effect is primarily associated with four of the nine causes - Harvest index (x5), number of tubers (x1), mean weight of tuber (x2), and girth of tuber (x4). The value for the total correlation is positive and maximum for x1 and followed by x2 (+0.6894 and 0.6040 respectively). Between these two causal components, x1 and x2, the relative proportion of direct effect on total effect is more for x2. The total effect of girth (x4) is negative and forms only a very small proportion of its direct effect.

2. Length of tuber (x3), which has been assigned to

the second order in the causal scheme has very little direct effect when compared to the total effect.

Strangely enough, the direct positive effect of harvest index (x5) gets more than nullified so as to give the total effect a negative sign.

3. The four readable component causes, length of stem (x6), number of nodes (x7), number of leaves retained at harvest (x8) and number of leaves abscissed during the 4th month (x9) were identified to belong to 3 different orders of importance, 1st, 2nd and 3rd in the causal scheme. Consequently variables x9 and x7 belongs to the 1st, x8 to the 2nd and x6 to the 3rd. Further x7 and x9 were proposed to be having their direct effect on the transitory effect-harvest index (x5). Between the two, x9 seems to have greater total effect on x5 which is negative. The direct effect is also negative and since the value is more than that of total effect the indirect effect is presumed to be of a positive nature and routed through x8, x6, x7, and x5. However, as far as the direct effect of x7 is concerned as against the total effect, the indirect effect evidently predominates, the sign of which is also positive. This effect is routed to x6, x8, x9, and x5 accordingly.

The number of leaves retained at harvest (x8) inflicts positive direct effect and negative total effect which indicates that the indirect effect is pronounced and negative. This effect is presumed to be routed through two path ways such as x8-x9-x5 and x6-x7 and x5.

Length of stem (x6) is responsible for positive direct effect which eventually becomes appreciably negative because of gross negative indirect effect routed through two path ways such as x8-x9-x5, and x7-x5.

Leaf area index

From the observations gathered in the course of experiment to study the effect of LAI (Leaf Area Index) and number of leaves abscissed on yield, the following trend as shown in Figures 3 & 3 is found out. The monthwar variation in the mean LAI from the 3rd month of planting (1.94) is progressively increasing and reaching the maximum (3.75) during the 5th month and then declining in the following month.

From the observations on the number of leaves abscissed during the 3rd, 4th, 5th, 6th and 7th months, a progressively ascending trend is noticed. The range is from 66 (4th month) to 284 (7th month). It is presumed that the tendency of a decline in the value for the LAI from the 5th month onwards is mainly due to the progressive increase in the number of leaves abscissed from the 5th month onwards. The finding seems to suggest that for the best results an optimum leaf area index (LAI) between 3.49 to 3.75 should be aimed at.

Holmes (1976) stressed the importance of leaf production and leaf abscission as important determinants of both total dry matter production and tuber yield.

Thus on the basis of the findings made during the course of study it is concluded that reliable selection criteria could be formulated for identifying genotypes with relatively high production potential in tapioca. In this contest the foremost importance should be attributed to the harvest index. Higher the value for the index better will be the productivity. Further, it should be remembered that for realising relatively higher values for the index the aerial part of the plant should weigh as less as possible at the time of harvest. But this should on no account be at the expense of an underdeveloped shoot system. On the contrary a plant with more number of nodes, situated relatively close together should be aimed at. As a supplementary feature the size of the leaves should be preferably larger and are to be borne by the stem in such a manner that maximum solar energy is trapped for increased photosynthetic activity. Based on observations and calculations made during the study it seems that the leaf area index should be kept optimum between 3.49 to 3.75. Further, it is felt that the whole complement of leaves should be fully developed as early as possible, and as and when the plant approaches harvest, majority of them should get abscessed in a relatively brief period.

SUMMARY

SUMMARY

(1) An experiment was conducted during June, 1979-March 1980, with 20 ecogeographically and genetically divergent varieties of tapioca (*Manihot esculenta* Crantz) in the premises of the Central Tuber Crops Research Institute at Trivandrum as a postgraduate project of the Kerala Agricultural University.

(2) The study was undertaken with the view to identify through carefully planned biometrical analysis reliable selection parameters in the crop.

(3) The field experiment was laid out in an R.B.D. consisting of 20 treatments in 3 replications. The middlemost plants in each plot constituted the sample. Plots were planted with 7 rows of 4 stem cuttings at 90 cm^2 spacing. The treatments were given identical management care.

(4) Data were collected in respect of the following 17 variables.

(1)	Yield of fresh tuber expressed gravimetrically	-	(Y)
(2)	Number of tubers per plant	-	(x1)
(3)	Mean weight of tuber	-	(x2)
(4)	Length of tuber	-	(x3)
(5)	Girth of tuber	-	(x4)
(6)	Harvest index	-	(x5)
(7)	Length of stem at harvest	-	(x6)

(8)	Number of nodes at harvest	-	(x7)
(9)	Number of leaves retained at harvest	-	(x8)
(10)	Number of leaves abscissed on the 4th month	-	(x9)
(11)	Number of branches	-	(x10)
(12)	Leaf area index on the 3rd month	-	(x11)
(13)	Leaf area index on the 4th month	-	(x12)
(14)	Leaf area index on the 5th month	-	(x13)
(15)	Leaf area index on the 6th month	-	(x14)
(16)	Number of leaves abscissed on the 5th month	-	(x15)
(17)	Number of leaves abscissed on the 6th month	-	(x16)

(6) The tabulated data were analysed statistically.

(7) From the ANOVA it was found that the treatments differed significantly for all the 17 variables. Further, on the basis of the values computed for the coefficient of variation, it was found that the extent of variation for each variable varied.

(8) The dependence of the variables were examined at the levels of the phenotype and the genotype. In addition, values for heritability (in the broad sense), and genetic advance and genetic gain at specified probability level under selection for these variables were estimated.

(9) Based on the information, as mentioned above, a distinction of relatively more important variables from the

less important ones was arrived at, and only the chosen variables were carried on further into subsequent procedures of analysis. These selected variables included

(1)	Yield of fresh tubers per plant	-	(Y)
(2)	Number of tubers per plant	-	(x1)
(3)	Mean weight of tuber	-	(x2)
(4)	Length of tuber	-	(x3)
(5)	Girth of tuber	-	(x4)
(6)	Harvest index	-	(x5)
(7)	Length of stem at harvest	-	(x6)
(8)	Number of nodes at harvest	-	(x7)
(9)	Number of leaves retained at harvest	-	(x8)
(10)	Number of leaves abscissed on the 4th month	-	(x9)

(10) An attempt was made to understand the cause-effect relationship in the crop using the Path Analysis method proposed by Wright (1921). Accordingly, a causal scheme was formulated in which the causal components were classified under three main categories such as transitory effects (x5), readily readable causal components (x6, x7, x8 & x9), and hidden or concealed causes (x1, x2, x3 & x4). Y remained as the effect. Further, the causal components were identified to belong to different orders of importance. Accordingly, x1, x2, & x4 belonged to the first order of the concealed component, x3 to the second order of the category

referred to above, x7 & x9 to the 1st order of the readily readable category of causes, x8 to the 2nd and x6 to the 3rd order of the same class.

(11) From the results, it was gathered that harvest index (x5) should be considered as the most dependable criterion for selection in this crop. Taking into consideration the readily readable causal components, the findings made during the course of the study seem to suggest that genotypes with potentially high tuber yield could be identified among those having relatively higher values for the harvest index, and that are inherently short statured with profuse foliage consisting of relatively large sized leaves which have become developed completely at a relatively earlier period of the life span, a majority of which eventually gets themselves abscissed fairly late, preferably towards the time of harvest. The optimum value for the LAI for efficient economic productivity is proposed in numerical terms.

(12) It appears, in general, that in tapioca yield of fresh tuber is influenced to a large extent by the tuber characters including length, girth, weight and number. In addition, harvest index too is identified as a reliable indicator of yield potential. A proposed concept on the nature of the shoot for potentially high yielders is being proposed.

(13) The implications of the findings of the study have been discussed at length.

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ABSTRACT

During a biometrical study conducted on 20 divergent types of tapioca (*Manihot esculenta* Crantz) in the premises of Central Tuber Crops Research Institute at Trivandrum, as a postgraduate programme of the Kerala Agricultural University, useful informations on the selection parameters become available. Accordingly, it was found that harvest index should be the best reliable criterion for effecting selection in favour of a desirable genotype from among others in a genetically heterogenic base population. Further, it is proposed that potentially high tuber yielders in the crop could be identified among relatively short statured ones with more number of large sized leaves that have became completely developed sufficiently early during development of the shoot. In addition, a tendency for relatively more number of leaves to become abscissed towards the time of harvest should also be considered as a positive sign of high tuber yield.