RP 827

THE GROWTH OF THE YOUNG COCONUT PALM (*COCOS NUCIFERA* L.)

I. THE ROLE OF THE SEED AND OF PHOTOSYNTHESIS IN SEEDLING GROWTH UP TO 17 MONTHS OF AGE

By M. A. FOALE*

[*Manuscript received May* 2, 1968]

Summary

The growth of coconut seedlings and the changes occurring within the seed were studied over a period of 17 months from the germination of the coconuts.

Removal of the husk prior to germination made possible an estimate of the endosperm content of each seed and also permitted the exact date of germination to be observed. Seedlings were grown with a non-limiting supply of water and nutrients; 63 seedlings were harvested on each of 10 occasions to enable a growth analysis to be made.

A high initial relative growth rate, arising through contributions by the endosperm, fell at 4 months to a level which remained roughly constant to 17 months. By 4 months the haustorium had reached its full size, but thereafter the relative contribution from the endosperm via the haustorium was much diminished.

Between 4 and 15 months a gradual change over to full dependence on photosynthesis took place. By 17 months less than 10% of the endosperm remained in the nut.

The rate of leaf production was constant with time, but the leaf area increased almost exponentially. There was some indication of a positive relationship between net assimilation rate and solar radiation. Some conclusions are drawn concerning cultural methods with young coconuts.

I. INTRODUCTION

The coconut palm has a very large seed (nut) with a hard shell; it is enclosed within a fibrous husk and is lined by a solid endosperm weighing from 50 to 600 g, depending on variety and on the growing conditions of the parent plant. Within the solid endosperm is a large vacuole filled with liquid endosperm (milk). The embryo lies within the endosperm, beneath a "germ pore" in the shell. At germination the haustorium, a spongy cotyledon (Selvaratnam 1952), expands into the vacuole which it eventually fills; the haustorium absorbs the material of the endosperm and transfers it to the developing seedling. Under normal germination with the husk intact there is a delay of several weeks until photosynthesis begins, because the shoot must pass through the husk (2–3 in. thick). Even after emergence a further period of about 5 weeks passes before the first leaf lamina unfolds.

The relationship between the endosperm and the seedling has not previously been investigated quantitatively, though Child (1964) presented data which gave an approximate indication of endosperm loss over a 6 month period.

---

* Joint Coconut Research Scheme, Yandina, British Solomon Islands.

Aust. J. agric. Res., 1968, **19**, 781–9

It has been shown in Ceylon that vigorous seedlings give a high yield of copra as mature plants (Liyanage 1955). The work here reported was undertaken to elucidate the role of the endosperm in seedling growth. It was hoped that a relationship might be established between some measurable seed characters and the vigour of the seedling which developed, as this would be of assistance in selecting good planting material. This latter aspect will be reported in a subsequent paper.

These studies were conducted at Yandina in the British Solomon Islands, latitude 8° S., on a site at sea-level.

II. Experimental Methods

The coconut seed is normally sown with the husk intact but this prevents an accurate observation of the date of germination. A further reason for removing the husk was to relate seedling growth to endosperm size, which can be estimated from the weight of a dehusked nut (Nathanael 1961). The coefficient of variation of a large sample was 3·1%. The ratio between endosperm weight and dehusked nut weight varies between varieties (Whitehead 1963; Foale 1964), so preliminary work was carried out to determine the appropriate conversion factors for the varieties used in this experiment. No difficulty was expected in growing seedlings from dehusked nuts, as it has been established that such seedlings develop quite normally (Nathanael 1958; Whitehead 1964); but to protect the very delicate shoot for the first weeks after germination, the husk was wrapped around the nuts again after weighing.

The experiment was continued for 17 months, by which time the endosperm was nearly exhausted or had decomposed. Ten harvests were made, two at intervals of 2 months, three at 1 month intervals when leaf tissue was first appearing, and finally five at 2-month intervals up to 17 months; at this time the seedlings were over 3 m high. Sixty-three seedlings were harvested on each of the 10 occasions, viz. 630 seedlings in the experiment. The details of three variety and three size group treatments included in the trial will be given in the second paper of this series. The individual harvest values presented in this paper are the means of 3 varieties × 3 nut sizes × 7 replicates, i.e. the mean values for 63 nuts.

All nuts were placed under moist sacks to await germination. Four weeks after germination they were planted in the field in holes 1 ft square and 1 ft deep, with a spacing of 2 ft between planting points. A plan of "selective thinning" was worked out so that after five harvests the remaining palms were all 4 ft apart. After seven harvests the palms were in an 8 ft triangular arrangement.

The soil was a free-draining clay loam of excellent structure. Leguminous mulch was applied liberally around each planting point, and coconut husks were used as mulch between the seedlings. Two applications of 100 g muriate of potash were made during the experimental period, to overcome any potassium deficiency. Irrigation was practised when the soil moisture tension, as indicated by tensiometers at 3, 9, and 15 in., rose above 0·5 atm.

Measurements on each seedling at each harvest were as follows.

Plant height.—The fronds were drawn up and the distance from the base of the plant to the tip of the longest leaf (frond) was measured.

Fresh and dry weights of endosperm, shoot, root, and haustorium.—The leaf laminae were weighed as a component of shoot weight. The endosperm dry weight was derived from addition of the weights of the solid and liquid (milk) endosperms. The former was determined by direct weighing, while the latter was estimated on the basis of 3·7% dry matter content, a value which had been arrived at in preliminary work on the liquid endosperm.

Leaf number.—Leaves unfold one by one from the single growing point of the plant. Total leaves were counted and also, in later harvests, the number which had senesced was noted.

Leaf area.—This was measured by weighing dry discs of known area punched from the leaflets, and then computing total area from the total dry weight of the leaf laminae.

Relative growth rate (R) and *net assimilation rate* (E).—These were calculated from the following formulae:

$$R = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1},$$

$$E = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1},$$

where W_1, W_2 and L_1, L_2 are the plant dry weights and leaf areas at times t_1 and t_2.

Two values of R were calculated, the first based on tops, roots, and haustorium, the second excluding the haustorium.

Two values of E were also calculated:

(1) "Apparent E", which included dry matter transferred to the plant from the endosperm.

(2) "Actual E", obtained after deducting endosperm loss from $W_2 - W_1$. For example, between harvests 4 and 5 the plant gained 33 g while the endosperm loss was 11 g.

"Apparent E" was based on 33 g gain and "actual E" on 22 g gain presumed to be due to photosynthesis.

The germination of the coconut is difficult to control, as it is largely independent of external water supply. In this experiment the germination date (i.e. the date when the embryo emerged through the germ pore) was noted for each individual seed. The harvest date for each seedling was then calculated from the date of germination. Within any one harvest there was a time range of about 4 weeks between the harvest dates of the first and the last seedlings. There is, however, very little variation in temperatures from month to month at Yandina (Table 1) and rainfall was supplemented with irrigation water as necessary. Variation in solar radiation was the only source of error associated with this time lapse, but as there was a similar spread of harvest dates within each harvest the overall effect of this variation on the pattern of seedling growth is believed not to have been appreciable.

III. Results

Table 2 shows the mean dry weight of seedlings at each harvest, the estimated weight of endosperm absorbed by the plant, and the plant height. The endosperm loss was calculated by deducting the endosperm weight at each harvest from the initial endosperm weight estimated from the weight of the dehusked nuts. The mean original endosperm weight was 225 g, so endosperm consumption by the seedling up to 17 months was about 93%. More than half of the nuts had begun to decompose by 15 months so that the percentages at 15 and 17 months are based only on the remaining nuts.

Table 1

Climatic data for the experimental period

Data	1964			1965					
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Mean max. temp. (°F)	87·5	88·4	88·1	87·2	86·9	87·6	87·8	88·5	87·3
Mean min. temp. (°F)	75·5	75·7	76·4	75·3	75·3	77·1	76·6	76·3	75·7
Daily sunshine (hr)	7·82	7·15	7·75	4·80	5·34	5·56	6·50	6·32	3·66
Rainfall per month (in.)	6·71	7·73	6·78	16·12	14·04	16·04	5·38	4·16	6·53

Data	1965						1966		
	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Mean max. temp. (°F)	87·7	85·8	86·4	86·9	87·1	85·1	85·5	85·6	87·5
Mean min. temp. (°F)	74·8	74·3	75·5	75·5	75·2	76·3	76·0	76·1	76·0
Daily sunshine (hr)	3·41	5·13	5·62	7·72	8·51	6·44	7·86	6·04	5·90
Rainfall per month (in.)	27·53	7·04	8·66	3·26	2·46	7·16	3·98	15·46	11·38

Table 2

Total dry weight of plant, total loss in weight of endosperm, and shoot height at 10 stages in the development of the coconut seedling

Measurement	Age of Seedlings (months)									
	2	4	5	6	7	9	11	13	15	17
Total plant weight (g)	12·3	59·4	79·8	113	146	242	663	1210*	2150*†	3080†
Total endosperm loss (g)	17·8	68·0	84·1	100	111	140	164	170	182	210
Shoot height (cm)	‡	69	91	106	122	147	181	217	286	326

* Root weight was not recorded at 13 and 15 months. Values were estimated from the curve for root weight.

† The haustorium weight was taken as remaining constant after 13 months. By age 15 months the haustorium of most nuts had decayed.

‡ Not recorded.

The natural logarithms of total plant weight and endosperm loss are plotted against time in Figure 1, together with the three components of the plant, viz. haustorium, shoot, and root. It may be seen that the gain in total weight (including the haustorium) for the first 6 months was approximately equal to the loss in weight by the endosperm. During the first 4 months a substantial part of the gain in weight was by the haustorium, but thereafter its weight increase was relatively small.

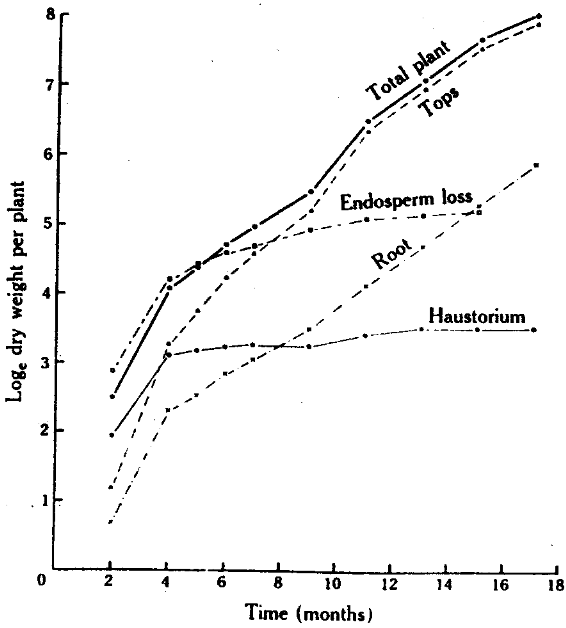


Fig. 1.—Dry weights of plant parts, total plant, and endosperm loss (log scale) plotted against time.

The endosperm weight loss between successive harvests is expressed as a percentage of plant weight gain in Figure 2. This gives an indication, for each harvest interval, of the relative proportions of dry matter coming from the endosperm and from assimilation in the photosynthetic tissue. The endosperm loss exceeded plant gain for the first harvest interval by 50% (perhaps an indication of the respiratory loss) and in the second by 6%. More reliance can be placed on the figure for the

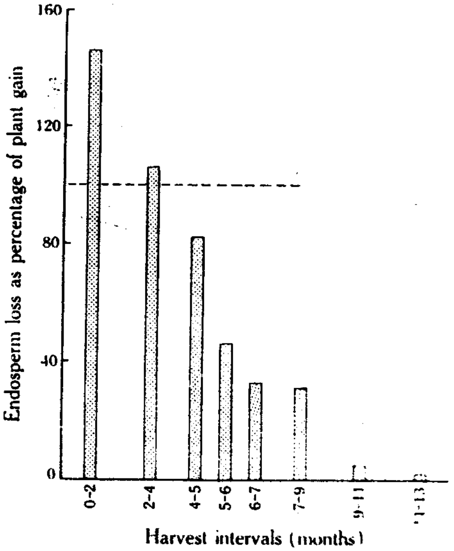
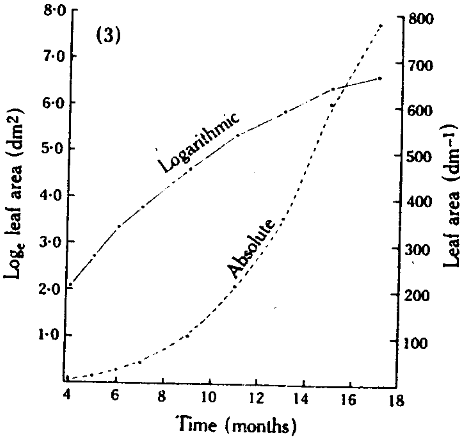


Fig. 2.—Relationship of endosperm loss and plant gain, illustrating the diminishing importance of the endosperm with time.

second interval because of the method of estimation of endosperm loss (see Section II). The estimated absolute loss between 0 and 2 months was about one-third of that in the 2–4 month period, but the same absolute error (±3% of original estimated weight of endosperm) applies to each figure.

The first leaf unfolded shortly after month 2, and three leaves had unfolded by month 4, but they were quite small, having a total area of 8 dm². The rate of leaf production was almost constant (0·93 per month); the leaf number increased from 3 leaves at 4 months to 16 leaves at 17 months. The leaf area on both an absolute and a logarithmic scale is plotted against time in Figure 3. There was a sharp increase in the area of each leaf compared with its predecessor.



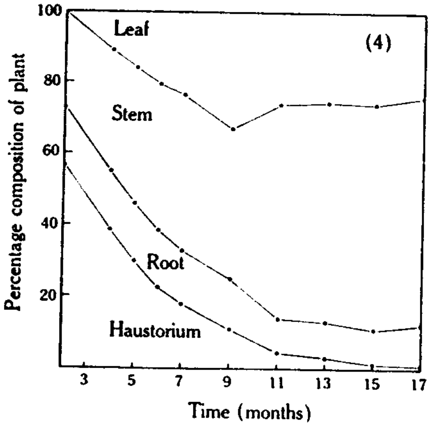


Fig. 3.—Area of green leaf throughout the experimental period.

Fig. 4.—The plant components, as percentages of total plant weight, plotted against time.

The four plant components, haustorium, root, non-photosynthetic shoot, and photosynthetic tissue (i.e. leaf laminae) are expressed as percentages of total weight in Figure 4. There is an expanding proportion of leaf and stem to month 11, and the three main components remained in constant proportion after that. The values for relative growth rate (*R*) for the first harvest interval were (g/100 g/week): shoot + root, 62; shoot + root + haustorium, 72. The remaining values are plotted in Figure 5. With advancing age the respective curves for whole plant and shoot + root come closer together as the haustorium diminishes in size relative to total plant weight. The general picture obtained of *R* was of an initial high value that fell rapidly to a level of *c*. 7·5 g/100 g/week and then remained fairly constant for the next 11 months.

The net assimilation rates, actual *E* and apparent *E*, are plotted in Figure 6 together with sunshine and rainfall data. Actual *E* rose from a zero value at 2 months, as photosynthetic tissue developed. From 5 months onwards there was some suggestion of a positive relationship between net assimilation rate and daily hours of bright sunshine, though with an aberrantly low value at 11–13 months. This low value is believed to have been due to inadequate watering during this interval.

IV. Discussion

A clear picture emerges of the growth pattern of the coconut seedling, and of the relative contributions by the endosperm and photosynthesis at different stages of the plant's development.

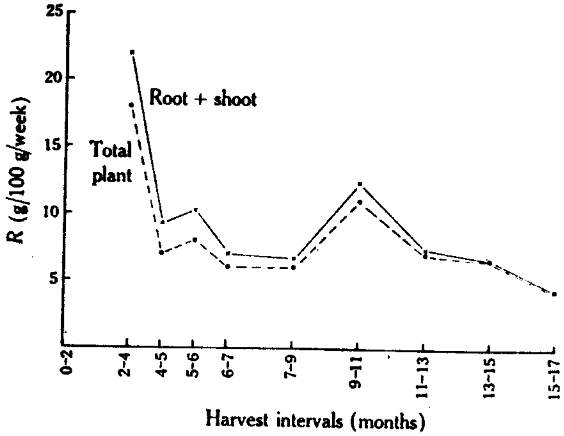


Fig. 5.—Trends in relative growth rate with time.

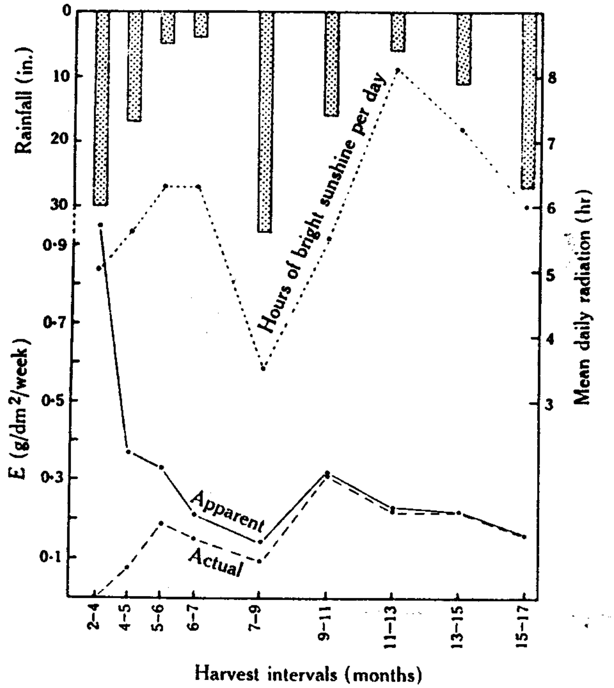


Fig. 6.—Net assimilation rate, hours of bright sunshine, and rainfall (columns), plotted against time.

——— Apparent *E*.

– – – – Actual *E*.

• • • • • Radiation.

The relative growth rate (whole plant) shows a steep decline from an initial value of 72 g/100 g/week to a fairly steady value of 7·5 g/100 g/week after 4 months. No doubt the decrease in *R* from a very high initial value down to this steady value was a continuous process. Just after germination the development of two organs

IV. DISCUSSION

A clear picture emerges of the growth pattern of the coconut seedling, and of the relative contributions by the endosperm and photosynthesis at different stages of the plant's development.

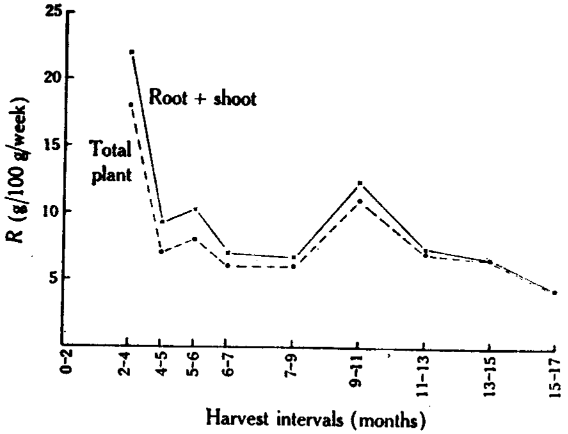


Fig. 5.—Trends in relative growth rate with time.

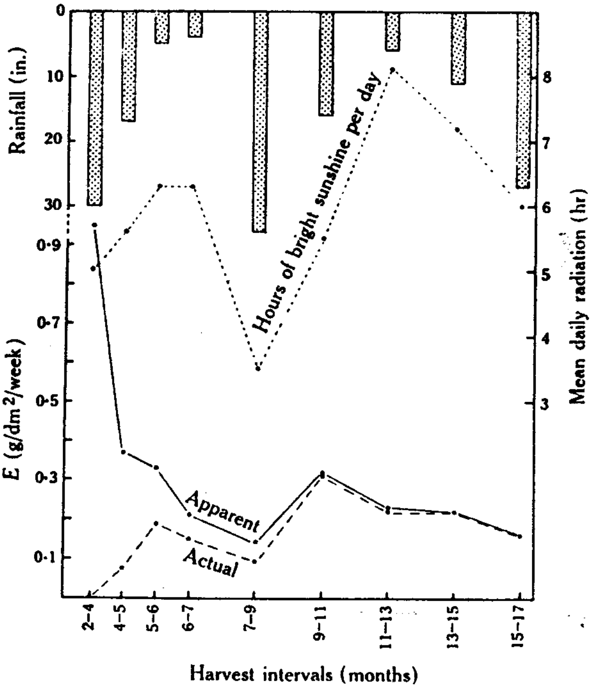


Fig. 6.—Net assimilation rate, hours of bright sunshine, and rainfall (columns), plotted against time.

——— Apparent *E*.

- - - - Actual *E*.

- - - - - Radiation.

The relative growth rate (whole plant) shows a steep decline from an initial value of 72 g/100 g/week to a fairly steady value of 7·5 g/100 g/week after 4 months. No doubt the decrease in *R* from a very high initial value down to this steady value was a continuous process. Just after germination the development of two organs takes place. The haustorium expands in roughly spherical form within the nut, while the shoot expands through the germ pore. Figure 1 shows that R for the haustorium is only very slightly less than that for the whole plant between month 2 and month 4. This results in a steady rise in the absorptive capacity of the haustorium as the area of surface contact with the endosperm increases. At first there is a large supply of liquid endosperm which is readily absorbed by the expanding haustorium. The liquid endosperm, however, is fully used up by 2½ months, and thereafter only that part of the haustorium actually in contact with the solid endosperm is able actively to absorb nutrients (Henry 1957).

The absorptive capacity of the haustorium is presumably a function of its surface area, which is proportional to the square of the radius while the weight of the haustorium is proportional to its cube. The increase in absorptive capacity of the haustorium is thus likely to lag behind its increase in weight, particularly as the distal surface does not become active in absorbing solid endosperm until the haustorium has completely filled the vacuole. While the plant is entirely dependent on the haustorium for growth substrate, R (whole plant) is bound to decrease steadily. After month 4, little further expansion of the haustorium is possible, as it has by now almost filled the vacuole. The absolute rate of use of the endosperm remains almost constant beyond this age (Fig. 1). which means that the rate of use relative to total plant weight steadily falls.

We see, therefore, two phases in the development of the coconut seedling. The first phase, from 0 to 4 months, has a high but decreasing R, and endosperm loss is in excess of the total weight gain of the plant (Figs. 2, 5). The second phase of growth, from 4 to 15 months, is one of practically constant R. At the beginning of this second phase the plant is almost completely supported by the endosperm, while at the end it depends entirely on photosynthesis. The change-over from internal to external "assimilation" has taken place without any major effect on the rate of growth. Figure 2 illustrates clearly the way in which the endosperm decreases in importance as a source of dry matter for the plant.

The apparent relationship between net assimilation rate, actual E, and hours of bright sunshine, is of considerable interest. It is mainly the fluctuations at low levels of sunshine which appear to affect actual E. This could indicate that at higher levels of sunshine the assimilatory capacity of the photosynthetic tissue is more than adequate to meet that part of the plant's needs not supplied by the endosperm.

It is interesting to speculate on the sensitivity to limiting water supply of the two processes which contribute dry matter to the plant (i.e. transfer from the endosperm, and photosynthesis). Photosynthesis involves heavy water loss by transpiration, and it might be safely assumed that, per unit of dry matter gain, more water is required by photosynthesis than by the physiological processes occurring in the haustorium. There is need for experimental work to clarify this point.

This study allows some conclusions to be drawn regarding cultural practice with the young coconut palm. It is commonly recommended (e.g. Child 1964) that seedlings should be grown in a nursery for 6–12 months prior to field planting, but the study here reported suggests that transplanting may be less harmful at 4–5 months.

The original recommendation for transplanting at 6 months or later arose from the belief that seedling selection, which gave an improvement in the yield of mature palms, was best carried out at this age. Seedlings were selected for vigour on the basis of plant height and sturdiness, leaf number, and stem girth.

When seedlings of 6–12 months of age are transplanted, common field experience is that growth is retarded and often stops almost completely for as long as 6 months. The seedling has only a small number of thick primary roots at this stage and they are easily damaged. Even when great care is exercised during transplanting, most roots die back, seriously reducing water uptake. If the greater part of plant dry matter gain is derived from photosynthesis, as is the case at 6–12 months, then reduced water supply will result in a reduced growth rate. If, on the other hand, the plant derives most of its growth substrate from an internal source, as is the case at 4–5 months, it will possess some measure of independence of full root activity in maintaining growth. Transplantation of seedlings during the time when they are wholly, or almost wholly, deriving dry matter from the endosperm would be expected to have much less effect on growth rate than transplanting at a later stage. Work is needed to determine whether selection on the basis of vigour can be done effectively on seedlings of a younger age than recommended in Ceylon.

V. Acknowledgments

I wish to thank Professor C. M. Donald and Dr. R. Knight of the University of Adelaide for their assistance in the planning of this experiment. Thanks are also due to Mr. A. H. Green of Unilever Plantations Group, London, and Mr. G. N. Wilkinson of the Division of Mathematical Statistics, CSIRO, for assistance with the design of the experiment and analysis of results.

This paper is published with the permission of the British Solomon Islands Government and Unilever Limited Plantations Group, which participate in the Joint Coconut Research Scheme within which this work was carried out.

VI. References

Child, R. (1964).—"Coconuts." (Longmans, Green & Co.: London.)

Foale, M. A. (1964).—Rep. Joint Coconut Res. Scheme, Br. Solomon Isl., Feb. 1963–Aug. 1964, 11.

Henry, P. (1957).—"Researches sur la croissance et le développement chez *Elaeis Guineenis* et chez *Cocos nucifera*, comparaisons avec d'autres palmiers." Thèse de doctorat, Paris. Cited by Frémond, Y., *et al.* (1966).—"Le Cocotier." p. 37. (G.-P. Maisonneuve & Larose: Paris.)

Liyanage, D. V. (1955).—Planting material for coconuts. *Ceylon Coconut Q.* **6**, 75–80.

Nathanael, W. R. N. (1958).—Rep. Chemist Coconut Res. Inst. Ceylon, 1958, 26.

Nathanael, W. R. N. (1961).—Rep. Chemist Coconut Res. Inst. Ceylon, 1961, 26.

Selvaratnam, E. M. (1952).—Embryo of the coconut. *Nature, Lond.* **169**, 714–15.

Whitehead, R. A. (1963).—Rep. Botanist Res. Dep. Coconut Ind. Bd, Jamaica, 1963, 36.

Whitehead, R. A. (1964).—Rep. Pl. Breeder Res. Dep. Coconut Ind. Bd, Jamaica, 1964, 46.