EFFECT OF DIFFERENT MOISTURE AND SHADE REGIMES ON SEEDLING GROWTH OF THREE OIL PALM *(Elaeis guineensis)* PROGENIES

BY

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DECLARATION

I hereby declare that except for references to people's work which have been duly cited, this work herein presented is the result of my own original research and that this thesis either whole or in part has not been presented for another degree elsewhere.

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DEDICATION

I dedicate this work to Pat, my wife and to my three daughters Linda, Yvonne and Freda who made a lot of sacrifices to make this work possible.

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Abstract

The effect of three different moisture and shade regimes on the seedling growth of three Dura x Pisifera oil palm progenies was investigated at the Oil Palm Research Institute, Kusi between July 1998 and February 2000. A split plot design with four replications was used. Data were collected on leaf number per plant, plant height, butt circumference and leaf area as well as dry weight of plant parts and total plant dry weight. Growth analysis was performed and correlation among traits calculated. Phenotypic and genotypic variances as well as heritability estimates were also determined. Significant effects on seedling growth due to shade, moisture supply and progeny as well as their interactions were observed. All the characters studied were significantly and positively ($P<0.01$) correlated with each other except leaf area ratio (LAR). The highest correlation were found between total plant dry weight and crop growth rate ($r^2 =$ 0.90) and between leaf area and plant height ($r^2= 0.81$). The highest phenotypic and genotypic coefficients of variations for plant growth parameters were those of net assimilation rate (NAR 81.57% and 75.51% respectively) and crop growth rate (CGR 80.43% and 64.86% respectively). For plant biomass the highest was for total plant dry weight (67.66% and 54.91% respectively) The highest broadsense heritability estimates for plant growth parameters were for crop growth rate (65.03%) leaf area index (68.03%) relative growth rate (80.38%). net assimilation rate (85.68%) and leaf area ratio (91.36%) while that for plant biomass was for total plant dry weight (65.86%) indicating high genetic control over these characters and the potential to select for desired levels of expression. The implications of these findings in oil palm nursery management and seedling selection are discussed.

CHAPTER ONE

1. INTRODUCTION

Oil palm *{Elaeis guineensis},* is of African origin (Jacquemard, 1998) and is the most important member of the genus *Elaeis* in terms of production and economic yields (Jones and Hughes, 1989). The oil palm provides approximately 17% of the World's supply of vegetable oils in the form of palm oil (Paranjothy, 1989). The oil palm can produce up to six tonnes of oil per hectare per year for up to 25 years under good plantation management and favourable climatic conditions.

In Ghana, the oil palm ranks second to cocoa in importance as a cash crop. It is the only cash crop that can be handled from establishment to processing at the rural level.

Spells of low or no rainfall are characteristic of the West African Oil palm growing belt (Hartley, 1988) and seedlings are therefore more difficult to raise in the seasonal climate of Africa than in the more uniform climate of the Far East and they are much more subject to nursery diseases.

A high level of solar radiation is also required for the growth and bunch production of the oil palm but the exact requirement either in terms of radiation or in terms of hours of sunshine for optimum yield has not been determined (Hartley, 1988).

The usual practice in the cultivation of oil palm is to establish a nursery where germinated seeds are sown in poly bags filled with topsoil. The seedlings are maintained in the bags for up to one year before being transplanted to the field.

Growth and development of seedlings at the nursery may be influenced considerably by shade regime, soil fertility, moisture supply, weed competition, pest and disease incidence.

The Oil Palm Research Institute of Ghana (OPRI) has developed several oil palm progenies for farmers in recent times. Genotypic differences in response to water supply, fertiliser requirements and tolerance to shade, pest and diseases may exist among these progenies especially at the nursery level. Differences in growth and vigour among the genotypes at the nursery stage may be related to differences in field performance after transplanting.

Farmers purchase approved sprouted seed nuts from OPRI and establish their nurseries applying arbitrary levels of moisture, fertiliser and shade. This has often resulted in considerable losses of seedlings at the nursery, thus reducing the number of seedlings available for transplanting to the field. Sub optimal conditions at the nursery may also lead to poor growth of seedling.

No definite recommendations on levels of moisture, fertilizer and shade are available to farmers. There is the need to determine the level of these factors to ensure optimum growth of seedlings and prevent losses of seedlings at the nursery.

The objectives of this study are to:

(a) Asess the effect of the interaction of moisture and shade regimes on the growth and development of three oil palm progenies at the nursery and

(b) assess the strength of genotypic differences among the three progenies in their response to different moisture and shade regimes.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Distribution of oil palm

The oil palm originated in West Africa in wet areas along riverbanks and in swamps. Today it is extensively cultivated in large plantations as well as smallholdings in South East Asia, West Africa, and Central and South America (Hartley, 1988)

The palm's high productivity together with improved cultivation techniques and availability of good planting material have all boosted its development into a profitable plantation crop. It now ranks as a very important export commodity for countries in Southeast Asia especially Malaysia and Indonesia (Wooi Kheng Choo, 1990).

The largest areas under cultivation are now found in Malaysia and Indonesia. As at the end of 1986, Malaysia had about 1.54 million hectares under oil palm cultivation and this was estimated to reach 2.63 million hectares by 2000 (Jalani and Ramie, 1996). In Africa, the largest plantings are found in Nigeria, Cameroun, Angola, Guinea, Ghana, Zaire and Ivory Coast (Jones and Hughes, 1989).

In Ghana, the area under cultivation increased from 18,000 ha in 1970 to 84,759 ha in 1986 and was estimated to reach 100,000 ha by 1990 (Anon, 1989). New producers in Central and South America are Columbia, Costa Rica, Brazil, Honduras and Ecuador (Jones and Hughes, 1989).

2.2. Climatic factors affecting oil palm production in West Africa

2.2.1. Rainfall and water deficit

In tropical regions, rainfall is often one of the main limiting factors for oil palm production (Ochs and Daniel, 1976). Inadequate water supply causes closure of the stomata preventing transpiration and photosynthesis. Water stress also leads to inadequate root development or impaired root functioning so that available nutrients are not taken up leading to reduced growth and yield (Corley, 1976).

Spells of low or no rainfall are characteristics of the West Africa oil palm growing belt (Hartley, 1988). Seedlings are therefore difficult to raise in the seasonal climate of Africa than in the more uniform climate of the Far East and they are much more subject to nursery diseases.

Ochs and Daniel (1976) studying the effect of water deficit on growth and yield in oil palms, observed that water deficit reduces growth and yield in the oil palm and can bring about vegetative disturbances, which are sometimes irreversible. According to Ferwerda (1977) prolonged drought is detrimental to growth and yield in the oil palm as a result of stomatal closure and failure of the spear leaf to open. Hartley (1988) also reported that in mature palms, water deficit (drought) can lead to the production of male inflorescence with a consequent reduction in sex ratio, the proportion of female inflorescences to the total number of inflorescences produced.

Different oil palm progenies however have differing growth characteristics and associated stress response and thus perform differently under the same climatic conditions.(Hartley, 1988). Hardon *et al.* (1972) found leaf area to vary with genotype. Observed progeny differences in root size would also relate to efficiency of water uptake and stress response. In two locations of different water deficit values, Hartley (1988) observed significant height differences among palms of the same genetic origin.

Of the greatest importance in the growth of seedlings, whether in polybags or field nurseries, is the supply of water. Soil moisture stress imposed on oil palm seedlings depressed seedling height even after 5 months of relief of stress (NIFOR, 1985). Leaf area, stem girth and total dry matter produced were also significantly reduced by soil moisture stress. The severity was found to differ with the stage of growth of the seedlings (NIFOR, 1985).

Comaire *et al.* (1994) investigating oil palm performance under water stress observed yields to be closely linked to water supply. Drought tolerance was found to be due to a combination of phenological or physiological characteristics. There was a tendency for resistant progenies to maintain lower stomatal conductance levels during the dry season. He also observed that resistant progenies seemed to have more extensive carbohydrate reserves that could be mobilised more easily in times of stress.

In Benin, Comaire *et al.* (1992) classifying various progenies according to their yields and drought response observed that during the dry season, the stomata remained open to a greater extent in progenies presumed sensitive. It was confirmed that the higher death rate found in sensitive progenies was the result of slower closing of stomata during the dry season. Evaluation of the relative degree of cellular damage further showed sensitive progenies to be more vulnerable when severe water deficit exist.

Villalobos *et al.* (1992) studying oil palm water status in response to drought in Costa Rica observed severe premature drooping of the lower levels, a substantial accumulation of unopened leaves (spears) and low stomatal conductivity in adult oil palms grown on sandy loam soil with no irrigation compared with irrigated oil palms. Chin and Sekaran-Nair (1980) investigating the effects of moisture stress on growth of oil palm seedlings in Malaysia found that moisture stress resulted in reduced growth in terms of stem diameter, leaf and root growth. Leaf crinkling in seedlings was more severe under moisture stress than under adequate moisture conditions. Moisture stress significantly reduced the total dry matter of shoots and roots.

Mendham (1971) studying the growth rate of oil palms in New Britain measured leaf area growth rate of tenera progenies from two genetic sources at three sites in the pre-bearing stage and observed very rapid growth rates when compared with reports from other countries. He also observed evidence of a positive correlation with rainfall and a negative correlation with solar radiation.

Maillard *et al.* (1974), who analysed the effect of drought on the oil palm, used an arbitrary index of drought susceptibility to characterise differences between oil palm strains. They discovered that higher seedling root growth at simulated low soil moisture levels and lower foliar damage at high temperatures may give an early indication of resistance to drought.

Wormer and Ochs (1959) reported that in oil palm, stomatal closure occurred and transpiration was reduced at soil pF greater than 3.0(soil moisture tension of 1 bar).

Over a five months period Corley (1976) discovered that net assimilation rate of polybag seedlings decreased approximately linearly as the number of days without watering was increased. From the findings and observation from the work cited above, the importance of water in the growth and development of the oil palm cannot be over emphasised. Water deficit is generally detrimental to seedling growth where it reduces vegetative growth and the mature palm where it leads to the accumulation of spears (unopened leaves.) reduces sex ratio resulting ultimately in reduced yield. However the extent of reduction in growth and yield due to water deficits, and the effectiveness of the plant physiological processes to mitigate the effect of water deficit is determined in part by the genetic make up of the individual palm or progeny. Further studies on the response of various progenies to varying moisture supply could provide some valuable information upon which some general recommendation can be made.

2.2.2. Effect of solar radiation on growth and development of oil palm

Another environmental component which has a large influence in determining the photosynthetic output is light. Solar radiation in the oil palm is often measured as sunshine hours only. From several observations made Hartley (1988) stressed the importance of solar radiation for growth and bunch development of the oil palm.

Although sunshine is not a major problem in most parts of Africa, it can constitute a real problem in some production areas where prolonged overcast conditions leading to few sunshine hours causes a reduction in growth and net assimilation rate and low production of female inflorescence.

Broekmans (1957) observed that in countries such as Nigeria with marked seasonal differences in hours of sunshine, the differentiation of female inflorescence as shown by the sex ratio at flowering was much higher during the months with many hours of sunshine than during the months with few. As might be expected, areas of very high rainfall have few hours of sunshine. Hartley (1988) reported that shading palms of all ages reduces growth and net assimilation rate. In adult palms, it reduces the production of female inflorescence. Pruning the leaves of adjacent palms to improve light penetration was found to increase the production of female inflorescence and a positive correlation was found between annual sunshine data and yield (Spamaaij, 1960).

Allen (1954) observed no significant differences in seedling loss when seedlings were subjected to various shade regimes with and without watering in the dry season. In another experiment to test the effect of heavy watering with and without shade on losses in the nursery, he observed significantly less seedling losses when seedlings were subjected to shade and normal watering in the dry season (4.51/seedling/week) than when grown under no shade with heavy watering (9 1/seedling/week). He therefore concluded that shading of oil palm seedlings during the dry season was a good cultural practise.

Rajagopalan (1974) investigating the influence of irrigation and shading on the occurrence of blast disease of oil palm seedlings observed that shading of palm seedlings particularly during the hot dry period was most effective in controlling the disease. Shading did not have any deleterious effect on general palm growth. Supplementary irrigation alone did not reduce the loss of seedlings due to blast.

Subronto and Taniputra (1979) in an experiment to investigate the influence of nursery shade on field growth of oil palm in Indonesia observed that during the nursery stage of one year, oil palm plants in 61% and 79% light intensity were the most vigorous in growth. They had the highest leaf area, leaf number, rachis length, and leaflets per rachis, leaf dry weight and bole girth. Plants in 17% and 38% light intensity were the least vigorous. However upon transfer to the field, plants from the low light intensities grew most rapidly and after one year, differences between treatments had narrowed and some had lost significance. High light intensity at the nursery stage stimulated early field flowering and resulted in a higher number of inflorescence per palm.

Subronto *et al.* (1982) observed that low light intensity in the nursery did not show a significant effect on the growth of the oil palm up to the fourth year of field planting. Low light intensity tended to cause higher production in the first year of harvest but the yield differences among the treatments were statistically not significant.

In a study on the influence of shade and the use of baby polybags on the growth of oil palm seedlings, Pandjaitan and Taniputra (1972) observed that germinated oil palm seeds raised in small polybags under shade for six months before being transplanted into larger bags performed no better than those raised in unshaded larger bags throughout the nursery stage. Rees (1963b) found that net assimilation rate decreased in oil palm seedlings as light intensity was decreased by shading and despite an increase in leaf area ratio, relative growth rate decreased. It was also observed that net assimilation rate tended to increase as solar radiation increased over a four-month period.

Wormer (1958) showed that relative growth rate in the oil palm followed the same trend as daily hours of sunshine over a six-month period. Corley (1973) showed that the number of leaves produced depends on the light intensity reaching the oldest leaves at the canopy. Thus under heavy shade, the growth of the leaves is very much depressed. Milthorpe (1956) showed that yield of crops depend, largely on the rate of development and maintenance of leaf surface. In the oil palm where each frond axis subtends only one inflorescence, the rate of frond production sets an upper limit to the rate of inflorescence production.

Subronto *et al.* (1987) in an evaluation of the influence of nursery shade on the growth and yield of four Dura x pisifera (DxP) oil palm progenies using five levels of shading (0%, 21%, 39%, 62% and 83%) with relative light intensities between 17 and 100% discovered that after an observational period of eight years no correlation was found between the intensity of nursery shading and crop growth rate, net assimilation rate, vegetative dry matter yield and bunch yield.

Work done on the effect of solar radiation and shade on the growth and development of oil palm as reviewed above generally indicates that in adult palms (field planted) high and sustained solar radiation results in high vegetative growth, high NAR and high sex ratio resulting ultimately in high bunch yield.

In seedlings however conflicting results have been obtained. While some workers reported that shading led to a reduction in vegetative growth, NAR and RGR, others did not observe any deleterious effect of reduced light intensity due to shading on seedling growth. In some cases the most vigorous plant with the highest leaf area, leaf number, leaf djy weight, butt circumference and rachis length were observed not under full sunlight (o% shade) but rather under some level of shade suggesting that some amount of shade is necessaiy at the nursery.

In view of these conflicting reports with regards to seedling growth, it is necessary to investigate the effect of solar radiation and shade on performance at the nursery.

2.3 Growth analysis studies in oil palm

Plant growth measurements are usually based on dry weight, since increase in dry weight represents the increase in plant material resulting from photosynthesis and mineral absorption (with minerals generally comprising less than ten percent of dry weight). The difficulty with direct measurement of dry weight is that it is destructive and if more than one measurement is required, different batches of plants must be used, thus increasing the variability of the results.

Numerous different parameters have been used to measure oil palm growth. In general a parameter with some obvious physiological significance should be chosen, for example, leaf area provides an estimate of photosynthetic potential, while rate of leaf production will be related to the activity of the apical meristerm. Leaf area is the area of leaf surface usually used to qualify the photosynthetic component.

For the early lanceolate leaves the product of length and greatest width gives a good estimate of area. True leaf area is a constant proportion of about 0.57 of this product. For bifurcate leaves the product of length of one lobe and width where the two lobes meet can be used, for true area a correction factor of 0.5 is applied. (Corley, 1976).

The area of pinnate leaves in older seedlings can be estimated by the method of Hardon *et al.* (1969).

Leaf area expansion is initially more related to air temperature (Milthorpe, 1959) subsequently, leaf area expansion is more responsive to solar radiation (Blackman and Black, 1959). Nutrient deficiency reduces growth in general and leaf area in particular. Corley and Mok (1972) showed that N and K increase leaf area. Corley and Mok (1972), observed that mean leaf area in oil palm varies with age while Hardon *et al.* (1972), also observed a variation in mean leaf area with genotype.

Hardon *et al.* (1969), studying the relationship between leaf area and yield in the oil palm in Malaysia observed large but systematic changes in frond area in young palms because both leaflet number and size increased with age. In older palms however, the relative variation was much smaller. Maximum leaf area was found in palms approximately 8 years old after which the value remained more or less constant. Parallel to the increase in leaf area with age, Hardon *et al* (1969) also observed an increase in total yield of bunches. The similarity of leaf area and yield trends in the initial stages of planting indicate that the latter may be strongly influenced by the development of leaf area. Declining bunch numbers inspite of a continuous increase in the average bunch size suggest that insufficient assimilates are available for development of all the bunch primordia produced by the palm.

Leaf area index (LAI) defined as leaf area per unit area of land is the functional size of the crop standing on the land area and is an index of mean crop leafiness and describes in broad terms the productive capacity of a stand of vegetation.

In a newly germinated crop LAI remains below 1.0 for some time, since the total leaf area of the young seedlings is negligible in relation to the land area on which they stand. As the crop develops it increases until it reaches its maximum value (defined as that which supports the maximum rate of dry matter increase) when the lowest layers of leaves are only just able on average, to maintain a positive carbon balance.

Rees (1963a) observed a ceiling leaf area index of about 5.0 for mature palms and about 3.0 for seedlings in West Africa. Corley *et al.* (1971) observed that LAI reached a value of about 4.0 by 10.5 years, which is about the age at which the area of successive individual leaves stops increasing.

Because leaves must often be removed to harvest the fruit bunches, there is a practical limit, to the number of leaves per palm of about 40. According to Corley *et al.* (1971) it is this factor that prevents LAI from reaching higher values rather than any physiological limitation. Corley and Mok (1972) showed that high N levels give rise to faster LAI development. Similar effect has been observed with irrigation.

Net assimilation rate (NAR) is defined as the rate of increase in plant dry weight per unit leaf area over a limited period (Gregory, 1926). NAR expresses growth in terms of foliar surface and therefore allows us to see if any treatment makes the leaves efficient or if their efficiency merely changes with time. NAR declines with leaf age (Watson, 1947a) and is limited by low solar radiation (Blackman and Black 1959, Rees 1961) and governed by temperature (Gregory 1926, Milthope 1959, Rees, 1959). NAR provides an estimate of net photosynthetic production. In mature palms, calculation of NAR is of limited value since it is affected by many different factors, but during seedling growth in the relatively uniform nursery environment it appears probable that differences in NAR will indicate real differences in photosynthetic rate. NAR could therefore be considered as a seedling selection criterion. Because so many factors affects NAR, differences in NAR may often be difficult to explain and are not always directly related to differences in rate of photosynthesis. Corley (1976) has observed that variation in the number of leaves per palm causes apparent differences in NAR. Rees (1963a) reported that there appears to be no relationship between net assimilation rate and season in the nursery environment.

Rees (1963a) observed low values for relative growth rate (RGR) in oil palm seedling ranging from 1.8 to 3.2 percent per day. Shade reduced RGR. As RGR is related to NAR by the leaf area rates (LAR), differences in trend with season from those of NAR are due to variations in LAR and in relative leaf growth rate. Rees (1963a) observed increasing LAR values with increasing shade in oil palm seedlings. In plants well adapted to shade LAR initially increased and then dropped with increasing light to about 0.8 dm^2/g at full sunlight. At any instant in time RGR=NAR x LAR and NAR and LAR may therefore be helpful in explaining variations in RGR. LAR gives an estimate of the proportion of photosynthetic to non-photosynthetic tissue and Corley (1973), has suggested that attempts should be made to increase LAR by selection. Such selection and such might well be performed at the seedling stage.

Relative leaf area growth rate (RLAGR) represents the rate of increase in leaf area per unit area present from two measurements of leaf area. Williams and Hsu (1970), pointed out that, because oil palm leaves are produced in regular sequence from a single growing point, it is possible to estimate leaf area at any preceding time from only single set of measurements. They suggested that from the area of two consecutive leaves and an assumed constant rate of leaf production, an approximate value of RLAGR could be obtained, which would be of value as a seedling selection criterion. The net rate of photosynthetic production by a plant can be estimated from the rate of accumulation of dry matter. The rate can be expressed per unit ground area (Crop growth rate CGR). Crop growth rate (CGR) is affected by a range of factors including temperature, (Milthope,

1959) radiation levels, (Blackman and Black, 1959) and water and nutrient sup (Corley and Mok, 1972) and the type and age of the plant (Watson, 1947). These fact affect the size and efficiency of the leaf canopy and hence the ability of the crop convert solar energy into useful growth. Henry (1958) showed that fresh weight of palm seedlings increased exponentially with age; the product of leaf number and length the longest leaf followed a similar trend, he suggested that this product might be a use non-destructive index of seedling growth. Wormer (1958) also showed a cl< relationship between the fresh weight of the above ground parts and the length of largest leaf and stated that dry weight was a constant 30 percent of fresh wei throughout the nursery period. Wong (1969) showed that the length of the largest leaf \ correlated with dry weight. Corley (1976) also reported that the diameter of the base the stem was similarly correlated with dry weight.

Many different parameters with some physiological significance have been u: by several workers as reviewed above to measure and characterise growth in oil palm. Some of these characters are influenced by climatic factors and mineral nutrition. So correlations have been established between these parameters and some use characteristics of the mature palm example bunch yield. For seedling selection purpo however it is necessary to demonstrate that heritable variation in these parameters oc< that could result in genetic improvements.

CHAPTER THREE

3. MATERIALS AND METHODS.

3.1 Experimental Site

The experiment was conducted between July 1998 and February 2000 at the oil palm research institute (OPRI) Kusi (0.6.00N,001.45W), situated about 500 meters above sea level. The experimental area was fairly flat but gently sloping in the North south and East-West directions. The original semi-deciduous forest vegetation of the area was cleared in 1967, since then, topsoil from the surrounding area has been used to fill bags for polybag nursery at the experimental area.

The soils in the experimental site are sedentary. The soils of the upper and middle slope are of the Nzema series (Ferric Acrisol). Colluvial soils of the Kokofu series (Ferri-Plinthic Acrisol FAO/UNESCO) occur on the bottom slopes (Asiamah and Senayah, 1991). The area is in a zone characterised by relatively high rainfall that falls in two seasons. The major rainy season occurs from April to July while the minor one begins in September lasting till the end of October or mid-November. Average annual rainfall is about 1425 mm.

3.2 Experimental Design and Treatments

3.2.1 Experimental materials

Three Dura x Pisifera (DxP) oil palm progenies (Table 1) obtained from the OPRI were germinated using the Dry Heat Method (Hartley, 1988) and used for the study. The seeds were incubated in lots of 300 from 5th August 1998 to 12th October 1998. Germinated seeds were sorted out of the lots from 30th October 1998 to 28th February 1999.

Table 1: Description of progenies used

Progeny-name	Parents	Sources of parents
Pi (progeny code 54)	(UR666x 851.123) x (1.3056T x 32.2612T)	Deli x (Calabar x Calabar)
P_2 (progeny code 77)	5.37 Deli selfedx 32.2612T selfed	Deli x Calabar
P_3 (progeny code 84)	851.168 Deli selfedx 851.326T selfed	Angola x Sibiti

3.2.2 Calibration of moisture levels

Different volumes of water were added to the same quantity of the top soil/sand mixture used for nursing the sprouted nuts in pots. Gypsum blocks that had previously been soaked in water overnight were inserted into the pots (l^block per pot). The blocks were covered with firming the soil around the blocks and ensuring good contact between the block and the soil to eliminate air pockets.

The pots were put in airtight plastic bags and the blocks allowed equilibrate with the moisture in the soil for 2 days. The moisture content of the various soils in the pots was then determined using a moisture meter to read the blocks. Samples of the soil from the various pots were taken and dried in the oven at 105°c to constant weight and the moisture content determined.

The bulk densities of the soil samples in the various pots were determined and subsequently their volumetric water contents calculated. The moisture meter readings previously obtained were plotted against the volumetric water content values to obtain a linear graph and the equation of the line determined. With this equation it was possible to determine the volumetric water content of the soil corresponding to any moisture meter reading. Based on this equation the three moisture levels were selected and by regular monitoring and watering as and when necessary, these three levels were maintained throughout the experiment. One gypsum block was inserted into one bag in each subplot of 30 plants at half the depth of soil in the bag for determining and maintaining the moisture status of the plot.

3.2.3 Establishment of Shade Regimes

The shade treatments, "no shade" (foil sunlight), "50% shade " (50% foil sunlight) and "75% shade "(25% foil sunlight) were established using shade nets. Bamboo poles were used to erect an inverted V structure, which was covered with gauge 500 transparent polythene material to keep out the rain, the nets were then put on top of the polythene to provide the needed shade. For the no shade treatments only, the transparent polythene sheets were used to keep out the rain. In all there were 12 structures each measuring 6 m x 12.5 m x 2 m representing the three shade levels replicated four times.

3.2.4 Experimental treatments and field layout

The experiment was conducted using the split plot design with four replications. The treatments were made up of a factorial combination of the three factors namely shade regimes, progenies and moisture supply. The main plots consisted of three shade levels namely, "no shade" (Si), medium (50%) shade (S2) and heavy (75%) shade (S3). The subplots consisted of combinations of the three progenies (Pi, P2, P3) and three moisture supply regimes (Wi, W2, W3) corresponding to low 50% - 60%FC (Wi), 65-75%FC (W2) and high 80-90%FC (W_3). The upper moisture level (W3), 80%-90% of field capacity corresponded to adding about 4.5 litres per seedling per week as recommended by Allen (1954). The two lower levels (W2 and Wi), 65%-75% and 50%-60% field capacity corresponded to 4 litres per seedling per week and 3.5 litres per seedling per week respectively.

Each subplot had 30 plants arranged in 2 rows of 15 plants with a spacing of 30 cm x 30 cm. Subplots were spaced 40 cm apart and main plots 3 m apart.

3.3 Planting and cultural practices

Black polybags of dimension 35.6 cm x 45.7 cm layflat were filled with 15kg of topsoil -sand mixture (ratio 2:1) in October 1998. The soil used for filling the bags was from the Kokofu series (Ferri-Plinthic Acrisol- FAO/UNESCO). Soil in this series occupies middle to lower slope sites and is developed from colluvial material derived from phyllite and greywacke drifted from upslope. It is deep, moderately well to imperfectly drained with silty loam topsoil and silty clay subsoil with high water retention capacity. It is acidic with pH range of 4.0-4.3 throughout its profile. Its week fine and medium sub angular blocky structures favour root penetration, water movement and aeration (Asiamah and Senayah, 1991).

The lower third of the bags were perforated to enhance drainage of excess water.

Germinated oil palm seednuts were sown singly in the bags from 11th to 17th March, 1999 and the bags were shaded with palm fronds immediately after seeds were planted till the plants had produced two leaves (approximately two months after planting) at which stage the palm fronds were removed.

Hand watering was done every other day. Sulphate of ammonia was applied at a rate of 25g per 9 litres of water and applied to 200 seedlings weekly for the first four months. The seedlings were mulched with sawdust. Routine weed control was carried out by hand picking weeds from the polybags as and when necessary, and by spraying with roundup herbicide at a rate of 200 mis per 15 litres of water to the area between subplots at three months intervals

Disease control was carried out by weekly spraying of plants with 14g Dithane M45 in 9 litres of water. Insect pests were controlled by spraying with unden insecticide at a rate of 100 mis to 15 litres of water on weekly basis. The shade treatments were applied at the four-leaf stage.

3.4 Data collection

Data collection commenced when seedlings were four (4) months old. Data were taken on a monthly basis for six months. Ten plants per plot were selected at random for data collection. The following data were collected.

3.4.1 Number of leaves per plant

This was determined by counting the number of leaves on a seedling on a monthly basis and information obtained used in calculating the rate of leaf production.

3.4.2 Plant height (cm)

This was measured as height from the soil level in the bag to the tip of the longest leaf using a meter rule at monthly intervals from four to eleven months.

3.4.3 Butt circumference (cm)

Butt circumference was measured using a vernier calliper to determine the diameter at two places on the butt (a position on the trunk of the young seedling where the leaf bases are fused) 0.5 cm from the soil level. Measurements were taken at monthly interval. The circumference was determined by the formula TT*d.* Where TT was taken as 3.14 and *d* is the average diameter calculated.

3.4.4 Leaf area (cm^2)

A non-destructive method was used. The length and greatest width of each leaf were measured with a ruler on each of the plants and the true leaf area estimated by multiplying the product by appropriate correction factor (0.57 for lanceolate leaves and 0.5 for bifurcate leaves) as described by Corley (1976).

3.4.5 Plant dry weight (g)

Plant dry weight was determined twice during the experiment, at 4 months after planting and at the end of the experiment (11 months). Five plants were sampled for this measurement. The plants were carefully remove from the bag and the top soil in the bags wash off to recover all broken roots. The plants were cut and separated into roots, leaves and stem with leaf bases.

The dry weight of plant parts and total plant dry weight were determined by drying to constant weight at 65°C in an oven and adding the weight of the different plant parts.

3.4.6 Growth analysis

The following growth parameters were calculated using the appropriate formulae as follows:

$$\mathbf{(W_2\text{-}Wl)(log_e\ A_2\text{-}loge\ A,)}$$

Net Assimilation Rate (EA) = g/dm/wk

$$\mathbf{Log_B\ W_2\text{-}loge\ Wi}$$

Relative Growth Rate (R_w) = %/day

$$\mathbf{t2\text{-}ti}$$

$$\mathbf{(A_2\text{-}A_1)(l0g_e\ W_2\text{-}l0g_e\ W,)}$$

Leaf Area Ratio (F) $\mathrm{cm^2/g}$

$$\mathbf{(Log_eA_2\text{-}log_eA_1)(W_2\text{-}W_I)}$$

$$\mathbf{l0g_e\ A_2\text{-}l0g_e\ A,}$$

Relative Leaf Area Growth Rate (R_A)

Leaf area

Leaf Area Index (L)

Ground area

Crop Growth Rate (C) = Net Assimilation Rate x Leaf Area Index
= E_A x L

Where Wi and W2 and Ai and A2 are total dry weights and leaf areas respectively at times ti and t2.

3.5: Statistical Analysis.

The data was analysed using Analysis of variance (ANOVA) and where significant differences were observed, least significant difference (LSD) was used to separate the means. Phenotypic correlation between growth parameters measured and other traits were also determined.

Genotypic and phenotypic coefficients of variation were determined using the methods of Burton (1952) as follows:

$$\boldsymbol{PCV} = \frac{\text{^-}}{X}\boldsymbol{x}\ 100$$

Where a is the standard deviation and X the general mean of the trait being investigated. The genotypic coefficient of variation is therefore as follows

$$GCV = \frac{=}{X}\text{x}\ 100$$

Heritability (h^2) in the broadsense was estimated as $h^2 = \text{—f-}\ {}_{a}2$

Where a_g and $<j^2_{ph}$ refer to genotypic and phenotypic variance respectively (Allard 1960)

The form of variance analysis and mean square expectations from which estimates of the various variation and covariance components were obtained are given in Table 2 (Allard 1960).

Table 2: Form of varianceanalysis

Source of variance	d.f	Expectation of mean square
Progenies	**(P-l)**	$CT^2 + Ra^2 + Rs^2_{pw} + RWcr^2_s + RSW\ a^2_p$
Progenies x Shade	**(P-1XS-1)**	$a^2 + Ra^2_{psw} + RWa^2_{ps}$
Progenies x Water	**(P-1)(W-1)**	$\&e + R^{\circ 2}_{psw} + Rscr],$
Progenies x Shade x Water	**(P-1)(S-1)(W-1)**	$°l + {}^{R}<r^2_p»$
Error	**(R-1)(PSW-1)**	oi

P, R, S and W refer to the number of progenies, replications, shade and water levels respectively.

Thus it is possible to obtain estimate of the following pertinent components of variance.

a^2 - A genetic component arising from genetic differences among progenies.

$<j^2_{ps}$ - A component arising from interaction of progenies and shade. It measures whether differences in performance between families depend on level of shade present.

cr^2_{pw} The progenies-by-water component of variance.

$<j^2_{psw}$ The progenies-by-shade-by-water component.

o^2_e The error variance.

2 2 2 2
Total Phenotypic variance <r\ = a^2 + ——— + —+ ——— + -C7e
p p S W SW RSW

R = Number of replications, S = Shade levels, W = Water levels.

Phenotypic correlation analyses among growth parameters were also determined.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of interaction of moisture and shade regime on seedling growth of three oil palm progenies

4.1.1 Number of leaves per plant

Table 3 shows the mean squares for number of leaves from 4 to 11 months after planting. The interaction between shade, progeny and water did not result in significant differences in leaf number throughout the experimental period. Of the first order interactions, only progeny by water interaction (PxW) showed significant differences ($P<0.05$) in leaf number from the 8th to 11th month after planting (Table 3). With regards to the main effects, significant differences ($P<0.05$) in number of leaves produced under different shade levels were observed from the 7th to the 11th month after planting. There was however, no significant difference among progenies.

Again, the different water supply levels did not result in significant differences in number of leaves produced throughout the experimental period.

Table 4 shows the effect of progeny x water interaction on leaf production from 4 to 11 months after planting. Between 8 and 11 months after planting, progeny 1 at the second water level, (P_1W_2) produced significantly ($P<0.05$) higher number of leaves per plant than the other progeny-water combinations.

Table 3: Mean squares for number of leaves at 4-11 months after planting.

Source of variation	d.f	Month after planting						
		4	6	7	8	9	10	11
Reps	3	3.25	0.45	1.45	0.02	0.13	0.07	0.04
Shade(S)	2	2.11	0.28	9.41*	6.44*	9.43*	35.35***	14.14**
Error 1	6	0.41	0.58	1.35	0.05	1.23	0.68	0.72
Progeny (P)	2	0.44	0.41	0.0003	0.16	0.13	0.21	0.07
Water (W)	2	0.15	0.0032	0.06	0.0044	0.26	0.08	0.12
SxP	4	0.62	0.16	0.44	0.44	0.68	0.54	0.53
SxW	4	0.06	0.17	0.34	0.13	0.31	0.22	0.16
PxW	4	0.31	0.37	0.55	0.93*	0.77*	1.03*	0.77*
S x P x W	8	0.48	0.24	0.35	0.34	0.38	0.32	0.27
Error 2	72	0.30	0.22	0.25	0.29	0.30	0.32	0.28

*, **, *** Significant at 5%, 1% and 0.1% levels respectively.

Table 4: Effect of progeny x water interaction on leaf number at 4-11 months after planting

Months after planting	Progeny-water level combinations[a]									
	PiW,	**P,W_2**	PiW_3	P_2W,	p_2w_2	P_2W_3	P_3W,	p_3w_2	P_3W_3	**LSD($P<0.05$)**
4	**4.5**	**4.7**	**4.6**	**4.4**	**4.2**	**4.5**	**4.7**	**4.3**	**4.3**	**NS**
6	**5.1**	**5.5**	**5.2**	**5.1**	**5.0**	**5.1**	**5.3**	**5.1**	**5.3**	**NS**
7	**5.8**	**6.3**	**5.9**	6.0	**5.7**	6.2	6.1	**5.9**	6.0	**NS**
8	**6.4**	**6.9**	**6.4**	**6.4**	6.2	**6.7**	6.8	**6.4**	**6.5**	**0.4398**
9	**6.7**	**7.2**	6.8	**6.9**	6.6	**7.2**	**7.1**	**6.9**	**7.1**	**0.4474**
10	**7.4**	**7.9**	**7.6**	**7.5**	**7.2**	**7.7**	**7.8**	**7.4**	**7.5**	**0.4640**
11	**7.5**	8.1	**7.8**	**7.7**	**7.6**	8.0	8.0	**7.7**	**7.8**	**0.4340**

a: Pi =(UR666 x 851.123) x (1.3056T x 32.2612T) ; P_2 = 5.37 Deli selfed x 32.2612Tselfed ; P_3 =851.168 Deli selfed x 851.326Tselfed.
W,= 50-60%FC(low); W_2 = 65-75%FC(medium); W_3 = 80-90%FC(high).

Table 5 shows the effect of shade on leaf number from 4 to 11 months after planting. Consistently, seedlings under the "no shade" treatment produced the highest number of leaves with those under "heavy shade" producing the lowest number of leaves. From the 7th to the 10th months after planting there was no significant ($P<0.05$) difference between plants under "no shade" and "medium shade" with regards to leaf production. However plants under "no shade" and "medium shade" produced significantly higher number of leaves per plant than plants under "heavy shade".

4.1.2 Leaf Area per plant

Table 6 shows the mean squares for leaf area from 4 tol 1 months after planting. The second order interactions, shade x progeny x water did not significantly affect leaf area throughout the experimental period. The first order interaction shade x progeny, shade x water and progeny x water interactions also led to significantly influenced leaf area of seedlings at different stages of growth (Table 6). The different shade levels significantly ($P<0.05$) affected leaf area from the 6th to the 8th month after planting only. The influence of progeny on leaf area was observed only in the 8th month after planting. Different water supply levels did not lead to significant differences in leaf area during the experimental period.

Table 7 shows the effect of shade x progeny interaction on leaf area from 4 toll months after planting. Differences in leaf area between progenies under different shade regimes were signifcantly ($P<0.05$) at 8th, 9th and 11th month after planting. From the 7th to 11th month after planting, progeny 3 under "no shade" (S_1P_3) produced the highest leaf area among the three progenies. The same was due 8 tol 1 months after planting; under "medium shade" but progeny 3 and progeny 1 under "heavy shade" (S_3P_3) produced the lowest leaf area or the smallest leaves over the same period. Under heavy shading, progeny 2 (S_3P_2) produced the largest leaves.

Table 5: Effect of Shade on leaf number at 4 to 11 months after planting

Months after planting	**Shade regime**			
	No shade	**Medium shade**	**Heavy shade**	**LSD(P=0.05)**
4	**4.7**	**4.5**	**4.2**	**NS**
6	**5.6**	**5.2**	**4.8**	**NS**
7	**6.7**	**6.2**	**5.1**	**0.9281**
8	**7.1**	**6.7**	**5.8**	**0.8170**
9	**7.6**	**7.2**	**6.1**	**0.8860**
10	**8.5**	**7.7**	**6.5**	**0.4752**
11	**8.7**	**8.0**	**6.7**	**NS**

Table *6:* Mean squares for leaf area (cm^2) at 4-11 months after planting

Source of variation	d.f	Month after planting						
		4	6	7	8	9	10	11
Reps	3	115822	574690	422957	1205683	1110110	2125228	2349201
Shade (S)	2	23438	143469*	523170**	1218504*	1164317	154270	1352242
Error (a)	6	6193	14239	32378	177411	433889	51132	416718
Progeny (P)	2	16831	8567	1618	118564*	124370	40342	121438
Water (W)	2	4550	11825	3496	14391	9007	153120	112811
SxP	4	6925	36655	57392	200057***	243757***	148244	314248***
SxW	4	3867	7380	18027	93116*	86542	93492	128302
PxW	4	7202	21830	38236	80207	97977	239379**	370875***
S x P x W	8	7985	18565	21524	47368	62678	79384	101001
Error (b)	72	5369	15530	26511	36531	44726	61622	77074

*, **, *** Significant at 5%, 1% and 0.1% levels respectively

Table 7: Effect of shade x progeny interaction on leaf area (cm^2) 4-11 months after planting.

Months after planting	Shade-progeny combinations^a									
	S,Pi	S,P$_2$	SiP$_3$	S$_2$Pi	S2P2	S2P3	S$_3$P,	S3P2	S3P3	LSD(P=0.05)
4	282	291	222	293	241	247	238	202	216	NS
6	691	546	672	587	589	565	446	488	442	NS
7	976	905	1050	877	898	813	598	695	622	NS
8	1316	1180	1564	1170	1188	1228	789	918	803	284.6
9	1568	1333	1694	1321	1335	1463	963	1138	978	432.5
10	1867	1672	1898	1631	1584	1689	1182	1325	1185	NS
11	2106	1819	2104	1859	1827	2080	1404	1611	1418	433.2

a: Si = "No shade" (0%); S2 = "Medium shade"(50%); S3 = "Heavy shade"(75%)
P =(UR666 x 851.123) x (1.3056T x 32.2612T) ; P$_2$ = 5.37 Deli selfed x 32.2612Tselfed ;
P$_3$ =851.168 Deli selfed x 851.326T selfed.

Table 8 shows the effect of shade x water interaction (SxW) on leaf area from 4 to 11 months after planting. Seedlings under full exposure performed best in combination with the highest water supply level (S1W3). Under both medium and heavy shade the highest leaf areas were produced in combination with medium soil moisture supply (S2W2 and S3W2).

Significant progeny x water interactions for leaf area were present only at 10 and 11 months after planting (Table 9). At the lowest water supply (Wj), progeny 3 was consistently the best with respect to leaf area per plant. However the overall best combination of progeny and water supply level was progeny 1 under medium water supply (PiW_2). Progeny 3 was also very sensitive to high water supply (W_3) but leaf area for progeny 2 was highest at the highest water supply level.

Table 10 shows the effect of shade on leaf area from 4 tol 1 months after planting. Seedlings under "no shade" had larger leaf areas than those under shade, with those under "heavy shade" having smaller leaves than those under "medium shade". Differences in leaf area between seedlings under "no shade" and "medium shade" were smaller than differences between those two and those under "heavy shade".

The trend observed in leaf production was again observed in expansion in leaf area with the highest leaf areas being associated with plants under "no shade " and the lowest with plants under "heavy shade". This observation was true throughout the study period.

Table 8: Effect of shade x water interaction on leaf area (cm^2) 4-11 months after planting.

Months after planting	**Shade-water combinations** [a]									
	S,W,	S,W_2	S1W3	S_2W,	S_2W_2	S_2W_3	S_3W,	S_3W_2	S_3W_3	**LSD(P=0.05)**
4	**253**	**249**	**293**	**252**	**255**	**273**	**238**	**206**	**211**	**NS**
6	**608**	**650**	**651**	**582**	**590**	**549**	**456**	**496**	**424**	**NS**
7	**927**	**985**	**1019**	**880**	**877**	**832**	**650**	**653**	**612**	**NS**
8	**1250**	**1345**	**1465**	**1224**	**1241**	**1121**	**854**	**865**	**790**	**283.0**
9	**1431**	**1523**	**1641**	**1374**	**1426**	**1318**	**1077**	**1027**	**975**	**NS**
10	**1681**	**1881**	**1875**	**1642**	**1733**	**1529**	**1274**	**1278**	**1141**	**NS**
11	**1836**	**2166**	**2027**	**1939**	**1920**	**1886**	**1523**	**1499**	**1412**	**NS**

a: Si = "No shade" (0%); S_2= "Medium shade"(50%); S_3 = "Heavy shade"(75%);
Wi = 50-60%FC(low); W_2 = 65-75%FC(medium); W_3 = 80-90%FC(high).

Table 9: Effect of progeny x water interaction on leaf area (cm^2) 4-11 months after planting.

Months after planting	Progeny-water combinations[a]									
	PiW,	PiW_2	P1W3	$P_2W!$	p_2w_2	p_2w_3	PsW.	p_3w_2	P3W3	LSD(P=0.05)
4	241	263	289	252	221	260	250	206	229	NS
6	541	641	522	528	546	551	579	549	552	NS
7	764	900	788	857	792	849	837	822	825	NS
8	1038	1189	1049	1077	1030	1179	1214	1232	1149	NS
9	1204	1404	1243	1291	1181	1334	1388	1391	1357	NS
10	1414	1806	1460	1552	1455	1574	1630	1631	1510	205.7
11	1638	2079	1652	1752	1649	1856	1907	1858	1817	230.1

a: Pi =(UR666 x 851.123) x (1.3056T x 32.2612T) ; P_2 = 5.37 Deli selfed x 32.2612T selfed ; P3 =851.168 Deli selfedx 851.326T selfed.
Wi = 50-60%FC(low); W_2 = 65-75%FC(medium); W_3 = 80-90%FC(high).

Table 10: Effect of Shade on leaf area (cm^2) at 4 to 11 months after planting

Month after planting	Treatments			
	No shade	Medium shade	Heavy shade	LSD(P=0.05)
4	265	260	219	NS
6	636	574	459	90.7
7	977.0	863	638	136.8
8	1354	1195	837	320.2
9	1532	1373	1026	NS
10	1812	1635	1231	NS
11	2010	1915	1478	NS

Differences in leaf area among seedlings of the three oil palm progenies were significant only at 8 months after planting (Table 11).

However, progeny 3 had larger leaves than the other two progenies over the study period.

Table 11: Influence of progeny on leaf area (cm^2) at 4 to 11 months after planting

Months after planting	Progeny			
	Progeny 1	Progeny 2	Progeny 3	LSD(P=0.05)
4	271	245	228	NS
6	568	541	560	NS
7	817	833	828	NS
8	1092	1095	1198	92.4
9	1284	1269	1378	NS
10	1560	1527	1590	NS
11	1790	1752	1861	NS

4.1.3 Plant height.

Table 12 shows the mean squares for plant height from 4 to 11 months after planting for the three oil palm progenies under various water-shade regime combinations. Interaction between shade, progeny and water (SxPxW) levels were not significant for plant height throughout the experimental period. Shade x progeny (SxP) interactions showed significant differences in plant height in the 11th month after planting while progeny x water interactions (PxW) showed significant differences in plant height in the 9th and 10th months after planting. Differences in water supply levels did not signifcantly influence plant height in the study. Average over all water and shade levels, differences in plant height among three progenies were not significant.

Table 13 shows the effect of shade x progeny interaction on plant height from 4 to 11 months after planting. Generally for all three progenies, plants were tallest under "no shade". Under "medium and heavy shade"; progeny 2 produced taller plants than the other progenies. In the 11th month after planting, progeny 3 under "no shade" (S_1P_3) gave the highest height and was significantly different ($P<0.05$) from plant height under "heavy shade" for all progenies (S_3P_1, S_3P_2 and S_3P_3).

Table 14 shows of the effect of progeny x water interaction on plant height from 4 to 11 months after planting. Though differences in progeny-water combinations were not significantly different except for the 9th and 10th months after planting, there were some peculiar trends. Generally P_3 tended to perform better than Piand P_2 in association with the lowest water level (Wi). In association with medium watering (W_2), Pi appeared to perform best while P_2 performed better in association with the highest watering level (W_3). In the 10* month after planting P_1W_2 gave the greatest height but it was not different ($P<0.05$) from P_2W_3. It was however significantly ($P<0.05$) different from P_1W_1, P_1W_3 and P_2W_2 in terms of increase in height.

Table 15. Shows the effect of three shade levels on plant height from 4 to 11 months after planting. From the 6th month onwards, however it was observed that plant height decreased across the three shade levels. Seedlings under “no shade” were the tallest. Those under “heavy shade” were the shortest. Those under “medium shade” being intermediate in height between shaded and non shaded. Significant differences ($P<0.05$) in height due to the different shade levels were observed in the 7th and 10th months after planting. At 7 month after planting, plants under "no shade" and "medium shade” were significantly taller ($P<0.05$) than those under " heavy shade". At 10 months after planting however, significant differences existed only between plants under "no shade" and those under" heavy shade".

Table 12: Mean squares for plant height (cm) at 4-11 months after planting.

Source of variation	d.f	Month after planting						
		4 6 7 8 9 10 11						
Reps	**3**	**137.85**	**552.72**	**301.47**	**474.88**	**673.00**	**1774.45**	**1501.03**
Shade(S)	**2**	**85.89**	**17.92**	**113.10***	**177.24**	**494.66**	**1321.30***	**1151.97**
Error 1	**6**	**14.50**	**3.93**	**11.86**	**71.57**	**234.94**	**214.33**	**285.74**
Progeny (P)	**2**	**17.34**	**27.90**	**10.80**	**5.91**	**32.69**	**26.51**	**6.74**
Water (W)	**2**	**6.91**	**4.67**	**12.69**	**7.51**	**5.51**	**62.65**	**35.52**
SxP	**4**	**35.84**	**15.58**	**11.91**	**29.22**	**62.11**	**90.49**	**116.49***
SxW	**4**	**19.83**	**12.34**	**13.20**	**11.28**	**50.71**	**33.79**	**22.09**
PxW	**4**	**11.20**	**6.53**	**17.31**	**30.68**	**76.64***	**120.56***	**105.74**
S x P x W	**8**	**16.30**	**5.63**	**12.51**	**10.34**	**15.66**	**37.66**	**49.70**
Error 2	**72**	**12.87**	**12.84**	**15.72**	**17.82**	**27.59**	**39.89**	**41.77**

*, Significant at 5%, level.

Tablel3: Effect of shade x progeny interaction on plant height (cm) 4-11 months after planting.

Months after planting	Shade-progeny combinations[a]									
	S1P1	S1P2	S,P_3	SjP,	S2P2	S2P3	S_3P!	S3P2	S3P3	LSD(P=0.05)
4	29.1	30.3	27.4	32.1	29.0	32.2	32.3	30.3	33.0	NS
6	41.6	40.4	43.8	40.3	40.7	40.5	38.0	39.9	40.7	NS
7	48.3	47.6	50.4	46.7	48.2	47.4	43.6	44.2	44.0	NS
8	52.2	51.5	55.0	52.0	52.7	51.7	46.8	49.0	46.7	NS
9	61.5	60.6	65.9	56.7	57.6	57.0	49.4	53.0	50.3	NS
10	76.5	73.9	79.1	65.3	67.9	67.3	55.5	60.0	55.5	NS
11	78.4	73.7	79.5	68.8	71.2	69.2	57.9	62.9	58.3	11.73

a: Si = "No shade" (0%); S_2= "Medium shade"(50%); S_3 = "Heavy shade"(75%);
P, =(UR666 x 851.123) x (1.3056T x 32.2612T) ; P_2 = 5.37 Deli selfed x 32.2612T selfed
P_3 =851.168 Deli selfed x 851.326T selfed.

Table 14: Effect of progeny x water interaction on plant height (cm) 4-11 months after planting.

Months after planting	Progeny-water combinations [a]									
	PiW,	PiW_2	P1W3	P_2W,	p_2w_2	p_2w_3	P_3W,	p_3w_2	p_3w_3	LSD(P=0.05)
4	30.0	31.2	32.3	30.4	28.8	30.4	31.6	30.5	30.5	NS
6	39.7	40.9	39.2	40.6	39.8	40.6	42.2	41.8	40.8	NS
7	45.8	47.6	45.1	47.1	45.7	47.1	46.8	48.7	46.3	NS
8	50.0	52.0	49.1	51.3	49.5	52.2	51.3	52.3	49.7	NS
9	54.4	59.0	54.2	56.9	55.0	59.5	58.5	58.0	59.8	4.33
10	62.3	70.8	64.2	66.7	65.2	69.8	67.3	68.2	66.5	5.20
11	66.0	73.1	65.9	69.0	67.5	71.1	69.3	69.4	68.3	NS

a: Pi =(UR666 x 851.123) x (1.3056T x 32.2612T) ; P_2 = 5.37 Deli selfed x 32.2612T selfed P_3 =851.168 Deli selfed x 851.326T selfed.
Wi = 50-60%FC (low); W_2 = 65-75%FC (medium); W3 = 80-90%FC(high).

Table 15: Effect of shade on plant height (cm) at 4 to 11 months after planting

Months after planting	Shade regime			
	No shade	Medium shade	Heavy shade	LSD (P=0.05)
4	28.9	31.1	31.9	NS
6	41.9	40.5	39.5	NS
7	48.8	47.4	43.9	2.942
8	52.9	52.1	47.5	NS
9	62.7	57.9	50.9	NS
10	76.5	66.9	57.0	12.507
11	77.2	69.7	59.7	NS

4.1.4 Butt circumference.

Table 16 shows the mean squares for butt circumference (cm) from 4 to 11 months after planting. The second order interactions shade x progeny x water (SxPxW) was not significant throughout the experimental period.

Progeny and water (PxW) interactions as well as shade and water (SxW) interactions also did not lead to any significant difference in butt circumference during the study period.

Shade x progeny (SxP) interactions however, had significant effect on butt circumference in the 9th month after planting. Among the main factors, only shade levels had significant ($P<0.05$) effect on butt circumference. These differences were present at the 6th, 7th, 8th and 10th months after planting.

Table 16: Mean squares for Butt circumference (cm) at 4-11 months after planting.

Source of variation	d.f	Month after planting						
		4	6	7	8	9	10	11
Reps	3	2.91	24.26	1.49	2.40	3.09	11.84	4.53
Shade(S)	2	19.57	6.38*	15.48*	22.46*	27.66	41.98*	46.76
Error (a)	6	0.78	0.97	1.36	2.84	6.26	6.72	10.45
Progeny (P)	2	1.22	0.59	0.60	0.99	0.24	0.60	1.04
Water (W)	2	0.44	1.64	0.40	1.15	2.62	0.62	3.58
SxP	4	0.96	1.28	1.47	2.05	4.29*	2.60	3.61
SxW	4	0.17	0.44	0.14	1.30	2.65	0.38	3.55
PxW	4	0.43	0.22	0.87	1.68	2.92	2.75	2.82
S x P x W	8	1.28	0.57	0.45	0.57	1.84	2.87	3.23
Error (b)	72	0.52	0.62	0.87	1.15	1.30	1.48	1.64

*, Significant at 5%, level.

Table 17 shows the effect of shade x progeny interaction on butt circumference from 4 to 11 month after planting. For each progeny, the butt circumference decreased with increasing shade level. Under "no shade", progeny 1 had the largest butt circumference and progeny 2 had the lowest. However, under "medium and heavy shade", progeny 2 had a larger butt circumference than the other two progenies.

The percentage increase in butt circumference for the three oil palm progenies differed under the three shade levels (Table 18). Under "no shade", butt circumference increased by 213.6%, for "medium shade" by 179.6% and for "heavy shade" by 160.4% from the 4th to the 11th month after planting respectively. Between 6 to 10 months after planting differences in butt circumference were significantly different ($P<0.05$) among the three shade regimes.

Table 17: Effect of shade *x* progeny interaction on butt circumference (cm) 4-11 months after planting.

Months after planting	Progeny-shade combinations [a]									
	SiP,	S,P$_2$	S$_1$P$_3$	S$_2$P$_1$	S$_2$P$_2$	S2P3	S3P1	S$_3$P$_2$	S3P3	LSD(P=0.05)
4	4.51	4.62	4.49	4.59	3.66	4.40	3.26	3.00	3.15	NS
6	7.51	6.63	7.12	6.11	6.12	6.06	5.23	5.56	5.04	NS
7	9.82	9.04	9.30	8.15	8.29	8.19	5.50	5.99	5.25	NS
8	11.25	10.39	10.53	9.09	9.28	9.05	6.07	6.81	6.00	NS
9	12.43	11.07	12.16	9.95	10.31	10.1	6.82	7.5	6.64	2.25
10	14.08	13.4	13.8	11.45	11.74	11.67	7.49	8.35	7.21	NS
11	14.66	13.63	14.44	11.78	11.99	11.71	8.14	8.77	7.57	NS

a: Si = "No shade" (0%); S2= "Medium shade"(50%); S3 = "Heavy shade"(75%);
Pi =(UR666 x 851.123) x (1.3056T x 32.2612T); P$_2$ = 5.37 Deli selfed x 32.2612T selfed
P$_3$ =851.168 Deli selfedx 851.326T selfed.

Table 18: Effect of shade on Butt circumference (cm) at 4 to 11 months after planting

Months after planting	Shade regime			
	No shade	Medium shade	Heavy shade	LSD(P=0.05)
4	4.54	4.22	3.13	NS
6	7.09	6.10	5.28	1.3533
7	9.40	8.21	5.58	1.6047
8	10.72	9.14	6.29	2.320
9	11.89	10.12	6.99	3.445
10	13.76	11.62	7.68	3.571
11	14.24	11.79	8.16	NS

4.2 Effect of the interaction of moisture and shade regimes on dry weights of plant parts in three oil palm progenies

4.2.1: Dry weights of roots, leaves and stems

Table 19 shows the mean squares for dry weight of plant parts at 11 months after planting. Interaction between shade levels, progenies and water supply levels (S x P x W) did not produce significant differences in root, leaf, stem and total plant dry weight. Shade x progeny (S x P) interaction produced significant differences in stem dry weight. Progeny x water interaction also produced highly significant (PO.Ol) and significant (P<0.05) differences in leaf and stem dry weights respectively.

The different shade levels also produced significant (P<0.05) differences in root, stem and total plant dry weight.

Table 19: Mean squares for dry weight (g) of plant parts at 11 months after planting

Source of variation	d.f	Plant part			
		Root	Leaf	Stem	Total dry weight
Reps	3	1337.9	76.3	583.8	3682
Shade (S)	2	3150.6*	1586.9	4589.5*	42266*
Error (a)	6	465.3	440.9	615.2	4929
Progeny (P)	2	204.0	16.6	21.5	1972
Water (W)	2	231.3	7.7	54.3	255
SxP	4	386.4	86.0	307.8*	1548
SxW	4	376.5	283.6*	131.4*	1606
PxW	4	453.1	414.7**	382.6*	1809
SxPxW	8	467.9	71.1	70.2	1057
Error (b)	72	444.2	85.6	104.6	1066

*, **, Significant at 5%, 1% and levels respectively

4.2.1.1 Root dry weight (g)

Both first and second order interactions among shade levels, progenies and water supply levels did not produce any significant differences in root dry weight. Among the main factors, only differences in shade levels led to significant differences in root dry weight (Table 20). Plants under the "no shade" treatments produced significantly ($P<0.05$) higher root dry weight than those under the heavy shade treatments. However, the differences in root dry weight between plants under “no shade” and “medium shade” were not significant.

Table 20: Effect of shade on dry weight (g) of plant parts at 11 months after planting

Shade level	Root	Stem	Total dry matter
No shade	27.4	43.6	123.4
Medium shade	25.8	33.5	94.1
Heavy shade	9.3	21.0	55.1
LSD(P=0.05)	18.1	14.3	40.5

4.2.1.2 Leaf dry weight (g)

The interaction between shade levels, progenies and water supply levels (SxPxW) did not significantly influence leaf dry weight throughout the experimental period (Table 19). Shade and progeny (SxP) interactions did not also influence leaf dry weight significantly. Shade and water (SxW) interactions however led to significant differences in leaf dry weight at 11 months after planting (Table 21).

The highest leaf dry weights were almost invariably associated with plants under "no shade." and "medium shade" with those under "heavy shade" giving the lowest values for leaf dry weight. Between plants under "no shade" and "medium shade" there was no significant differences in leaf dry weight except in combination with "high watering".

Within a particular shade level increasing water supply did not result in significant differences in leaf dry weight. However, under any particular moisture supply regime, increasing shade level from full exposure to "heavy shade" resulted in significant differences in leaf dry weight.

4.2.1.3 Total plant dry weight (g)

Total dry matter was not significantly affected by both second and first order interactions between shade, progeny, and water supply levels. Shade levels however led to significant differences in total dry matter at 11 months after planting (Table 20). Total dry matter generally decreased with increasing shade from "no shade" to "heavy shade". Significant differences (P<0.05) in total dry matter existed between plants under the "no shade" and "heavy shade" treatments. Between the "no shade" and "medium shade" treatments and also between the "medium shade" and "heavy shade" treatments, differences in total dry matter production were not significant (Table 20).

Table 21: Interaction of shade and water regimes on leaf dry weight (g) at 11 month after planting

Shade regime	**Water regime**		
	Low water	**Medium water**	**High water**
No shade	**38.1**	**43.3**	**45.2**
Medium shade	**39.4**	**31.7**	**28.7**
Heavy shade	**25.4**	**25.2**	**28.7**

LSD (P< 0.05): 13.463

Table 22 shows the effect of progeny x water interaction on leaf dry weight at 11 months after planting. Under low water supply, progeny 3 produced the highest leaf dry weight. Under medium water supply, progeny 1 had the highest leaf production, while progeny 2 produced the highest dry matter under high water supply. However, differences among progenies were significant at low and medium water supply but not at high water supply.

Table 22: Effect of progeny x water interaction on leaf dry weight (g) at 11 months after planting.

Progeny	Water regimes		
	Low water	Medium water	High water
Progeny 1	28.7	40.0	32.3
Progeny 2	34.0	30.0	37.4
Progeny 3	40.2	31.0	32.9

LSD ($P<0.05$): 7.629

4.2.1.4 Stem dry weight (g)

Table 23 shows the effect of first order interactions, (progeny x shade, progeny x water and shade x water) on stem dry weight at 11 months after planting. All the three first order interactions were significant for differences in stem dry weight.

Differences in stem dry weight between progenies were highest in plants under "no shade" and smallest in those under "medium shade". Differences in stem dry weight between progenies varied depending on the water supply level. The highest differences occurred under low moisture supply. Progeny 3 had its highest stem dry weight occurring at low water supply but those of progeny 1 and progeny 2 occurred under medium and high water supply, respectively.

Within any particular shade regime, differences in water supply level did not produce significant differences in stem dry weight. Averaged over all progenies, seedlings under "no shade" and high water supply produced the highest stem dry weight.

Table 23: First order interactions of progeny, shade regimes and water supply level for stem dry weight (g) at 11 months after planting

Shade regime	**Progeny**		
	(UR666X 851.123) X (1.3056T x32.2612T) (Pi)	**5.37 Deli selfedX 32.2612T selfed (P*)**	**851.168Deli selfed X 851.326T selfed (P_3)**
No shade	**48.9**	**42.9**	**40.0**
Medium shade	**30.7**	**33.1**	**36.7**
Heavy shade	**16.2**	**22.2**	**24.7**
LSD (P=0.05): 14.955			
Water regime	**Progeny**		
	(UR666x 851.123) X (1.3056T X32.2612T) (Pi)	**5.37 Deli selfed X 32.2612T selfed (Pa)**	**851.168Deli selfed X 851.326T selfed (Ps)**
Low water	**25.7**	**37.9**	**32.1**
Medium water	**30.9**	**30.2**	**37.0**
High water	**37.9**	**29.8**	**32.8**
LSD (P=0.05): 8.349			
Shade regime	**Water regime**		
	Low water	**Medium water**	**High water**
No shade	**36.6**	**44.8**	**49.4**
Medium shade	**37.4**	**32.8**	**30.2**
Heavy shade	**20.5**	**20.3**	**22.3**
LSD (P=0.05): 14.955			

4.3 Effect of interaction of moisture and shade regimes on growth rates of three oil palm progenies

4.3.1 Growth characteristics

Table 24 shows the mean squares for leaf area growth rate (LAGR), leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR) at 11 months after planting. Shade x progeny interactions produced significant ($P<0.05$) differences in relative leaf area growth rate (RLAGR), leaf area index (LAI) and crop growth rate (CGR) while shade x water (SxW) and progeny x water (PxW) interaction produced significant differences in net assimilation rate (NAR) and leaf area index (LAI) respectively. The different shade levels had highly significant effect on relative growth rate (RGR), leaf area index (LAI) and crop growth rate (CGR). Influence of progeny produced highly significant differences ($P<0.01$) in net assimilation rate (NAR) and significant effects on relative growth rate (RGR), leaf area ratio (LAR) and leaf area index (LAI). Water supply levels did not have any significant effect on the various growth characteristics.

4.3.1.1 Net Assimilation Rate (NAR)

Second order interactions among shade regimes, progenies and water supply levels did not produce significant differences in net assimilation rate (NAR). With the first order interactions, only those among shade regimes and water supply levels signifcantly affected NAR (Table 24 It was observed that for plants under "no shade" and " heavy shade" increasing the water supply led to a corresponding increase in NAR. For those under medium shade however increasing water supply led to NAR peaking at medium water supply level above which it dropped (Table 25).

Within any particular shade regime differences in water supply level did not produce significant differences in NAR(Table 25). Across the three shade levels NAR dropped from "no shade" to" heavy shade" irrespective of the associated water supply level.

Plants under "no shade" in combination with high water supply level produced the highest NAR while the lowest NAR value was observed in plants under "heavy shade" in combination with low water supply.

Progeny influence produced highly significant differences (PO.Ol) in NAR. Progeny 2 and progeny 3 which produced the same NAR values had signifcantly higher NAR than progeny 1 (Table 26).

Table 24: Mean squares for NAR, RGR, LAR, RLAGR, LAI, and CGR at 11 months after planting

Source of variation	d.f	NAR	RGR	LAR	RLAGR	LAI	CGR
Reps	**3**	**0.05955**	**0.286x1 O'^{4}**	**125.89**	**0.199x lO^{-4}**	**0.8572**	**0.3478**
Shade(S)	**2**	**0.28641**	**0.850 xlO^{-4}****	**1290.67**	**0.733x1 O'^{5}**	**8.0084***	**5.5929***
Error 1	**6**	**0.11573**	**0.783 x 10"^{5}**	**296.28**	**0.196 xlO^{-5}**	**0.9584**	**0.7539**
Progeny(P)	**2**	**0.07511****	**0.101 x lO^{-4}***	**390.37***	**0.308 x 10‘^{6}**	**1.6945***	**0.3370**
Water (W)	**2**	**0.00561**	**0.128 xlO'^{6}**	**47.99**	**0.151 x 10'^{5}**	**0.0525**	**0.1014**
SxP	**4**	**0.02971**	**0.200x1 O'^{5}**	**74.23**	**0.519 xlO'^{5}***	**1.0374***	**0.3939***
SxW	**4**	**0.03991***	**0.107 xlO'^{5}**	**132.93**	**0.508x1 O'^{3}**	**0.0964**	**0.1171**
PxW	**4**	**0.00417**	**0.423x1 O’^{5}**	**7.45**	**0.230 x 10'^{3}**	**1.1326***	**0.1067**
S x P x W	**8**	**0.00823**	**0.297 x 10'^{5}**	**67.25**	**0.348 x 10'^{5}**	**0.4616**	**0.0947**
Error 2	**72**	**0.77496**	**0.213 x 10'^{5}**	**80.93**	**0.168 xlO'^{5}**	**0.4197**	**0.1360**

*,** Significant at 5% and 1% levels respectively.

NAR: Net Assimilation rate.	RGR: Relative growth rate.
LAR: Leaf area ratio.	RLAGR: Relative leaf area growth rate.
LAI: Leaf area index.	CGR: Crop growth rate.

Table25: Effect of shade x water (SxW) interaction on NAR at 11 months after planting

Shade level	Low water	Medium water	High water
No shade	**0.418**	**0.430**	**0.483**
Medium shade	**0.403**	**0.423**	**0.306**
Heavy shade	**0.225**	**0.263**	**0.314**

LSD (= 0.05): 0.2007

Table 26: Influence of progeny on growth parameters (NAR, RGR, LAR, LAI) at 11 months after planting

Progeny	NAR	RGR	LAR	LAI
(UR666 x 851.123) X (1.3056T X32.2612T) (PI)	0.310	0.00961	35.18	2.778
5.37Deli selfed X 32.2612T selfed (P2)	0.389	0.01035	30.09	2.371
851.168Deli selfed X 851.326T selfed (P3)	0.389	0.01030	29.02	2.704
LSD(P=0.05)	0.0531	0.000687	4.240	0.3053

4.3.1.2 Relative growth rate (RGR)

Relative growth rate (RGR) was significantly affected by progeny and shade levels. As with NAR, progeny 2 and progeny 3 produced significantly higher RGR then progeny 1. Between progeny 2 and 3 however differences in RGR were not significant (Table 26). The three shade levels also affected RGR significantly ($P<0.05$). Generally it was observed that RGR values decreased with increasing shade level from "no shade" to "heavy shade" (Table 27)

Plants under "heavy shade" were associated with a significantly lower RGR than those under "medium shade " and "no shade". Between plants under " medium shade" and "no shade", differences in RGR were not significant.

4.3.1.3 Leaf area ratio (LAR)

Both first and second order interactions among shade levels, progenies and water supply levels did not produce significant differences in LAR. Among the main factors LAR was only affected by progeny.(Table 24)

Progeny 1 (P,) had a signifcantly ($P<0.05$) higher LAR than progeny 2 and progeny 3 however, between progeny 2 and 3 differences in LAR were not significant (Table 26).

Table 27: Effect of shade on RGR, LAI, and CGR at 11 months after planting

Shade levels	RGR	LAI	CGR
No shade	0.01140	3.068	1.280
Medium shade	0.01071	2.657	0.911
Heavy shade	0.00845	2.127	0.492
LSD($P<0.05$)	0.001583	0.5646	0.5008

4.3.1.4 Relative leaf area growth rate (RLAGR)

Second order interaction among shade levels, progenies and water supply levels did not produce significant differences in RLAGR. Among the first order interactions only SxP effects produced significant differences ($P<0.05$) in RLAGR (Table 28).

Under " no shade" progeny 3 produced the highest RLAGR. Under both medium and heavy shade levels, progeny 2 produced the highest RLAGR.

Under "no shade" progeny 3 produced significantly higher RLAGR than progeny 2. Under medium and heavy shade however, the performance of the three progenies with regards to RLAGR was not different. While progeny 1 and 2 appeared to be quite stable in RLAGR over the three shade regimes the same cannot be said for progeny 3 whose performance under "no shade" was significantly different from its performance under medium and heavy shade.

Progeny 2 under increasing shade was associated with increasing RLAGR even though the differences were not significant.

Table28: Effect of shade x progeny interaction on relative leaf area growth rate (RLAGR) at 11 months after planting

Shade levels	Progeny 1	Progeny 2	Progeny 3
No shade	0.00820	0.00756	0.00912
Medium shade	0.00766	0.00781	0.00774
Heavy shade	0.00738	0.00793	0.00689

LSD (P =0.05): 0.001107

4.3.1.5 Leaf area index (LAI)

Second order interactions among shade levels, progenies and water supply levels did not produce significant differences in leaf area index (LAI). Among the first order interactions, shade by progeny (SxP) and progeny by water (PxW) produced significant differences in LAI. For the main factors, progenies and shade levels produced significant differences in LAI (Table 24). Table 29 shows the effect of shade x progeny (SxP) interaction on LAI at 11 months after planting.

Under "no shade" progeny 3 produced the overall highest LAI. Under "medium shade" progeny 1 produced the highest LAI while under "heavy shade" progeny 2 produced the highest LAI. Under "no shade" significant differences ($P<0.05$) LAI existed between progeny 3 and progeny 2. Under medium and heavy shade however, there were no significant differences in LAI among the three progenies.

Progeny 3 appeared to be quite sensitive to shade since significant differences ($P<0.05$) occurred in its performance over all the three shade levels. In the case of progeny 1, significant differences ($P<0.05$) in LAI were observed in its performance under "no shade" and "heavy shade"only. Progeny 2 appeared to be relatively stable over all the three shade levels since differences in LAI produced under all the shade levels were not significantly different. The three progenies reacted differently under the various shade regimes with regards to their LAI.

Table 29: Effect of shade x progeny interaction on leaf area index at 11 months after planting

Shade levels	Progeny 1	Progeny 2	Progeny 3
No shade	3.2	2.5	3.4
Medium shade	3.0	2.4	2.7
Heavy shade	2.2	2.2	2.0

LSD (P=0.05): 0.6600

Table 30 shows the effect of PxW interaction on leaf area index at 11 months after planting. Under the lowest water supply (Wi) progeny 3 produced the highest LAI.

Under "medium” water supply progeny 1 produced the highest in LAI.

Under "low and heavy watering", no significant differences were observed in LAI resulting from interactions involving the 3 progenies.

Under "medium water supply, however significant differences $(P<0.05)$ in LAI were present between progeny 1 and 2 and also between progeny 1 and 3. Between progeny 2 and 3 however differences in LAI were not significant. The performance of progeny 1 under "medium" water supply was significantly higher than its performance under low water supply. Progeny 2 and 3 however were quiet stable in performance over all the three water supply levels. It was observed that increasing water supply did not always lead to an increase in LAI in PxW interactions (Table 30).

Table 30: Effect of progeny x water (PxW) interaction on leaf area index 11 months after planting

Progeny	**Low water**	**Medium water**	**High water**
(UR666 x 851.123) X (1.3056T x 32.2612T) (P,)	**2.5**	**3.1**	**2.7**
5.37Deli selfed X 32.2612T selfed (P_2)	**2.4**	**2.1**	**2.6**
851.168Deli selfedX 851.326T selfed (P_3)	**2.9**	**2.5**	**2.7**

LSD (P<0.05): 0.5289

Progeny influence produced significant (P<0.05) difference in LAI.

Leaf area indices for progeny 1 and progeny 3 were significantly (P<0.05) higher than that for progeny 2 but between progeny 1 and progeny 3 there was no significant difference in LAI (Table 26).

Shade levels also significantly affected LAI. Plants under "no shade" had signifcantly (P<0.05) higher LAI than those under "heavy shade" but not different from those under "medium shade" (Table 27).

4.3.1.6 Crop growth rate (CGR)

Second order interaction between shade levels, progenies and water supply levels did not significantly affect crop growth rate throughout the experiment. Among the first order interactions, only SxP significantly affected CGR.

Table 31 shows the effect of SxP interaction on crop growth rate.

Under the "no shade" treatment, progeny 3 produced the highest growth rate. Under the "medium shade" treatment, progeny 2 produced the highest growth rate while progeny 3 produced the highest crop growth rate under "heavy shade". Within a particular shade regime however, no significant differences existed between the three progenies. Across the three shade levels, significant differences ($P<0.05$) in crop growth rate among the progenies were observed.

Progeny 1 under "no shade" produced significantly ($P<0.05$) higher crop growth rate than when it was under medium and heavy shade. Also progeny 3 under "no shade" produced a significantly higher crop growth rate than when it was under medium and heavy shade. Crop growth rate in progeny 2 under the three shade levels was not significantly different.

Table 31: Effect of shade x progeny interaction on crop growth rate at 11 month after planting

Shade levels	**(UR666x 851.123) X (1.3056T x 32.2612T)** (Pi)	**5.37Deli selfed X 32.2612T selfed (P_2)**	**851.168Deli selfed X 851.326T selfed (P_3)**
No shade	**1.280**	**1.019**	**1.541**
Medium shade	**0.748**	**1.027**	**0.960**
Heavy shade	**0.421**	**0.549**	**0.567**

LSD (< 0.05): 0.5256

Differences in shade levels also led to significant difference in CGR. Generally crop growth rate decreased as the level of shade increased from "no shade" to "heavy shade". The "no shade" treatments led to significantly ($P<0.05$) higher CGR than the "heavy shade" treatments but were not different from the "medium shade" treatment. The medium and heavy shade treatments were not significantly different from each other with regards to CGR (Table 27).

4.4 Phenotypic and genotypic variability in plant growth parameters and biomass

4.4.1 Variation in growth parameters and plant biomass

Table 32 shows the phenotypic and the genotypic coefficient of variation for the various growth parameters and plant biomass. A wide range of variation in plant growth parameters was observed. For plant growth parameters, phenotypic coefficient of variation ranged from 9.46% for leaf number to 81.57% for NAR while genotypic coefficient of variation ranged from 3.44% for leaf number to 75.51% for NAR.

Leaf number per plant, plant height (cm), relative leaf area growth rate (RLAGR), butt circumference (cm) leaf area (cm^2) and relative growth rate (RGR) had low phenotypic and genotypic coefficients of variation suggesting little potential for improvement in these characters. Leaf area ratio (LAR) and leaf area index (LAI) had average (medium) phenotypic and genotypic coefficients of variation while net assimilation rate (NAR) and crop growth rate (CGR) had the highest phenotypic and genotypic coefficients of variation.

For plant biomass, phenotypic coefficient of variation ranged from 40.99% for both root dry weight and leaf dry weight while genotypic coefficient of variation ranged from 11.98% for leaf dry weight to 54.91% for total plant dry weight. Plant biomass generally had low to average genotypic coefficients of variation.

Table 32: Phenotypic and genotypic coefficients of variation for plant growth parameters and biomass

Character	Pcv(%)	Gcv(%)
Leaf Number	9.46	3.44
Leaf area (cm^2)	33.46	19.35
Plant height (cm)	13.59	3.77
Butt circumference (cm)	17.28	8.97
Root dry weight (g)	40.99	25.01
Stem dry weight (g)	49.20	17.24
Leaf dry weight (g)	40.99	11.98
Total plant dry weight (g)	67.66	54.91
NAR	81.57	75.51
RGR	34.79	31.19
RLAGR	23.00	7.00
LAR	65.77	62.86
LAI	60.28	49.72
CGR	80.43	64.86

4.4.2: Heritability estimates of growth parameters and plant biomass

The heritability estimates of growth parameters ranged from 7.70% to 91.36% (Table 33). The highest heritability estimates were of leaf area ratio (LAR) followed by net assimilation rate (NAR) and relative growth rate (RGR. The lowest heritability values were of plant height, relative leaf area growth rate (RLAGR), leaf number per plant, butt circumference and leaf area per plant. Leaf area index (LAI) and crop growth rate (CGR) had heritability values above 60%.

Table 33: Phenotypic and genotypic variances and heritability of plant growth parameters and dry weight (g) of plant parts

Character	Phenotypic variance	Genotypic variance	Broad sense Hertibility (%)
LeafNumber	0.542425	0.07180	13.24
Leaf area (cm^2)	363175.60	121438.0	33.44
Plant height (cm)	87.50	6.74	7.70
Butt circumference (cm)	3.881	1.041	26.82
Root dry weight	548.20	204.00	37.21
Stem dry weight	258.88	31.80	12.28
Leaf dry weight	193.64	16.55	8.50
Total dry weight	3782.27	2491.0	65.86
NAR	0.08766	0.07511	85.68
RGR	1.2565 x 10"^{5}	1101 xlO'^{5}	80.38
RLAGR	3.228 x 10'^{6}	2.99 x 10"	9.26
LAR	427.31	390.37	91.36
LAI	2.4975	1.6945	68.03
CGR	0.5182	0.3370	68.03

Heritability values for dry weight of plant parts and total biomass ranged from 8.50% for leaf dry weight to 65.86% for total plant dry weight. Stem dry weight had heritability estimate below 15%, root dry weight had heritability estimate above 35% while total plant dry weight had a heritability estimate above 60%.

4.5 Association among characters

Table 34 shows the phenotypic correlation among traits. Leaf number per plant at 11 months after planting was significantly and positively correlated with leaf area per plant ($r^2 = 0.59$), plant height ($r^2 = 0.54$); butt circumference ($r^2 = 0.77$) and total plant dry weight ($r^2 = 0.49$). Leaf number per plant was also negatively correlated with leaf area ratio (LAR) and this was significant ($r^2 = 0.14$). Leaf number per plant was again significantly and positively correlated with NAR ($r^2 = 0.23$), RGR ($r^2 = 0.40$); LAI ($r^2 = 0.38$) and CGR ($r^2 = 0.48$).

Butt circumference at 11 months after planting correlated significantly and positively with leaf number ($r^2 = 0.77$), leaf area ($r^2 = 0.63$), plant height ($r^2 = 0.64$) and total plant dry weight ($r^2 = 0.51$). Butt circumference was also significantly and positively correlated with NAR ($r^2 = 0.21$) ; RGR ($r^2 = 0.31$) ; LAI ($r^2 = 0.38$) and CGR ($r^2 = 0.47$) but with LAR ($r^2 = 0.16$) the correlation was negative and significant.

Leaf area per plant and plant height at 11 months after planting were also significantly and positively correlated with the other traits mentioned above except total plant fresh weight and leaf area ratio (LAR) with which the correlations were negative.

Among the dry weight of plant parts (leaf dry weight, stem dry weight, root dry weight and total plant dry weight) significant and positive correlations were observed. The growth parameters (NAR, RGR, LAI, and CGR) were all significantly and positively correlated with each other as well as with the other traits.

Some of the highest (significant) and positive correlations were found between leaf area and plant height ($r^2 = 0.82$) ; CGR and total plant dry weight ($r^2 = 0.90$) ; leaf number and butt circumference ($r^2 = 0.77$) ; butt circumference and plant height ($r^2 = 0.64$), butt circumference and leaf area ($r^2 = 0.63$). Others were stem dry weight and leaf dry weight ($r^2 = 0.73$) ; stem dry weight and total dry weight ($r^2 = 0.64$) NAR and CGR ($r^2 = 0.62$) CGR and RGR ($r^2 = 0.52$), CGR and leaf dry weight ($r^2 = 0.50$).

TABLE 34: Phenotypic correlation coefficients for association among traits.

Trait	Leaf number	Leaf area	Plant height	Butt circum	Total plant dry weight	NAR	RGR	LAR	LAI	CGR
Leaf number		0.76***	Q 73***	0.88***	0.70***	0.48***	0.63***	-0.38***	0.62***	0.69***
Leaf area		-	Q 90***	0 79***	0.70***	0.33***	o49***	-0.24*	0.74***	0.64***
Plant height				0.80***	Q 7|***	o37***	0.46***	-0.28**	0.76***	0.65***
Butt circum					0 7j***	0.46***	0.56***	-0 39***	0.62***	0.69***
Total plant dry weight						o 77***	0.65***	-0 53***	0.57***	o 95***
NAR						-	0.74***	-0.74***	0.12*	0.79***
RGR							-	-0.57***	0.35***	0.72***
LAR								-	0.07	-0.51***
LAI									-	0.58***
CGR										-

*, **, ***: Significant at 5%, 1% and 0.1% levels respectively.

CHAPTER FIVE

5. DISCUSSION

5.1 Interaction of moisture and shade regimes on growth and development of oil palm progenies

Progeny x water interaction led to significant differences in leaf production from the 8th to the 11th month after planting. The highest leaf number was produced by progeny 1 in association with medium water supply level (P1W2) and the lowest number by progeny 2 in association with medium water supply level (P2W2). This seems to suggest that the two progenies have different efficiencies at which they utilise water for growth and might thus have different requirements of the resource. This finding is in agreement with Hartley's (1988) observation that different oil palm progenies have differing growth characteristics and associated stress response and thus perform differently under the same climatic conditions.

Differential production of leaves due to differences in water use efficiencies will ultimately result in photosynthetic systems with different capacities for dry matter production and eventually yield. The screening and early identification of progenies with inherent high water use efficiencies in establishing high capacity photosynthetic systems at the nursery stage will aid the breeder in his selection of ultimately higher yielding palms.

Progeny 3 in combination with the lowest water level (50-60% FC, P3W1) was in this respect better than other progeny-water interactions for though statistically they were not different, progeny 3 required the least water for the production of similar number of leaves.

Increasing water supply in PxW interactions did not always lead to corresponding increase in leaf production in oil palm. Shade affects leaf production in the oil palm. Leaf production declines with increasing shade. Shade level 1(0% shade) produced the highest number of leaves while shade level 3 (75% shade) produced the lowest number of leaves.

The number of leaves present at anytime is the difference between the total number of leaves produced up to that time and the number which have died. It therefore depends on the number of growing points, the length of time during which they produce leaves, the rate of leaf production during this period and the duration of the leaves. Physiological analysis of leaf production must therefore take account of those factors involving meristematic activity, the division of shoot meristems leading to increase in the number of growing points, the rate of production of leaf primordia among others and those determining the senescence and death of leaves.

Watson (1952) has observed that light stimulates rapid cell division in meristematic tissues in leaf primordium leading to increased leaf production. Increasing shade (reducing light) therefore depresses the rate of cell division at the meristematic region of the leaf primordium thereby lowering leaf production. Subronto and Taniputra (1979) observed reduced leaf number with increasing shade in oil palm at the nursery.

Corley (1973) showed that the number of leaves produced is dependent on the light intensity reaching the oldest leaves in the canopy. He also observed a reduction in leaf number with increasing shade in oil palm and attributed the death of the lower leaves to their being shaded out below their photosynthetic compensation point.

Rees (1963a) observed similar reduction in leaf number per plant in oil palm seedlings under different shade levels at the nursery. The lowest leaf number occurred under the heaviest shade (89% shade) and the highest number under 0% shade. Navasero and Tanaka (1966) also observed reduced leaf production induced by low light (i.e. heavy shade) in rice. Maggs (1960) also observed that 76% (i.e. 24% full sunlight) shade decreased leaf number in apple trees.

Even though it has been generally established that increasing shade reduces leaf area in the oil palm, the interaction between the progenies studied and the various shade levels with regards to leaf area per plant was not very clear. While it was observed that the lowest leaf area was obtained in the interaction involving the heaviest shade level and the highest one in the interaction involving the"no shade" treatment, there were other interactions involving plants under "no shade" and "medium shade" that produced essentially the same leaf areas as the lowest, which occurred under the heaviest shade. Perhaps some other factors were at play than can just be explained by progeny and shade effects.

Shade x water interactions led to significant ($P<0.05$) effect on leaf area only in the 8th month after planting. The plants under "no-shade" with highest water supply (80-90%FC) treatments produced the highest leaf area while the lowest occurred in plants under the heaviest shade with heaviest water supply (75% shade 80-90% FC).

It is significant to note that the treatment giving the highest leaf area (0% shade, 80-90% FC) was not different from medium shade combined with low or medium water supply.

This implies that for short periods such as during the dry season when water is generally difficult to come by and blast incidence is high, some temporary shade up to about (50% full sunlight) could be provided at the nursery in association with reduced watering (50-60% FC or 65-75% FC) without a significant reduction in leaf area and hence overall seedling growth. This will reduce blast and ensure that a greater number of seedlings attain transplantable stage at the right time.

Allen (1954) did not find any deleterious effect of shading on growth of seedlings during the dry season and recommended that shading with normal watering (4.51itres/seedling/week) instead of no shade with heavy watering (91itres/seedling/week) was a good cultural practice.

Significant differences in leaf area attributable to progeny x water interactions were observed in the 10th and 11th month after planting. Progeny 1 under "medium" water supply level which produced the highest leaf area was significantly ($P<0.5$) different from the same progeny under low and high water supply, indicating that water requirement for optimum leaf area production seems to be at least partly dependent on progeny. Knowing the water requirements for optimum growth of the various progenies at the nursery stage can greatly cut down the cost of water application in terms of amount and frequency.

Total leaf area per plant diminished as shade level increased from 0% to 75% (i.e. 100% full sunlight to 25% full sunlight). While differences between 0% shade and 50% shade were not significant with respect to increase in leaf area, real differences existed between 0% shade and 75% shade. From the above it can be inferred that if other beneficial effects can be gained by the application of shade to oil palm seedlings at the nursery, then a maximum of 50% shade (i.e. 50% sunlight) can be applied without appreciable reduction in total leaf area per plant.

This finding is in agreement with the observation of Subronto and Taniputra (1979) who reported that leaf area in oil palm seedlings reduced with increasing shade and that plants in 62-83% shade were the least vigorous. Rees (1963a) also reported similar findings in oil palm seedlings subjected to varying shade at the nursery. Leaf area dropped with light intensity from 100% full daylight to 11% full daylight.

Variation in leaf size may arise from effects on cell division, resulting in differences in cell division or on cell extension. It may be probable that increasing shade had a negative effect on the rate of cell division and expansion in the leaf tissue of the oil palm. Monselise (1951) however found leaf area of citrus (sweet lime) seedlings to be increased by shading. Milthorpe (1945) on the other hand found that shading reduced leaf area of flax by decreasing both leaf number and leaf size. Maggs (1960) also found that heavy shade (76% shade i.e. 24% sunlight) decreased total leaf area in apple.

The overall effect of a reduced leaf area is that leaf area index will be low and the photosynthetic active surface for the reception of radiation will be reduced, consequently dry matter production will be affected resulting in a lower crop growth rate. The length of time to reach transplantable stage will be longer and total number of transplantable seedlings reduced.

Genetic differences between the progenies studied with regards to increase in leaf area became evident in the 8th month after planting where it was observed that progeny 3 produced significantly higher leaf area ($P<0.05$) than the other two progenies. Other workers have also reported differences in leaf areas attributable to genetic effect in crops like sugar beet, wheat and potatoes (Watson, (1947a). In oil palm, Corley and Mok (1972) found leaf area to vary in different crosses. Spamaaij (1960) observed differences of 10-15% in leaf area between progenies growing in the same field.

Asafii-Agyei (1973) in an earlier work on leaf characters and their relationship to yield in oil palm at OPRI also observed significant differences between progenies for leaf area. He attributed some of the differences to inbreeding depression and their different genetic origins. It is important to note in this work too that while progeny 1 and progeny 2 have both Deli and African origins, progeny 3 is solely of African origin.

Broekmans (1957) has also noted that difference in the level of leaf production and hence leaf areas are related to differences in the genetic constitution of the palm or to differences in the environment in which the palms are grown. As normally only one inflorescence can develop in each leaf axil, it is clear that leaf production in oil palm is an important yield factor. Rate of leaf production therefore limits the possible rate of inflorescence production. It is also an expression of the growth rate of the palm. Selection for high leaf production may therefore lead to possible high yield even though it has been observed that leaf production is affected by the environment (Hardon *et al.* 1969). Foale (1968) also reported that leaf area in coconut could be genetically controlled.

The identification and selection of progenies with higher leaf areas at the nursery stage will lead to plants with high crop growth rate in the field and higher yields since leaf area has been found to be positively and significantly (P=0.01) correlated with yield in the oil palm. (Hardon *et al.* 1969) In this present study leaf area was also significantly correlated with crop growth rate (PO.OOl, r^2 =0.64).

Significant shade x progeny interaction effects were observed in the 11th month after planting and seem to suggest that in such interactions shade is a major determinant of growth in height. The greatest height was obtained under "no shade" and "medium shade" in the case of progenies 2 and 3 while the least height was obtained under "heavy shade" in all the 3 progenies. Excessive shade (i.e. more than 50% shade) at the nursery could therefore lead to reduced growth as has been observed by other workers (Corley 1973, Maggs 1960, Milthorpe 1945, Rees 1963a, Subronto and Taniputra 1979, Watson 1952).

The results of progeny x water interaction on plant height confirm the point already made that increasing water supply to the oil palm seedling does not necessarily lead to increased growth (height). Progeny 1 under medium water supply produce the best performance in terms of growth in height but the same progeny under high water supply produced a significantly lower height. The conclusion can therefore be drawn that the progenies used for this study had different moisture requirement for optimum growth. While it has generally been observed that all things been equal increasing water supply results in higher growth in oil palm, progeny influence is also important in determining the overall utilisation of water for growth.

Generally it was observed that progeny 3 performed best in association with the lowest water level than the other two progenies, in association with medium and the heavy watering, progeny land progeny 2 were the best performers respectively. Perhaps their genetic origins are partly responsible.

Plant height decreased in all the 3 progenies as shade levels increased and light intensity decreased. Significant differences in height due to shade occurred in the 7th and 10th months after planting The lowest plant height was recorded under the 75% shade level (S_3) while the highest was under the" no shade" treatment (Si). Medium shade (50% shade) was associated with a plant height that was not significantly different from that obtained in plants under "no shade".

A possible explanation for this observation (reduction in height with increasing shade) could be the suppression of the activity of apical buds or meristems by reduced light intensity. Another explanation could be as a result of reduced level of net photosynthesis due to low light intensity and hence inadequate resources for vegetative growth. Hartley (1988) reported that shading reduced growth in oil palm.

Shade x progeny interaction on butt circumference was significant ($P<0.05$) in the 9th month after planting. Under heavy shade (75% shade) all the progenies gave the lowest butt circumference but under the 0% shade (100% sunlight) the interaction resulted in the three progenies producing the highest butts, this shows that the overall effect of increasing shade level in shade x progeny interaction was to cause a decrease in butt circumference irrespective of the progeny involved in the interaction.

Within a particular shade level, progeny differences did not significantly affect butt circumference. In otherwards the effect of environment (shade) seems to be very dominant in determining the observed growth in butt circumference. The level of shade to choose could therefore be very critical.

The observation that progeny 1 performed under the 0% shade treatment better than the other two progenies leading to its greatest butt circumference while under 'heavy shade' progeny 2 gave the highest value for butt circumference followed by progeny 1 and lastly by progeny 3 seems to suggest that apart from the depressive effect of increasing shade on butt circumference in oil palm seedlings, the specific genetic make up of the progeny involved in the interaction may determine the extent of the reduction. Under full exposure progeny 1 produced the greatest butt circumference followed by progeny 3 lastly by progeny 2. Considering the percentage reduction in butt circumference with increasing shade from full exposure to 75% shade however, progeny 3 had the greatest reduction (45.4%) followed by progeny 1 (45.1%) and lastly by progeny 2 (32.3%). Progeny 2 therefore appears to be more stable in its performance under the three shade levels.

Butt circumference in oil palm seedling decreases with increasing shade level. Medium shade appears to be optimum shade level for oil palm seedling at the nursery for unimpaired growth in butt circumference. If water and nutrients are not limiting the input of solar energy sets the ultimate limit to photosynthesis and dry matter production by crops. With increasing shade the intensity of incident radiation diminishes and the photosynthetic system operates below capacity resulting in reduced photosynthesis. Since respiration is however unimpaired and uses up some of the photosynthates the net effect may be that fewer assimilates become available for growth such as increase in butt circumference. This finding is in agreement with the observation of Subronto and Taniputra (1979) who reported that oil palm seedlings grown in 17% and 33% light were the least vigorous and had reduced bole girth while those in 61% and 79% light intensity were the most vigorous in growth.

In the present study differences between 100% sunlight and 50% sunlight with regards to butt circumference was not significant, however significant differences existed between 100% sunlight and 25% sunlight and also between 50% and 25% sunlight. Shade up to a maximum of 50% full sunlight can therefore be supplied at the nursery during the dry season without adverse effect on butt circumference.

Significant shade x progeny interaction effects were also observed with regards to increase in stem dry weight at transplantable stage. Significant difference in stem dry weights were not detected in interactions involving the three progenies under a particular shade level but in interaction involving the progenies across the three shade levels, significant differences ($P<0.05$) were observed. In these interactions stem dry weight decreased with increasing shade irrespective of the progenies involved. While generally differences in stem dry weights in interactions involving 0% shade and 50% shade were not significant those in interactions involving 0% shade and 75% shade were significantly different ($P<0.05$). It is obvious from the results that in this interaction shade plays a more dominant role in determining stem dry weight and a shade level of between 0-50% would not adversely affect increase in stem diy weight in oil palm.

Increasing water supply within a particular shade level did not lead to significant differences in stem dry weight in shade x water interactions. Under 50% shade stem dry weight actually decreased as water supply was increased from 50% - 60% FC to 80-90% FC even though differences were not significant. Perhaps light intensity becomes the limiting factor to photosynthesis.

Omoti *et al.* (1987) using correlation and regression analysis established that water use was more highly and significantly correlated with solar radiation in oil palm. The observation that plants under "no shade" in combination with high water supply and those under "medium shade" in combination with low water supply are not statistically different from each other in stem dry weight but different from those under "heavy shade" in combination with high water supply is an important observation and means that the interaction between plants under "medium shade" with low watering and those under "no-shade" with high watering are comparable with regards to increase in stem dry weight. This implies that when water is hard to come by as occurs during the dry season, unimpaired growth can still be obtained by combining shading with reduced watering in the nursery.

Progeny x water interaction effects on stem dry weight and leaf dry weight were significant at 11 months after planting. Even though there seemed to be a pattern in progeny x water interaction effects on stem and leaf dry weight, it was not very clear and therefore difficult to explain. The three progenies produced essentially the same stem dry weight but in association with different water supply levels. When a particular progeny is considered across all the three water supply levels it is observed that increasing water supply does not always result in increase in stem dry weight. Thus in terms of stem dry weight, progeny 3 in association with the lowest water supply level (P3W1) appeared to be the best interaction followed by progeny 1 under medium water supply and progeny 2 under high water supply.

The associated dry weights were not significantly different from each other but considering the fact they were produced under different available moisture supply levels then the interaction involving the lowest moisture supply becomes important.

A similar pattern was observed with leaf dry weight but in this instance progeny 2 in combination with medium water supply produced the highest dry weight. These observations go to emphasise the assertion that even in just the three progenies used in this work considerable variation exist in their water use efficiencies.

There is therefore the need to incorporate a lot of progenies developed at OPRI in such studies in order to obtain as much information as possible about their individual characteristics.

Under the 0% shade (full sunlight) treatment, increasing the water supply led to an increase in leaf dry weight even though the differences were not significant. This indicates that when sunlight and other nutrients are adequately available water supply could limit photosynthesis and hence dry matter accumulation.

The interaction involving plants under “no shade” and the highest water level (S1W3) produced the highest leaf dry weight probably due to the combined effect of both water and sunlight in the initiation and differentiation of vegetative primordia in the apical meristems and the enlargement of the cells thus differentiated (Slatyer 1969). This might have resulted in the development of a photosynthetic system with both high capacity and efficiency.

Also sunlight and water are two very important requirements needed for photosynthesis. Their abundance in this particular interaction probably accounts for the associated high leaf dry weights. Under medium shade however the effect of interaction involving shade and the three water levels on leaf dry weight were the exact opposite of the observation made under the 0% shade level. Increasing water level led to a decrease in leaf dry weight. Perhaps below a critical light intensity then light may become limiting to photosynthesis. The situation under the heaviest shade level was not very well understood. Leaf dry weight dropped slightly with the application of medium water level (S_3W_2) but increased under high water level.

For all the water levels considered, leaf dry weight generally decreased as the level of shade increased and the lowest leaf dry weights were associated with shade x water interaction involving the highest shade level (75% shade). This indicates that shade is the major factor determining performance in this interaction and that in oil palm light intensity determines the efficiency of utilisation of available water for dry matter production. It is again pertinent to note that leaf dry weight produced under "medium shade" in combination with low water supply and "no shade" in combination with high water supply were not significantly different indicating that medium shade and low watering is equally as good as no shade with high watering.

Growth in terms of the increase in total weight of plant results mainly from the surplus of carbohydrate production by photosynthesis during daylight over that part of the carbohydrate so formed which is subsequently oxidised in respiration. Since incident light intensity is a major determinant of the photosynthetic rate coupled with the depressing effect of reduced light intensity on leaf production and leaf area expansion, it is not unexpected that shade application led to significant differences in root, stem, leaf and therefore total plant dry weights. Because of the generally low level of photosynthates produced under increasing shade level, the proportion of photosynthate available for vegetative growth after satisfying respiratory requirements will be lower still hence affecting the dry weight of the various plants parts. Root, stem and total plant dry weights decreased with increasing shade from 0% shade to 75% shade. Differences between the 0% shade and 50% shade treatments with respect to the dry weight of the above mentioned plant parts were however not significant. Between the 0% shade and 75% shade treatments however, the differences were significant ($P<0.05$). The application of some shade up to about 50% of full sunlight during the dry season will therefore not significantly reduce dry matter production of oil palm seedlings.

Several workers (Rees (1963b); Subronto *et al.* (1987); Subronto and Taniputra (1976); Hartley (1988) have reported similar findings on the effect of shade on dry matter production in oil palm.

Shade x progeny interactions affected RLAGR, LAI and CGR. It was observed both under 50% shade and 75% shade that RLAGR values were essentially the same for all the three progenies. Under "no shade" however, progeny 3 was not different from progeny 1 but it was significantly higher in RLAGR than progeny 2. Across the three shade levels it was observed that for progenies 1 and 2 increasing shade led to a reduction in relative leaf area growth rates indicating that shade plays a dominant role in this interaction. The situation with progeny 2 however was the opposite in that increasing shade resulted in increasing relative leaf area growth rate. This observation is difficult to explain since reducing light intensity has been generally found to result in reduced expansion in leaf area through its negative effect on cell differentiation and expansion.

The highest LAI (3.4) recorded under shade x progeny interaction involved progeny 3 under "no shade" and the least LAI (2.0) was observed in progeny 3 under heavy shade The greatest leaf area was recorded by progeny 3 in the 8th month after planting. Under shade x progeny interaction too, progeny 3 in association with “no shade” produced the greatest leaf area in the 8th, 9th and 11th months after planting. This seems to indicate that generally progeny 3 was better in terms of growth in leaf area. It was observed that increasing shade had a depressive effect on LAI and that the highest value of 3.1 was obtained under full sunlight and the lowest of 2.1 under 25% full sunlight. Again when the influence of progeny on LAI is considered, it was observed that progeny 3 and 1 had the highest LAI of 2.7 and 2.8 respectively with progeny 2 having the lowest LAI of 2.4.

When shade x progeny interactions on LAI were considered, generally higher values of LAI were observed than in the separate cases above. In this instance the highest LAI value of 3.4 was observed under full sunlight involving progeny 3. Also under "medium shade" (i.e. 50% sunlight) progeny 1 had a LAI of 2.9 which was higher than the LAI value of 2.7 observed under shade level 2 above.

The interactions between shade and progeny seems to increase LAI in the regime near full sunlight though with increasing shade a reduction in LAI occurs. This has not been recorded in the literature. Thus even though shade leads to reduced growth in oil palm in general, certain progenies have the inherent ability to interact better with shade than others leading to comparable performance with those grown in full light.

No clear trend was established under the influence of progeny x water interaction on leaf area index. This seems to point to the existence in these progenies of different efficiencies in utilising available water for leaf area expansion and growth in general.

Crop growth rate (CGR) was affected by shade x progeny interactions at transplantable stage. Within a particular shade level, differences in progenies did not lead to a significant effect on CGR however across the three shade regimes it was observed that crop growth rates declined as light intensity reduced for all the three progenies and that for progenies 2 and 3 in particular CGRs associated with "no shade" were significantly higher than those for medium and heavy shade. No such differences were observed for progeny 2 which seemed to be more stable over the 3 shade levels.

Progeny 2 under "no shade" produced the highest CGR while the same progeny under heavy shade produced the lowest. The influence of reducing light intensity on net photosynthesis is probably being demonstrated here.

Even though in this study both shade and water did not significantly affect NAR, the interaction between shade and water led to significant differences ($P<0.05$) in NAR. Rees (1963a) in his work on growth of oil palm seedling in full sunlight and in shade reported that except at the lowest light level used (11.1% full daylight) there was very little effect of light on NAR. Under full sunlight increasing water supply led to increasing NAR with the highest NAR being achieved in plants under "no shade" in combination with high soil moisture supply. Perhaps in full sunlight photosynthesis is limited by water supply. Omoti *et al.* (1987) reported water use in oil palm to be highly and significantly correlated with solar radiation.

Hardon *et al.* (1969) attributed the differences in total dry matter production in oil palm between the Malayan and West African environment to the absence of long annual period of overcast weather and the better distributed annual rainfall in southern Malaysian leading to a substantial increase in the efficiency of utilisation of available light for photosynthesis. Other workers have also found that NAR was depressed by reduction in water supply (Tiver 1942; Petrie, Arthur and Wood 1943; Tiver and Williams; 1943; Morton and Watson 1948).

Under "medium shade" the highest NAR value was obtained in combination with medium water level. The interaction between medium shade and high water supply resulted in a drop in NAR, probably light became limiting.

The NAR value associated with medium shade in combination with medium water supply (0.423) was not significantly different from the highest NAR value 0.483 obtained in plants under "no shade" in association with high water supply. This shows that in terms of NAR 50% shade in combination with reduced watering (65-75% FC) is comparable to that obtained in full sunlight with high watering (80-90% FC). The lowest NAR value was obtained in plants under "heavy shade" in combination with low water supply interaction and this is not unexpected since both reduced light intensity and moisture supply is known to adversely affect NAR.

Shade level had significant effects on relative growth rate (RGR), leaf area index (LAI) and crop growth rate (CGR) at transplanting stage. Increasing shade (reducing light intensity) led to declining values for all the three growth parameters mentioned above. For RGR plants under "no shade and medium shade" produced significantly ($P<0.05$) higher rates than those under "heavy shade". For LAI and CGR seedlings under "no shade" produced significantly higher values than those under 75% shade but not different from plants under 50%shade.

Relative growth rate is the increase in plant material per unit of material per unit of time. RGR is affected by environmental factors. Hunt (1978) has indicated that in general any departure from adequate supply of light, mineral nutrients, water, suitable temperature regime or from freedom from external toxins will produce an adverse effect on RGR. From the above it is expected that increasing shade resulted in decreasing RGR values. Also this observation is in agreement with the finding of Rees (1963a) who observed a reduction in RGR with increasing shade in oil palm seedlings at the nursery. Wormer (1958) observed that relative growth rate in the oil palm followed the same trend as daily hours of sunshine. Blackman and Wilson (1951) also demonstrated the dependence of RGR upon the level of illumination received in several crops. Oil palm can therefore tolerate a maximum of 50% shade in the nursery without a reduction in relative growth rate.

Leaf area index (LAI) defined as leaf area per unit area of land describes the functional size of the crop standing on the land area. The observed drop in leaf area index with increasing shade or reducing light is in line with the observation of Hardon *et al.* (1969) who attributed the differences in optimal leaf area index in oil palm between the Malayan and West African environments to the amount of useful sunlight received in these two regimes.

The effect of light in inducing and stimulating differentiation of vegetative primordia in apical meristems and cell enlargement in leaf tissues could be responsible for the observed drop in LAI with reducing light. The phenomenon has also been observed by other workers in other crops (Milthorpe, 1945) in flax; Gregory (1921) in cucumber and Black (1963) in subterranean clover).

In this study at the nursery the highest leaf area index observed was 3.1 for the plants grown in full sunlight this is in agreement with the optimal LAI of 3.0 reported by Rees (1963a) in oil palm seedlings in Nigeria but lower than the LAI of 5 reported by Rees (1962) to be the optimum (i.e. self maintaining) in West Africa at 8 years after planting. This supports the claims that leaf area increases with age up to a plateau about 8 years after planting.

Crop growth rate (CGR) also declined with increasing shade level from full sunlight to 25% full sunlight. CGR is the increase in dry weight per unit land area per unit time and depends on the rate of dry matter increase per unit leaf area or NAR which is a measure of the efficiency of the photosynthetic system, and on the area of green leaf per unit land area usually referred to as the leaf area index (LAI).

The NAR of a crop canopy is positively correlated with light intensity up to full sunlight and the rate of dry matter production per unit leaf area is mainly determined by the radiation income (Webster and Wilson 1980). CGR therefore depends on LAI and NAR and since these two parameters are positively correlated with light intensity it follows therefore that decreasing light intensity will result in decreasing crop growth rate as was observed in this study. Corley (1973) observed that high light penetration through the oil palm canopy led to a maximum CGR through its effect on LAI.

In all these three growth parameters being discussed (RGR, LAI, and CGR) it is important to note that shade level of up to 50% of full sunlight at the nursery did not cause significant adverse effects on the growth of the oil palm seedlings. 75% shade (i.e. 25% full sunlight) however resulted in significantly ($P<0.05$) lower growth rates. Significant differences ($P<0.05$) in values for NAR, RGR, LAR and LAI due to the influence of progeny were observed at 11 months after planting.

Progeny 2 and 3 had similar NAR and RGR values, which were significantly higher than those for progeny 1. For leaf area ratio (LAR) the opposite was observed. Progeny 1 had significantly higher value than progenies 2 and 3 which were not different.

LAI values for progeny 3 and progeny 1 were different from that for progeny 2. Between progeny 1 and progeny 2 no differences occurred.

Hardon *et al.* (1972) also found significant differences in NAR between some oil palm families. Small but significant differences in NAR have also been found between varieties of potatoes, and high-sugar content strains of sugar beets appear to have a greater NAR than strains bred for high yield Watson (1947a). Goodall (1950) reported differences in NAR in cocoa seedlings from the progeny of four trees.

The influence of progeny on RGR has also been observed in other crops by other workers. Hunt (1978) reported that in a study on seven local collections of *Holcus lanatus* (Yorkshire fog) and five of *Fistula orina* (sheep's fescue) differences in RGR between collections of the same species were slight but occasionally significant ($P<0.05$). RGR is the product of NAR and leaf area ratio (LAR) and since these components have been demonstrated to be influenced by progeny effects it is not unexpected that RGR differed with progeny in this work.

Leaf area ratio (LAR) is the ratio of total leaf area to whole plant dry weight and in the broadsense represents the ratio of photosynthesising to respiring material within the plant. Since the components of the plant photosynthetic system comprise the number of leaves and size of leaves (i.e. area) and it has been demonstrated that in oil palm these are all influenced by progeny it follows that LAR will also be influenced by progeny.

The association of high NAR with low LAI (progeny 2) and vice verse in progeny 1 in this work, was also observed by Rees (1963) in oil palm seedlings grown in full sunlight.

Net assimilation rate is often negatively correlated with LAI (Watson, 1958) presumably because mutual shading increases as LAI increases.

Asafu-Agyei (1973) observed significant differences between progenies for number of leaflets leaf length and leaf area in oil palm.

LAI was significantly influenced by progeny in this work. Progeny 3 and progeny 1 had higher LAI than progeny 2. This is not surprising since progeny 3 had a significantly higher leaf area than the other 2 progenies. Probably progeny 1 also made some improvements in leaf area getting to the end of the study even though this was not established.

Asafu-Agyei (1973) observed similar progeny differences with respect to LAI in oil palm. Hardon *at al.(*1969) also observed significant differences in LAI in a number of progenies of palms growing in West Malaysia.

5.2: Genotypic and phenotypic variability and heritability of growth parameters among oil palm progenies

A wide range of variation was found in the plant growth parameters studied as indicated by their phenotypic and genotypic coefficients of variation. Leaf number per plant, plant height and butt circumference generally had lower phenotypic and genotypic coefficients of variations while NAR, LAR, LAI and CGR had higher values of approximately 50-80%. Leaf area and RGR had values below 40%. In terms of plant biomass, total plant dry weight had the highest phenotypic and genotypic coefficient of variation, which ranged from 67.66% to 54.91% respectively.

This range of overall variations in the parameters studied is quiet encouraging since for any improvement and selection in any desired character to be possible, there should be the existence of a wide range of variability in the population for that character.

The low level of variation in some of the characters (root, leaf and stem dry weight as well as leaf number, leaf area, plant height, butt circumference and RLAGR) suggest little potential for their improvement through selection.

An examination of the broadsense heritability estimates of the characters reveal that generally for those characters with low variability, their heritability (broadsense) estimates were also low. In particular leaf number per plant, plant height; RLAGR stem and leaf dry weights had heritability estimates below 20% suggesting large environmental influence on these characters. It also suggests difficulty in controlling the environmental influences and reducing it so that genetic effects can be effectively isolated.

While butt circumference and leaf area per plant had broadsense heritabilty estimates of about 27% and 33% respectively, root dry weight, total plant dry weight, CGR LAI, LAR RGR and NAR had heritabilty estimates above 50% with most of them above 65% and a few (RGR NAR and LAI) between 80% and 91% indicating high genetic control over their expression and the opportunity to select for desired level of expression.

Hardon *et al.* (1972) however observed a low genetic component of variation in NAR (though significant differences between families were found) in oil palm and suggested that improvenmet in yield through selection for high NAR may not be very rewarding. This is because in mature palms NAR is affected by many different factors. During seedling growth in the relatively uniform nursery environment it appears probable that differences in NAR will indicate real differences in photosynthetic rate. Thus NAR could also be considered as a seedling selection criterion.

In this work the highest heritabilty estimates (Broadsense) was obtained in LAR (91%) but it was found to be negatively and significantly correlated with all the other important growth parameters as well as with crop growth rate. Hardon *et al.* (1972) again showed that selection for LAR in oil palm might not be very successful. Breure and Corley (1983) also reported that selection for high LAR in giving palms capable of yielding well at high density was not effective. Wilson and Cooper (1970a) found LAR and NAR of iyegrass(*Lolium perenne*) and *L. multiflorum)* selections to be negatively correlated minimising effectiveness of selection for either factor.

In the light of the fore going discussion, leaf area per plant, leaf area index (LAI), total plant dry weight and crop growth rate (CGR) may be better nursery selection indices for predicting performance and subsequent yield in the field in oil palm. The use of NAR may be important in identifying palms that have some advantages in growth, which results in more rapid early development in the field.

5.3 Correlation of growth parameters in oil palm progenies

With the exception of leaf area ratio (LAR) all the characters studied were highly and positively ($P>0.01$) correlated with each other. All these characters were also highly significantly and positively correlated with crop growth rate. The highest degree of association was found between total plant dry weight and crop growth rate ($r^2 = 0.90$) followed by that between leaf area and plant height ($r^2 = 0.81$)

Several workers have also found significant correlation between vegetative characters of oil palm in the nursery and yield. Subronto *et al.* (1989) in a study on nursery seedlings of oil palm showed that on several crosses the butt diameter and leaf area could be used as selection criteria in 9 month old seedlings since these were highly correlated with yield. Tan and Hardon (1976) reported that leaf area in the nursery was positively correlated with crop growth rate, mean leaf area and total plant dry weight, leaf area was also significantly correlated with leaf area index, bunch yield and bunch number. This work supports most of these findings.

Obasola (1970) reported significant correlation between progeny means for leaf dry weight in the nursery and mean bunch weight during the second to fifth years of production. Height in the nursery was also correlated with yield in the first two years of production and with mean bunch weight in the fifth year of production. Hardon *et al.* (1969) and Corley *et al.* (1971) also reported significant correlation between yield and leaf area index in oil palm.

In this work leaf area was observed to be strongly correlated with plant height and agrees with the observations of Hardon *et al.* (1969). This may be due to the fact that taller plants are not mutually shaded by other plants and receive maximum sunlight and hence benefit more from the effect of light in leaf expansion through increased cell differentiation and extension and the stimulation of differentiation of vegetative promordia in apical meristems.

Corley (1973) observed that NAR was negatively correlated with LAI. In this work even though the association was not negative it was low and insignificant. Increasing leaf area index results in mutual shading which ultimately reduces NAR.

An interesting observation is the negative correlation between LAR and all the parameters compared except total plant fresh weight and LAI with which its association was not significant. The probable explanation for this observation may be due to the fact that an increase in any of the other parameters is associated with increased plant dry weight which far exceeds the proportionate increase in accompanying leaf area hence causing the ratio to reduce. Selection for high LAI therefore may result in a reduction in all the other characters.

Yield in relation to seedling development at the nursery has been considered by Devuyst (1954) and Spamaaij (1955). The former drew attention to a relationship between leaf number and plant height in the nursery as a selection criteria for increased yield in later years. Spamaaij (1955) however criticised this approach, and showed that most of the nursery variation was not genetic in origin. From simple correlation coefficients calculated between seedling characters and characters measured on the palm in the field, Tan and Hardon (1976) observed that most characters at the pre-nursery stage were not significantly correlated with palm performance in the field, however the leaf characters measured at the later main nursery stage were found to be significantly correlated with many of the characters of mature palms. Nursery selection based on leaf characters such as leaf area, leaflet length, leaflet width and number of leaflets per leaf could therefore result in higher growth rates in the field and yields

The extent to which a desirable character can be improved depends on the variation within the population, so it is important to examine the traits which are positively correlated with crop growth rate and high total dry matter accumulation in terms of their heritabilities and variability before their possible use in selection can be considered.

6.0 CONCLUSION

Even though it has been determined that shade generally reduces growth in oil palm and this was confirmed in this study it was adequately established that moderate shade giving a relative light intensity of up 50% of full sunlight did not adversely affect the seedling growth and performance of oil palm progenies studied. Also the growth of oil palm seedlings under the combination of 50% full sunlight and reduced watering of 3.5-4 litres per seedling per week compared well with that of oil palm seedlings grown under full sunlight with 4.5 or more litres of water per seedling per week.

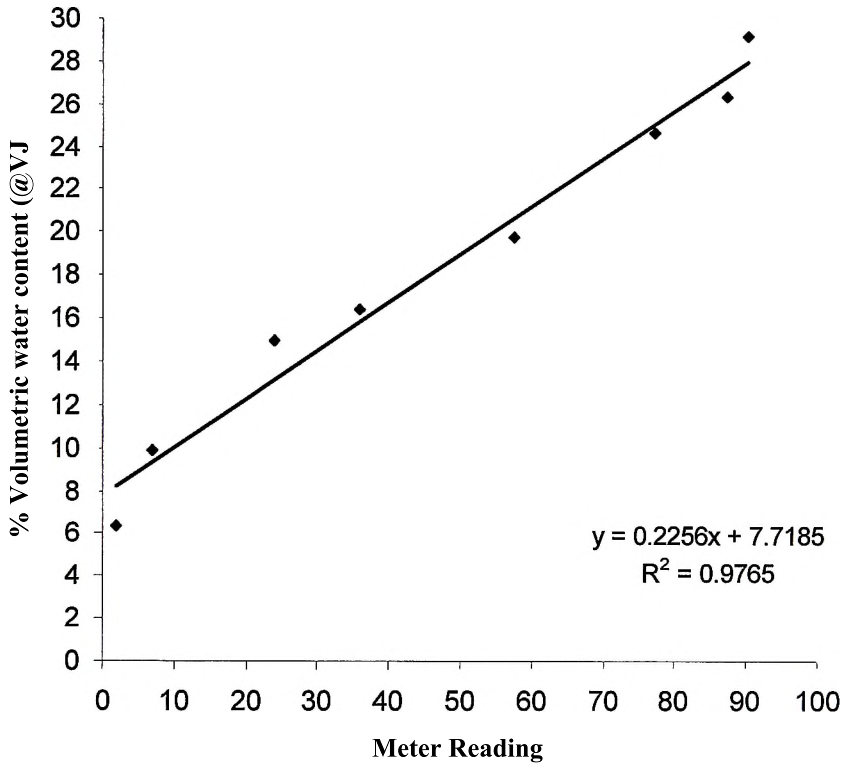
Of the three progenies studied, progeny 1 (Pi) seemed to be the best followed by progeny 3 (P3) in terms of the general considerations of the parameters studied.

Some of the interactions studied seem to suggest that different progenies have different inherent efficiencies with which they utilise resources such as water for dry matter production and growth.

There was large variability present in some of the growth parameters studied. Also their associated broadsense heritabilty estimates were high and these characters were positively correlated with yield. For purposes of nursery selection, where high growth rate is required for initial high field performance and subsequent high yields, LAI, total plant dry weight, CGR and NAR may be indices worth considering.

7.0 APPENDIX

7.1 Calibration of moisture meter


Calibration of moisture meter

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