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GERMINATION AND SEEDLING GROWTH OF *Gmelina arborea* ROXB.

by

NG LEONG-HAI

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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ABSTRACT

Gmelina arborea Roxb. is a forest tree species naturally distributed in the tropical and subtropical regions of Asia. Three seed sources were flown to Canada from Muak-Lek (Thailand), Sabah and Perak (Malaysia). *Gmelina arborea* is indigenous to Thailand but is an exotic in Sabah and Perak. The seed sources were used in a germination test under different temperature treatments and a seedling growth test under different light treatments. The objectives were to determine the optimum temperature for seed germination and light quality for seedling growth.

Nut sizes from the three sources were compared. The Perak and Sabah sources were significantly larger than the Thai source but the difference did not affect germination performance. The optimum constant temperature for germination using extracted seeds was found to be about 30°C. No germination was obtained at constant temperature below 18°C and seeds exposed to temperatures above 41.5°C were all dead after 14 days. No significant differences were found in germination performance among sources from Perak, Sabah and Thailand.

There were no significant differences in root-shoot ratios, root collar diameters, relative growth rates and net assimilation rates among test seedlings under different light treatments over the 60-day period. Nevertheless, indications of widening divergence were observed in all indices particularly after 48 days of growth. Significant

differences were obtained at certain intervals in shoot height, total dry weight and total leaf area among plants under different light treatments. Among the five lamp combinations, the 3SON light (3 sodium lamps), was most suitable for seedling growth up to 60 days. The SM61 light (1 sodium lamp, 1 mercury lamp and 6 incandescent bulbs), gave rise to the poorest seedling growth. Both Sabah and Perak sources indicated similar growth performances and also produced larger overall seedlings than the Thai source.

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☺☺☺☺☺

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1. INTRODUCTION

1.1 BACKGROUND OF *Gmelina arborea* Roxb.

1.1.1 GENUS AND FAMILY

Gmelina arborea Roxb. is a deciduous forest tree of medium to large size. It belongs to the same family as teak *Tectona grandis* Linn., Verbenaceae. It is sometimes regarded as 'white teak' in India because of its close resemblance in wood properties to teak (Nagle 1936). *Gmelina arborea* has common names like gamhar(Hindi), gumadi(Tamil), Yemani(Burmese) and is sometimes referred to by its generic name alone. The specific name for this species could either be cited for Roxburgh or Linneaus (Greaves 1981). The genus Gmelina is large and consists of about 45 species and subspecific taxa distributed naturally in tropical to subtropical Asia.

1.1.2 ECOLOGY AND DISTRIBUTION

Gmelina arborea has a wide distribution found naturally in Sri Lanka, India, Burma, Thailand, Vietnam and Southern China (Troup 1921, Chung 1971). Corner (1952) stated correctly that *Gmelina arborea* does not occur naturally in Malaysia, Indonesia, the Philippines and Australia but Rodger (1913) and Dassanayake and Fosberg (1980) reported otherwise. In its natural range, the minimum air temperature varies from -1°C to 16°C and the maximum temperature from

38°C to 48°C. Mean annual rainfall varies from 760 mm to 4500 mm (Streets 1962). This species has a strong preference for moist, fertile, freely-drained soil and is shade intolerant (Durant 1941). Compared with most other species encountered in the natural forests, it is a relatively short-lived tree (30-50 years) and is usually found colonizing ruderal areas (Greaves 1981). It is also intolerant of weed-competition, especially in early stages of development and on waterlogged-soil (Dawkin 1919, Durant 1941). Because of its ecological characteristics, *Gmelina arborea* is seldom found growing gregariously in natural forests (Troup 1921, Brandis 1972). In natural and mature stands, it is most frequently found with an average girth of 2 meters and a clear bole of 9 meters (Rodger 1913).

Flowers are large, yellow and zygomorphic and are borne in terminal racemiform thyrses (inflorescences). The flower is dioecous; one study suggested that self-pollination was unlikely to occur naturally because of the floral structure (Okoro 1978). Bowen and Eusebio (1982) studied controlled cross-pollination on grafted clonal stock and were able to produce full-sized fruits but did not test seed viability. In another study of pollination and breeding systems of cultivated *Gmelina arborea* in Costa Rica, the species was found to be self-incompatible (Bolstad and Bawa 1982). Flowering begins early, from age 3 to 7 depending on site and weather conditions. For mature trees, flowering could be observed throughout the year but with certain peak seasons

which vary yearly depending on weather conditions. Fruit maturation occurs about 45 to 48 days after pollination (Okoro 1978, Bowen and Eusebio 1982).

1.1.3 USES AND POTENTIAL

Gmelina arborea has been introduced to at least 35 tropical and subtropical countries for plantation purposes or on a trial basis (Greaves 1981). It grows rapidly and has wide adaptability. This species was planted in plantations as early as in 1879 in Kaptai, Bangladesh (Ghuznavi 1935) and also in upper Burma together with teak (Dawkin 1919). Early results were not very successful due to poor management and pest problems (Allsop 1945).

Nevertheless, this species showed great potential and was later introduced from Burma and India to many countries outside its natural range including Malaya in 1920 (Durant 1941, Pringle 1950). Other countries that have established plantations with this species include Nigeria, Philippines, Malaysia, India, Brazil, Malawi, Sierra Leone, Ivory Coast and Indonesia (Palmer 1973, Evans 1982). The Food and Agriculture Organisation of the United Nations is the major body providing technical as well as scientific aid to most of these countries in promoting trials and plantation establishment (Bowen and Eusebio 1982).

In an early report on *Gmelina arborea* by Balfoure (1970), the tree was reportedly found throughout India, Sri Lanka and Burma but the wood was scarce and expensive

because of its wide range of uses including medicinal. The wood has an average density of 481 kg/m³ at 12% moisture content (Nagle 1936). It has a smooth finish, good durability, high dimensional stability and has been used for panelling, poles, furniture and decking (Pearson and Brown 1932). The wood has been reported to be strong and does not warp or crack under water (Gamble 1922 , Roxburgh 1832).

The wood has typical hardwood fibre length and has been tested and found suitable for pulping (Peh 1964, Palmer 1973, Chinte 1971). Indeed, *Gmelina arborea* has been used as a source of raw material to supplement long-fibre material in the Philippines since 1976 (Eleazar pers. comm. 1985), in the Jari project, Brazil since 1979 (Nordin and Bolduc 1980) and in Nigeria (Okoro 1984). The species had also been found suitable for match-making and veneer production (Nagle 1936, Lee 1964) and for particleboard and plywood production (Nordin and Bolduc 1980).

Growth in the first 10 years is extremely rapid on fairly fertile and moist sites. This potential has given *Gmelina arborea* an important economic edge over many other species. Greaves (1973) reported that current annual increment (CAI) culminated between years 6 to 9 and mean annual increment (MAI) between years 11 to 15. In the Philippines, total yield was estimated to be 108 m³/ha with a MAI of 36 m³/ha by year three (Chinte 1971). A study in Malaysia showed that total yield was about 259 m³/ha between years 7 to 9 and that MAI was between 28 and 35 m³/ha

(Freezaillah & Sandrasegaran 1966). In Sierra Leone, Fox(1967) suggested that *Gmelina arborea* could reach 165 cm girth in 15 years and between 180 cm and 210 cm in 20 or more years. The average height growth reported at Jari, Brazil at 6-7 years was 22 meters and at 10 years it was close to 30 meters tall (Kalish 1979) The rapid growth of *Gmelina arborea* makes it possible to grow and manage it on a rotation of 10 to 15 years.

There is little problem with seed supply in this species because fruiting is regular and abundant. Fruit production begins at different ages depending on sites and climate. In the Philippines, fruit production begins at age 3 (Chinte 1971), at age 5 in Jari, Brazil (Woessner and McNabb 1979) and at age 7 in Nigeria (Pringle 1950). In Brazil, mature fruits are produced for a period of nine months in a year but peak production is in January and February (Woessner and McNabb 1979). In Perak, Malaysia, fruit production may be found throughout the year but peak production is in January (Yap and Wong 1983). In Nigeria and Sabah it was reported that there are two peak fruit production seasons which vary with weather conditions (Okoro 1978, Bowen and Eusebio 1983).

The fruit is a drupe consisting of a hard stony endocarp enclosed by a fleshy mesocarp and a leathery exocarp. Processing involves depulping, cleaning and drying. The depulped fruit is a stone(nut) containing 1 to 4 seeds depending on source (Bowen and Eusebio 1982). Processed stones with 8-10% moisture content can be stored well at 5°C for 1 to 2 years without losing significant seed viability (Yap and Wong 1983). Bonner (1983) classified *Gmelina arborea* seeds as orthodox bedause they could be stored for many years at low temperatures. Seedlings are easy to handle in nurseries and are not sensitive to transplanting. Field planting can be carried out using regular seedlings, stumped seedlings or stem cuttings (Kalish 1979, Zakaria and Ong 1982, Darus 1984).

1.2 OBJECTIVES OF STUDIES

The first part of this thesis is devoted to an investigation of the germination of *Gmelina arborea* seeds under different temperatures. Constant temperatures were used because the germination chamber was only capable of producing constant temperatures during each testing. The second part is devoted to an investigation of seedling growth under different light qualities. These two areas of study were initiated because there were limited research and information on them (Greaves 1981).

The objectives of the study on germination were:

1. To determine whether seed and nut sizes affect germination performance.
2. To determine the optimum and range of constant temperatures under which *Gmelina arborea* seeds can germinate.
3. To determine whether there is any difference in germination performance among seed sources from Sabah and Perak in Malaysia and Muak Lek in Thailand.

The objectives of the study on seedling growth under different light qualities were:

1. To determine the effects of different light qualities on seedling growth.
2. To determine the light quality most suitable for seedling production for outplanting.

3. To determine if there is any difference in growth performance among the sources from Sabah, Perak and Thailand.

Both studies in this thesis should provide useful information for seed germination and production of better seedlings than what is possible today by using only common sense and local experience . This information should help to make it possible to be more efficient in the use of available seed resources. It should also make it possible to design specific treatments and growing conditions suitable for the production of stocks for variable outplanting sites in term of soil conditions and air temperatures.

2. OVERVIEW

2.1 GERMINATION OF *Gmelina arborea*

2.1.1 THE FRUIT, NUT AND SEED

The success of a reforestation program depends on many factors of which seedling production is a vital one. Seedlings which have high vigor and a good potential to grow and establish quickly are desired in plantation establishment. The production of 'desired' seedlings is very much dependent on the quality of seeds and the conditions under which the seeds are collected, cleaned, dried and stored. It also depends on the conditions of germination and the development of the seedlings before outplanting.

The size of *Gmelina arborea* fruit varies within and among trees. The fruit is rounded and the average diameter ranges from 2.0 to 2.5 cm in diameter (Greaves 1981). Immature fruits are green in color, turn yellowish on maturing and eventually turn from brown to black prior to fermentation (Aminuddin and Zakaria 1980). The stony endocarp with seeds enclosed is called the 'nut' in this thesis. Each nut is ovoid in shape and has 4 chambers. Each chamber may or may not contain a seed. The chambers are located on the lateral sides of the nut and each chamber has a protective flap which opens and drops off during seed germination and emergence. The seed is ovoid in shape and flattened. Table 1 shows the average size of nuts and seeds

from plantations in Sabah from a variety of provenances. The data show that larger nuts tend to produce larger seeds. Figure 1 illustrates the cross-section of the fruit and nut structure of *Gmelina arborea*. Each nut has four flaps on the sides and a vertical cavity in the centre.

Table 1. Mean dimensions of nut and seed of *Gmelina arborea* planted in Sabah from different origins (Source: Bowen 1980).

Provenance	Nut Length (mm)	Nut Diameter (mm)	Seed Length (mm)	Seed Width (mm)
Philippines	16.6	9.7	7.6	3.8
Bangladesh	18.1	12.3	9.3	5.3
Nigeria(Sibuga)	15.8	8.6	6.5	3.3
Nigeria(Enugu)	16.4	10.4	8.4	4.2

Germination percentage of *Gmelina arborea* varies from one source to another. One factor which determines the percentage is the number of seeds per nut (Table 2). The results show that there is a wide variation in the mean number of seeds per nut. Sources from India had almost 60% empty nuts compared to 20% from Nigerian sources (Omoyiola 1974). The highest average seed yield per nut, obtained from a Nigerian source (location not mentioned), was 2.7 seeds (Bowen 1980). All sources suggest that nuts commonly contain one or more seeds per nut. Reasons for why seed production per nut is so low have apparently not been studied but yield depends on both environmental and genetic factors. With equitable environments and select sources, seed yields can

be increased significantly over native or introduced populations. Because *Gmelina arborea* is self-incompatible (Bolstad and Bawa 1982), cross-fertility is necessary for seed production and plantation spacing may be an important factor to control. Fruits are commonly eaten by cattle in Thailand.

Table 8. Distribution of seeds per nut (percent) and mean number of seeds per nut from various sources of *Gmelina arborea*.

No.	Sources	Dist. of Seeds/Nut 0	1	2	3	4	Seeds/Nut Means
1	Perak, Malaysia	0	23.2	44.0	20.4	12.4	2.2
2	Jari, Brazil	0	31.0	43.0	20.0	6.0	2.0
3	Nigeria(Arboretum)	18.8	46.4	15.3	16.7	2.8	1.4
4	Nigeria(Cpt.1294)	18.9	48.6	17.6	14.2	0.7	1.3
5	India(And.Pradesh)	60.5	23.8	14.1	1.6	0	0.6
6	India(Dehra Dun)	57.6	41.4	0.5	0.5	0	0.4
7	Sabah(fr.Philippines)	-	-	-	-	-	1.6
8	Sabah(fr.Bangladesh)	-	-	-	-	-	1.5
9	Sabah(fr. Nigeria)	-	-	-	-	-	1.6
10	Nigeria	-	-	-	-	-	2.7
11	Bangladesh	-	-	-	-	-	1.3
12	Gambia	-	-	-	-	-	2.1

(Sources: 1:Yap and Wong 1983, 2:Woessner and McNabb 1979, 3-6:Omoyiola 1974, 7-12:Bowen 1980.)

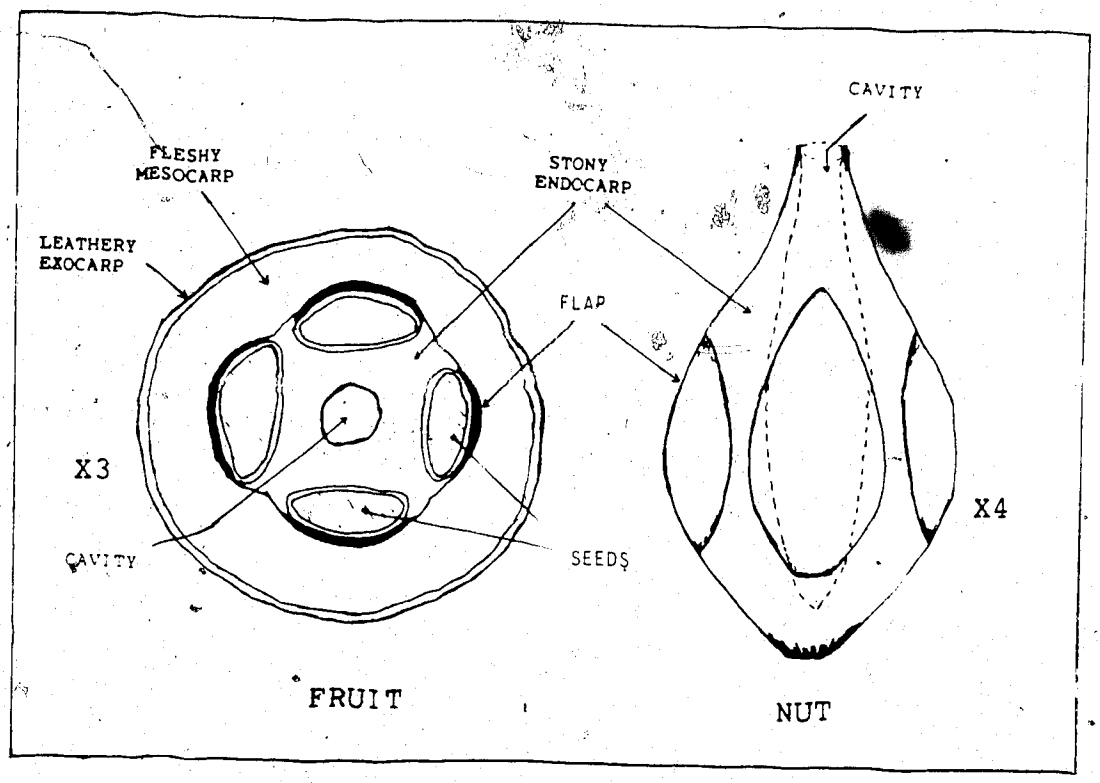

Figure 1. Cross section of *Gmelina arborea* Roxb. fruit and structure of nut. (Drawing by L.H. Ng)

2.1.2 GERMINATION OF NUT AND SEED

The germination process is influenced by a number of internal and external factors. Light, temperature, oxygen and water are among the most important external factors governing germination rate. These factors initiate a series of morphological changes that transform an embryo(seed) into a seedling. In short, the process of germination may be divided into five series of events: i) imbibition of water; ii) hydration and biochemical activation; iii) cell division and cell extension; iv) emergence of embryo from the seed; and v) the completion of nonrepetitive morphogenesis-the establishment of the primary body (Berlyn 1972). Germination studies on *Gmelina arborea* are few and limited. Most studies were carried out to determine the best stage for fruit collection, the best nut size to use, the drying temperature and the storage condition. No one appears to have studied light, temperature or water tension effects on rates of germination or total germination (Greaves 1981).

The number of seeds per nut and the size of seeds have economic and physiologic importance. Woessner and McNabb (1979) and Okoro (1984) showed that larger size nuts contained more seeds than smaller ones (Table 3). This is probably due to more favorable conditions where larger size nuts are produced which subsequently allow more seeds to develop. The results also show that larger nuts tend to produce more germinants probably because of the higher number of seeds per nut as well as having larger seeds.

Table 3. Number of seeds per nut and germination (percent) by nut size classes for *Gmelina arborea*.

No.	Class	Mean wt. per nut (g)	Mean no. seed/nut	Germination (Total%)[1]	Germination (Actual%)[2]
1	Large	1.367	2.2	117	53
2	Medium	1.073	1.7	40	24
3	Small	0.791	1.2	28	23
4	Large	1.379	-	111	-
5	Med.large	0.840	-	98	-
6	Med.small	0.582	-	87	-
7	Small	0.442	-	84	-

(Sources: 1-3:Okoro 1984, 4-7:Woessner and McNabb 1979)
([1]Total % = total germinants divided by no. of nuts)
([2]Actual % = total germinants divided by actual no. of seeds)

Fruit maturity also affects germination percentage. It has been shown that seeds from green to yellow fruits germinated best and seeds from brown to black fruits germinated poorly (Woessner and McNabb 1979, Aminuddin and Zakaria 1980, Bowen 1980). As the fruit ripens, the thick fleshy mesocarp layer starts to rot, probably a fermentation process. No one appears to have studied how the changes deteriorate the quality and viability of the seeds in the nuts. Wasuwanich (1984) showed that depulped fruits (without mesocarp or exocarp layer) produced seeds with much higher total germination than did fruits which were not depulped regardless of fruit condition. Table 4 shows the results of germination percentage for seed from different stages of fruit maturation as indicated by fruit color. It is suspected that by the time the fruits turn black on the ground, they have already experienced many hours of +50°C and certainly longer exposure than the yellow or green

fruits (Hellum pers. comm. 1985). Such high temperature exposure and duration are detrimental to seed quality and this subsequently reduces germination. The build-up of heat is probably due to the fermentation process and the greater absorption of heat from the sun by the black color of the fruits.

Table 4. Germination of *Gmelina arborea* from fruits collected from the ground.

Color	(a)Germination %	(b)Germination %
Green	91.6	93
Yellow-green	94.6	118
Yellow	91.9	122
Brown	52.6	88
Brown-black	-	48

(Sources: (a)Aminuddin and Zakaria 1980, (b)Woessner and McNabb 1979)

In a study of storage and its relationship to germination percent, Woessner and McNabb (1979) found that nuts kept at 5 to 10% relative humidity at 5°C only lost about 5 percent of their germination for every 12 months up to two years. In another report, germination dropped by 10 to 50% for four batches of nuts when stored at 10% moisture content and at 4 to 8°C over a 12 month period (Yap and Wong 1983). Fruits collected and kept in plastic or gunny bags produced almost no germination after 4 to 8 days (Wasuwanich 1984). In a study of drying conditions, nuts dried at 50 to 60°C over a period of 4 hours to about 10% moisture content yielded a germination percent of about 90% (Woessner and McNabb 1979). Bowen (1980) used warm air at 45°C for 17

hours to reduce moisture content to about 8 percent for best germination. In fact drying before seeding was recommended to obtain best germination (Wasuwanich 1984). It appears that seed viability depends greatly on temperature and duration of exposure. To maintain high viability of seeds, processed nuts must be stored at low temperatures (between 0 to 5°C) and at moisture contents less than 10%.

Some seeds also require after-ripening period to germinate well or some kind of pre-treatment to stimulate or promote germination. It was found in one study that soaking at 25°C for 17 hours followed by drying at 45°C for 7 hours yielded about 88 percent germination (Bowen 1980). The moisture content after drying for 7 hours was not determined. In the same study by Bowen (1980) and that of Wasuwanich (1984), stored nuts were also found to produce more germinants than fresh nuts. But Yap and Wong (1983) and Darus (1984) found that freshly collected and cleaned nuts gave rise to better results compared to stored nuts. Results are not consistent as to whether stored or freshly processed nuts produce more germinants.

Temperature is an important factor influencing seed germination because it affects its biochemical activities. The ability of seeds to respond to a wide range of temperatures will very much influence the distribution and survival of that species in nature (Thompson 1970 and 1972, Koller 1972, Townsend and McGinnies 1972). The temperature factor in seed germination may be viewed as i) high

temperature requirement; ii) low temperature or cold stratification and iii) alternating temperature requirement (Mayer and Poljakoff-Mayber 1975). Most seeds of the temperate zones require some cold stratification before they are able to germinate (Wang 1978, Adkin et al. 1984, Baskin and Baskin 1984) but cold stratification generally is not useful for tropical tree seed. Some temperate species do not require such treatment (Hellum 1968) depending, apparently, on the level of seed maturity at the time of testing. The effect of stratification on *Gmelina arborea* is not known as no one appears to have done any work on it. Presumably, in the tropics where temperature is always high and fairly constant all year round, there is little if any need for cold stratification of seeds before germination can proceed.

However, tropical tree seeds of many species develop severe dormancy by the time the seeds are ripe on the tree (Hellum and Wasuwanich 1984). In some cases, it has been suggested that alternating temperatures promote best germination (Mayer and Poljakoff-Mayber 1975, Thompson et al. 1977). The need for such alternating temperatures in germination testing would very likely depend on the ecological niche where the species grows. Pioneer species, like *Gmelina arborea*, could be expected to respond as well as or better to alternating rather than constant diurnal temperatures. Species close to climatic climax could be expected to germinate best under nearly constant diurnal temperature.

2.2 EFFECTS OF LIGHT QUALITY ON PLANT GROWTH

2.2.1 LIGHT AND PLANT GROWTH

Among the environmental factors, light is among the most important determinants of growth and development in plants. It is the fundamental source of energy that drives all vital life processes on earth. Plants are autrotrophs which utilise the radiant energy from the sun for the production of specific organic compounds which in turn undergo a cycling process in the ecosystem. Light is the visible portion of the electromagnetic spectrum which ranges approximately from 400 to 700 nanometers (Smith and Morgan 1981). The sensitivity curve for plants has its peak in the red (660 nm) and blue (450 nm) regions (Fukshansky 1981, Anon.1982). Far-red radiation (730 nm), which is outside the visible range, also has a strong influence on plant growth and development (Kendrick and Frankland 1976, Smith 1975). When radiant energy interacts with matter, such as a leaf surface, it acts as though it were composed of small packets of energy called photons. Each photon contains energy equal to Planck's (universal) constant (6.626×10^{-34} J. s^{-1}) times the velocity of light (3×10^{10} cm. s^{-1}) divided by the wavelength.

The phenotype of a tree is determined by its genetic make-up and the environment. The genetic factors set limits to variation in plant growth. Within these limits, the environmental factors determine the formative

characteristics of the plant. Among environmental factors, light is an important factor. Light drives photosynthesis, photomorphogenesis and photoperiodism. These processes depend on light quantity (photosynthetic photon flux density), light quality (spectral composition) and light duration (Leopold and Kriedeman 1975, Kendrick and Frankland 1976, Smith 1982).

Photoperiod in the tropics, between the tropics of Cancer and Capricorn, is nearly constant all year round. But in the temperate regions, photoperiod is an important triggering factor controlling dormancy and growth. As such, plants maximise growth and photosynthesis when environmental conditions are favorable and enter full-dormancy or semi-dormancy at other times. Very few studies of either the ecology or the physiology of tropical species have been carried out in comparison to temperate species (Mooney et al.1980, Whitmore 1980). In the case of *Gmelina arborea*, no studies have been reported on the effect of light on seedling growth (Greaves 1981).

Because there are few reports on the effects of light quality on woody perennials, annuals are also included in this brief review. Both annual and perennial species show similar physiological responses toward light. They both contain chlorophyll and photoreceptors which are able to perceive light quality, quantity and photoperiod. Annual plants complete their life-cycles in a few weeks or months whereas perennial plants are capable of continuous growth

for many years. As such, annual plants often have higher growth rates than woody perennial plants because the latter tend to allocate more of its photosyntates to wood formation and strength rather than leaf and fruit development. Growth rates also vary with seasons of the year between annuals and woody perennials.

2.2.2 EFFECTS OF LIGHT QUALITY ON ANNUALS

Shoot height and diameter are very much affected by light quality. Early studies of light effects on plant growth were carried out using incandescent tungsten filament bulbs. Under such light, plants usually produced thinner shoots and longer internodes than those grown in unfiltered daylight (Garner and Allard 1931). Arthur and Stewart (1935) grew buckwheat (*Fagopyrum esculentum* Meench) under four different light qualities and found that height growth was greatest with mazda (incandescent) lamps and least with mercury vapour lamps. Mitchell (1937) and Withrow and Withrow (1947) also showed that greatest stem growth was obtained under incandescant light but plants were spindly and under high pressure carbon arc lamps, plants were shortest. Using red-biased, balanced and blue-biased light treatments on various species, Warrington and Mitchell (1976) found that shoot lengths were always greatest under the red-biased and least under the blue-biased light. Blue light has also been shown to inhibit stem growth (Gaba and Black 1983, Meijer 1971).

Holmes et al. (1982) studied hypocotyl growth of *Sinapsis alba* L. in relationship to light quality and quantity. They found that hypocotyl elongation was promoted when the ratio of far-red to red light increased. In a similar study, Lecharny and Jacques (1982) also showed that internode elongation rate of *Vigna sinensis* L. was stimulated when far-red light was added to white light. They suggested that the stimulation was strictly depended on the energy ratio of far-red to white light and the photoreceptor involved was believed to be phytochrome.

Dry weight production differs under different light treatments. Arthur and Harvil (1937) found that greatest dry weight was obtained under sodium light and the least weight was produced under mercury light given equal energy inputs. Stevenson and Dunn (1965) and Dunn and Went (1959) also showed that red light produced the greatest dry weight. Using a combination of different lights on pea plants (*Pisum sativum* L.), Kwack and Dunn (1966) found that greatest dry weight was obtained with red plus blue light. Warrington and Mitchell (1976) found that shoot dry weight under red-biased light was at least twice as great as that in plants under blue-biased light for all species except ryegrass where the differences were less pronounced. Dry weight distribution between the shoot and root also differs under different light treatments. Warrington and Mitchell (1976) found that the root-shoot ratio was highest under blue-biased light and lowest under the red-biased light.

Relative growth rates (RGR) were almost 20 percent lower under blue-biased light than under either the balanced or red-biased light treatments for all species except ryegrass (Warrington and Mitchell 1976). This was probably due to the effect of red light (sodium lamps) which promoted greater leaf expansion and greater carbon fixation. The authors also found that plants grown under red-biased light produced higher amounts of carbohydrate than those grown under blue-biased light. But under blue-biased light, plants produced more amino-acids and proteins. In another study, Arthur and Harvil (1937) showed that plants grew well when exposed continuously for two months to sodium vapour lamps (more red light) but gradually started to degenerate. Such plants could be completely rejuvenated by two hours exposure each day to mercury vapour lamps (more blue light) when applied along with continuous sodium lamps. It appears that for proper and continuous growth, there is a need for both red and blue light. Red light is necessary for photosynthesis and leaf expansion whereas blue light is needed for protein and enzyme synthesis. An imbalance of these two light qualities results in poor growth and development.

2.2.3 EFFECTS OF LIGHT QUALITY ON PERENNIALS

Erez and Kadman-Zahavi (1972) used young peach plants (*Prunus persica* L.) grown outdoors under three different colored filters, two shade levels and a control to examine

the effect of light on plant behavior. The results showed that red plus far-red light produced the strongest growth activity and blue plus far-red light had a strong inhibitory effect on growth. It was found that blue light and blue plus far-red light acted antagonistically on apical dominance in which the former produced a shorter seedling while the latter produced a more erect, narrower and taller seedling. Blue light inhibits apical growth whereas far-red light promotes it. Another study using orange seedlings (*Citrus aurantium* L.) showed that red plus far-red light produced greatest height and leaf area growth. Height growth under blue plus far-red light was greater than blue light alone (Erner et al. 1972).

The effects of continuous light, of variable qualities, on oak seedlings (*Quercus robur* L.) were examined by Axelson et al. (1979). Morphological development was followed for 25 days. Results showed that under continuous white, blue and red light, stem growth terminated after about 10 days by formation of resting buds when seedlings were about 10 cm tall. But plants under continuous far-red light (wavelength over 700nm) showed continuous stem growth without formation of resting buds and the stem length was about 27 cm after 25 days. When far-red light was supplemented with short pulses (5 min.) of red-light each day, leaf area was increased up to 20 times. Morgan et al. (1983) examined the responses of *Pinus radiata* D. under different proportions of metal halide and tungsten halogen lamps. Results showed that a lower

red:far-red light ratio (more of far-red light) markedly increased shoot elongation and internode lengths. It was suggested that the red:far-red ratio and phytochrome photoequilibrium strongly influenced the photomorphogenesis of the plants.

Using light filters to produce different light qualities, Morikawa et. al. (1976) showed that hypocotyl growth increased with decreases in irradiance and remarkable height growth was promoted by the effect of far-red light. Dry weight increased with irradiance but was lowest under blue light. For birch seedlings, diameter growth and leaf dry weight were greatest under red light and lowest under blue light. Such methods of using light quality to control plant growth are useful in the tropics where irradiance and photoperiod are almost constant all year round. A study was carried out on growth responses of a few tropical tree species to light effects (Sasaki and Mori 1981). Results showed that internode elongation of seedlings under forest canopy shade was stimulated greatly and root growth was restricted. This was probably due to the lower red to far-red light ratio and also the lower light irradiance under the canopy shade. When seedlings were grown under artificial shade in the nursery, best growth for shoots was with 30 to 50% of full sunlight and best growth for roots was under 50 to 60% of full sunlight. Thus, controlling shading in the nursery can produce light conditions optimal for plant growth. The authors also found that shoot-root

ratios increased with a decline in light intensity.

Perennials show similar formative responses to those of annuals under different light qualities. Both species produce smaller root-collar diameters and longer internodes under lower red:far-red light ratios. Blue light has an inhibitory effect on apical growth and tends to produce shorter plants. Red light promotes rapid leaf expansion and also produces the highest dry weight. The results show that light quality has a strong influence on the morphological and physiological development of plants. It affects photosynthetic rate, carbohydrate and protein synthesis, carbon distribution in the plant and growth rates of different plant components. Thus, photomorphogenesis utilizes light qualities to 'trigger' or initiate reactions that control growth, development and differentiation. The pigment, phytochrome, is the photoreceptor which mediates the photocontrol of plant development. Phytochrome, under different light qualities, initiates physiological responses by regulating membrane permeability, gene activity, enzyme and hormonal levels (Kendrick and Frankland 1978, Smith 1975). Since plants respond differently under differing light quality, they could be induced to produce and develop certain characteristics which are desirable for outplanting purposes.

2.2.4 PERENNIAL SEEDLING CHARACTERISTICS

In forestry practice, the main function of a nursery is to produce seedlings of high quality for field planting. Seedlings can be treated under optimum conditons of light, temperature, water and fertilization in the nursery but are exposed to prevailing environmental conditions in the field. Thus to define 'high quality' depends on how well the seedlings can survive and grow under field conditions. Duryea (1984) defined a seedling as having high quality if it meets the expectation or standards of performance on a particular planting site. Such seedlings must be able to withstand environmental stresses and also to grow rapidly after having been outplanted. Under tropical condition, high daily temperatures can cause seedling mortality through high evapotranspiration. Thus, rapid seedling establishment in the field is very important because it leads to best survival and growth.

The morphological features for a high quality seedling include a high root to shoot ratio (dry weight basis) and a high root-collar diameter. A high root to shoot ratio indicates higher root volume and mass. This is necessary to ensure greater water uptake during the early and critical stage of establishment after outplanting. Adequate water uptake is important for overall growth and subsequently allows the seedling to grow rapidly. Higher survival and height growth were obtained for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beissn.) Franco and

menziesii (Mirb.) Franco), ponderosa pine (*Pinus ponderosa* Laws.), and jackpine (*Pinus banksiana* Lamb.) seedlings with larger root to shoot ratios (Lopushinsky and Beebe 1976, Hermann 1964, Carlson 1972).

Large root-collar diameters indicate sturdier plants which may be more resistant to smothering under field conditions. Larger root-collar diameters have been reported to produce better outplanting success (Anstey 1971 , Chavesse 1977 and Pawsey 1972). Shoot height at time of planting is sometimes considered an indicator of stock quality. Field survival may be positively correlated to height of seedling at time of planting (Richter 1971) but it may also be the reverse (Hermann 1964, Lopushinsky and Beebe 1976). Smith and Walters (1965) reported that survival was highest with intermediate shoot height for Douglas-fir. Seedlings with rapid height growth are generally preferred because of their competitive advantage against weeds.

3. METHODS AND MATERIALS

3.1 SEED SOURCES

Three seed sources collected from two States (Perak and Sabah) in Malaysia and from Muak Lek in Thailand were flown to Edmonton. Only processed nuts (with pulp removed), as illustrated in Figure 1 were studied. Their respective geographic locations and climatic diagrams are shown in Table 5 and Figure 2. On arrival, the nuts were stored in a refrigerator at about 5°C. The Malaysian sources were collected from plantation stands and the Thai source came from a native stand. The number of trees represented for the Malaysian sources is not known but the nuts from Thailand came from 15 native trees.The spacing among trees and history of the Thai stand is not available. The selection, collection and processing methods of the fruits and nuts followed local custom and were beyond the control of the author. *Gmelina arborea* is indigenous to Thailand and exotic to Perak and Sabah. The Perak source was introduced from Burma in 1920 (Durant 1941) and the Sabah source came from Nigeria (where it also was exotic). The origin of the Nigerian source is uncertain and may have come from Burma or Northern India (Pringle 1950).

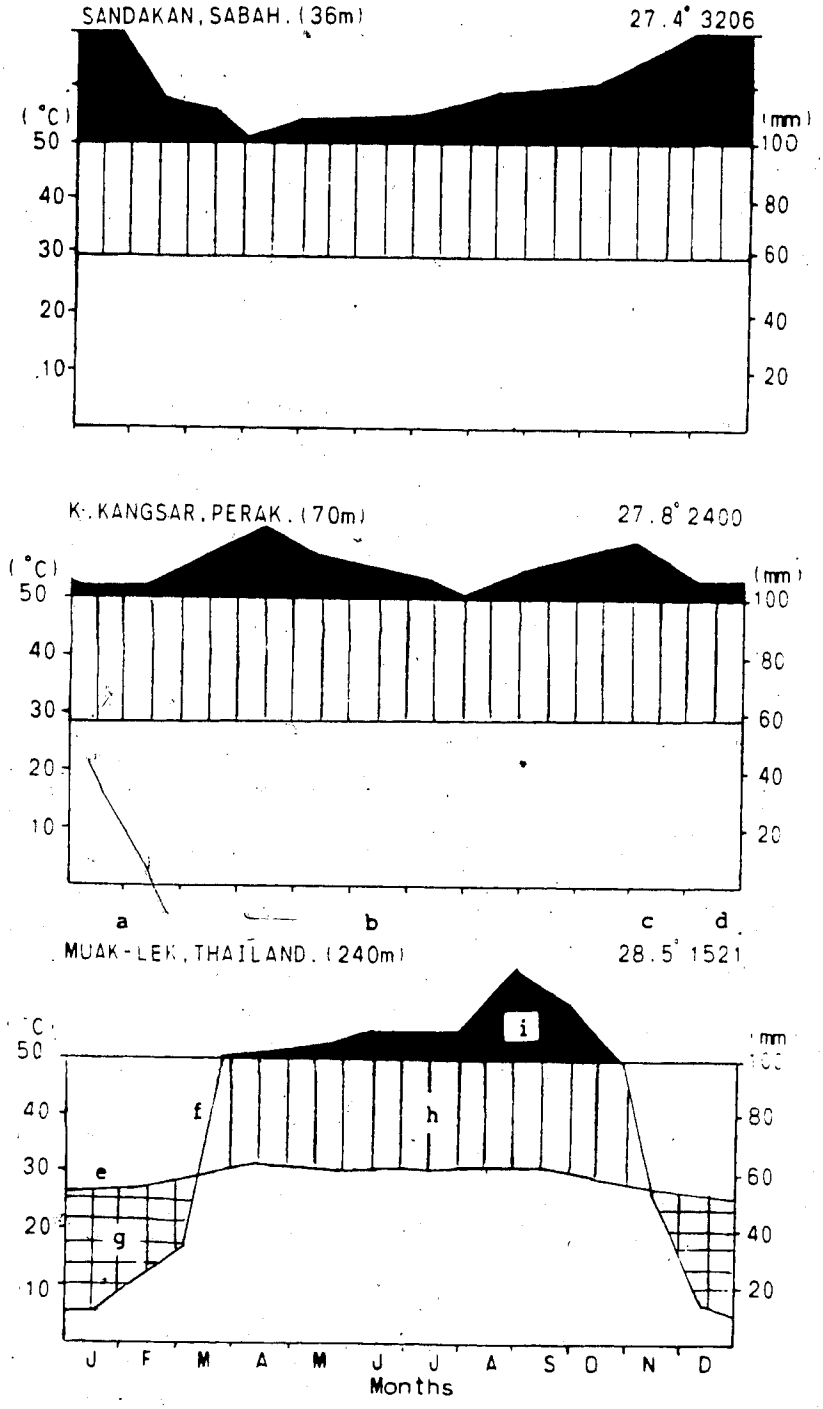

Figure 2. Climatic diagrams of locations where seed sources were obtained (Walter et al. 1975).
The labels denote: a=station; b=altitude above sea level; c=mean annual temperatures; d=mean annual rainfall; e=curve of monthly temperatures; f=curve of monthly rainfall; g=season of relative drought (hatched shading); h=season of relative humidity (vertical shading); i=mean monthly rainfall over 100 mm (scale reduced to 1/10, shaded black).

Table 5. Geographic locations of seed sources from Sandakan (Sabah), K. Kangsar (Perak) and Muak Lek (Thailand).

	Sources	Latitude	Longtitude	Altitude(m)
1.	Sabah	4° 57'N	118° 13'E	36
2.	Perak	6° 05'N	100° 46'E	70
3.	Thailand	14° 40'N	101° 20'E	240

(Sources: 1-2: Walter et al. 1975, 3: Wasuwanich 1984)

3.2 SEED AND NUT SIZES

To determine the average size of each nut, twenty nuts were taken at random from each source. The length and maximum diameter for each nut were measured. As for seed size determination, 20 seeds (extracted from nuts) were taken from each source at random. Due to the fragile nature of the seeds and their small size, individual seeds were not measured. The mean length and width of freshy extracted seeds were determined by measuring the 20 seeds together side by side (lengthwise and widthwise). Measurements were made to the nearest millimeter. For both nut and seed sizes, four replicates of each source were measured.

A germination test was carried out to determine the average number of germinants produced per nut from each source. One hundred nuts from each source were sown in moist peat moss to a depth of about 0.5 cm using plastic germination trays (without lid) which were placed in a Conviron seed germinator. Daylength was 12 hours long and the germinator was maintained at a constant temperature of 30°C . Total number of germinants per nut were counted after

21 days for each source. Each germinant was counted when the first pair of foliage leaves had emerged.

3.3 SEED GERMINATION AND TEMPERATURE

In this study, extracted seeds were used to determine the effects of temperature on germination. Sufficient nuts were cracked open by hand using pliers to release the seeds. The extracted seeds from the three sources were X-rayed seperately using a cabinet X-ray machine (Model M110NH, TF1 Corp. CT) at 14 KV and 5 mA for 15 seconds at a distance of about 47 cm from the light source. By examining the X-ray negative, seeds with incomplete cotyledon or embryo development and with internal damage (probably arising during extraction) were excluded from the experiment as suggested by Muller et al. (1956). Twenty seeds from each source were used in each of the five temperature treatments (see Table 6). The experiment was replicated four times using a 'temperature-gradient-bar' (TGB) chamber designed by Hellum (pers comm. 1983). The five temperatures tested were 19°C, 24°C, 30°C, 36°C and 45°C ±1°C. The temperature at each point was measured with a liquid mercury thermometer under normal room condition.

The TGB chamber is roughly rectangular in shape (30cm x 80cm x 90cm) with a window on top. Across in one direction are four parallel flat copper bars seperated from each other by about 7.5 cm . One end of the bar is connected to a heating device and the other end is connected to a cooling

unit. Both ends are thermostatically controlled. This system allows the production of the same range of temperatures along the four bars simultaneously. Each bar has a surface area of 10cm x 74cm . Seeds were placed on kimpack as a germinating medium over the top surface area of the copper bar at various predetermined points. Both ends of the kimpack were extended to a common pool of water below for water uptake. Each sample of 20 seeds was covered with a clear, square plastic petri dish (9cm x 9cm) during germination. Seeds with radicle growth equal to or greater than the length of cotyledons were counted as germinated. The germinated seeds were discarded progressively after being counted. Germination was counted daily over a period of 14 days. A second test to determine lethal temperatures for germination was carried out using only the Sabah seed source because there were insufficient Perak and Thai seeds. The same number of seeds and replications was used but the temperatures were 38°C, 41°C, 46°C and 52°C.

Table 6. Design of seed germination experiment with five temperature treatments.

Sources	Temperatures 19°C	24°C	30°C	36°C	45°C
Sabah	20x4	20x4	20x4	20x4	20x4
Perak	20x4	20x4	20x4	20x4	20x4
Thailand	20x4	20x4	20x4	20x4	20x4

(20x4: 20 seeds x 4 replicates)

3.4 SEEDLING GROWTH EXPERIMENT

The experiment was set up with a split-split plot design. Three walk-in controlled environment chambers (U. of A. Phytotron), each measures about 4m x 8m x 8m were used as three replicates. These chambers were located in the Department of Botany, University of Alberta. In each chamber, five compartments were constructed above the bench (180cm x 520cm) using perforated hardboard painted white as dividers. Within each compartment, different lamp combinations were set up on the frame above to provide a range of light qualities. Table 7 shows the five light treatments each having a different lamp combinations with their irradiances. The five lamp combinations were randomly allocated among the five compartments within each chamber.

Table 7. Lamp combinations and irradiances of the five light treatments

No.	Lamp combinations	Codes	PPFD μmol $m^{-2}s^{-1}$
1.	3 units SON	3SON	462
2.	2 units SON + 1 unit HPI	2S1H	420
3.	1 unit SON + 1 unit HPI + 6 units INC.	SM6I	356
4.	2 units HPI + 1 unit SON	2M1S	394
5.	3 units HPI	3MeH	374

SON: High Pressure Sodium Lamp 400W (SON/T Philips G/92/2)
HPI: High Pressure Metal Halide 400W (HPI/T Philips G/92/2)
INC.:Incandescent Bulb 150W (Sylvania)

Within each light treatment, the three sources were each represented by 60 seedlings (Table 8). The growth chambers were maintained with a photoperiod of 10 hour days

at 28±2°C and 14 hour nights at 26±2°C. Ten hours were assumed to provide the effective photoperiod under tropical condition. Relative humidity was maintained throughout at 75±5%; it was checked at intervals with a dewpoint hygrometer (Model 880 EG&G Int: Inc.). Due to the different radiant efficiencies of the various lamps and the fixed lamp frame, equal photosynthetic photon flux density (PPFD) for each compartment could not be obtained. Differences in PPFD among the five light treatments were minimized by raising the plants under the SM6I and 3MeH treatments. The spectral distribution and photon flux density were measured with a spectroradiometer (Model L1-1800 Li-Cor Inc.).

Table 8. Design of the seedling growth experiment under five light treatments.

Sources	Light Treatments				
	3SON	2S1M	SM6I	2M1S	3MeH
Sabah	4x5x3	4x5x3	4x5x3	4x5x3	4x5x3
Perak	4x5x3	4x5x3	4x5x3	4x5x3	4x5x3
Thailand	4x5x3	4x5x3	4x5x3	4x5x3	4x5x3

(4x5x3: 4 seedlings x 5 harvests x 3 replicates)

Seedlings for the experiment were grown from nuts in moist peat moss in a Conviron seed germinator until the emergence of the first pair of foliage leaves. Seedlings were carefully washed and seperated to minimise root damage. This took about 12 days and the seedlings were then about 4 cm tall. Seedlings of comparable height and size were selected from the three sources and transplanted into containers called Super-45 each measuring about 5cm x 6.3cm

x 22.5cm (Spencer-Lamaire Indus. Ltd.). Super-45 was found to be sufficiently large in a preliminary trial for root growth. The Super-45 containers were designed to fit into a metal tray which could hold a total of 27 containers. However, transplanting was done alternately in the containers and each tray had only 12 seedlings (4 seedlings x 3 sources). This allowed sufficient space for lateral growth of the crown of the test seedlings. The soil used was premixed and is called Cornell mixture (Hanan et al. 1978) (Table 9).

Table 9. Cornell Mixture Formula.

1.	6 cu.ft.	peat moss
2.	6 cu.ft.	vermiculite
3.	3 kg.	limestone powder
4.	3.2 kg.	14:14:14: osmocote fertilizer
5.	2 cups(10 ml.)	soil moistening agent
6.	18 gallons	water
7.	20 gm.	fritted trace elements

(Source: Hanan et al. 1978)

Seedlings were exposed to the five light treatments for a maximum duration of 60 days. At intervals of 12 days, 4 seedlings were harvested from each source under each light treatment. Using destructive techniques, the following measurements were made at each harvest:

1. Stem height (cm)
2. Root collar diameter (mm)
3. Leaf area (cm^2)
4. Dry weight of leaves (mg)

5. Dry weight of stems (mg)
6. Dry weight of roots (mg)

Stem height was measured with a ruler from the root collar zone to the shoot tip. Root collar diameter was measured with a dial thickness gauge (Fowler Co.) at the root collar zone. Leaf area was measured using a leaf area meter (Model 3100 Li-Cor Inc.). Plant parts were weighed after drying at 95°C for 24 hours in a convection oven (Napco M420). The drying condition was to ensure gradual drying and to prevent oxidation of carbon materials.

3.5 ANALYSIS OF DATA

3.5.1 SEED AND NUT SIZES

Seed and nut sizes were analysed using one-way analysis of variance. If there were significant differences among the sources, means were compared using the Student-Newmann-Kuels' (S-N-K) multiple range test at $P \leq 0.05$ level (Steel and Torrie 1980).

3.5.2 GERMINATION TEST

Two-way analysis of variance was used to compare results among the three sources, among temperatures and their interactions. Total percent germination for each temperature was calculated on day 14 from inception of

tests. The germinative rate, which is the number of days to achieve 50% of total germination over the 14 day period was also calculated for each temperature. Regression analysis and coefficient of determination were determined between germination percent and temperatures.

3.5.3 SEEDLING GROWTH

Using the growth data obtained in the experiment, classical plant growth analysis was used to calculate growth indices as described by Evans (1972), Hunt (1978) and Radford (1967). Growth indices calculated were relative growth rate (RGR); net assimilation rate (NAR) and root-shoot ratio (RSR). RGR and NAR are physiological indices whereas RSR is a morphological index. RGR represents the productive efficiency of the plant and measures the change of plant dry weight per unit of dry weight present per unit time. NAR represents the carbon assimilatory capacity of the leaves and measures the change of plant dry weight per unit assimilatory surface area per unit time. RSR represents the ratio of dry weight of root to shoot (stem plus leaves). These growth indices indicate the physiological and morphological conditions of the seedlings.

The formulae used in the calculation of the various growth indices were as follows:

1. $RGR = (\ln.W_2 - \ln.W_1) \div (t_2 - t_1)$

2. $NAR = [(W_2 - W_1)(\ln.A_2 - \ln.A_1)] \div [(A_2 - A_1)(t_2 - t_1)]$

3. $RSR = (Wr + Ws)$

W_1 : Total plant dry weight at time t_1
W_2 : Total plant dry weight at time t_2
A_1 : Total leaf area at time t_1
A_2 : Total leaf area at time t_2
Wr : Total root dry weight
Ws : Total shoot (stem + leaves) dry weight
ln. : Natural logarithm

After calculating the various indices at each harvest interval, a two-way analysis of variance was carried out to determine the differences among sources, light treatments and their interactions. The same analysis of variance was also calculated for shoot height, root collar diameter, total dry weight and total leaf area. Regression analysis was determined where there were no significant differences among sources or light treatments. The S-N-K multiple range test at $P \leq 0.05$ was used to test for differences in means at each harvest interval (Steel and Torrie 1980).

4. RESULTS

4.1 STUDY I: SEED AND GERMINATION

4.1.1 SIZE OF NUTS

Measurements of length and maximum diameter of nuts are presented in Tables 10 and 11. Analysis of variance was performed to determine if differences existed among sources and results are shown in Tables 12 and 13.

Table 10. Means and S.E. for length of nuts (mm). (n=20)

Rep.	Sabah'	Perak'	Thailand
1	17.64±0.51	17.91±0.42	14.83±0.50
2	17.90±0.57	16.91±0.49	14.38±0.52
3	16.76±0.34	18.30±0.37	14.47±0.41
4	16.88±0.37	16.67±0.32	13.46±0.45
Mean	17.30±0.46	17.45±0.43	14.28±0.48

('In Malaysia)

Table 11. Means and S.E. for max. diameter of nuts (mm). (n=20)

Rep.	Sabah'	Perak'	Thailand
1	9.85±0.26	10.71±0.15	8.65±0.19
2	9.58±0.26	10.47±0.23	8.63±0.24
3	9.51±0.26	10.22±0.23	8.68±0.21
4	9.23±0.25	9.48±0.15	8.64±0.31
Mean	9.54±0.26	10.22±0.21	8.65±0.24

('In Malaysia)

Table 12. ANOVA for sources (length of nuts).

Sources of var.	df	S.S.	M.S.	F	Sig.
Bet. sources	2	25.26	12.63	31.66	0.01
Within	9	3.59	0.399		
Total	11	28.85			

Table 13. ANOVA for sources (diameter of nuts).

Sources of var.	df	S.S.	M.S.	F	Sig.
Bet. sources	2	4.99	2.49	20.67	0.01
Within	9	1.09	0.121		
Total	11	6.08			

Analysis of variance showed that there were significant differences at the 0.01 level among the three source means for both length and diameter of nuts. Comparisons of means using the S-N-K test at 0.05 level showed that both Sabah and Perak nuts were significantly longer with larger diameter than the Thai source (Table 14). When all individual observations were considered, the same significant difference was obtained. The Sabah and Perak sources were not significantly different from each other.

Table 14. Comparisons among source means for length and diameter of nuts using the S-N-K-test.

Sources	Length(mm)	Diameter(mm)
Sabah	17.30 a	9.54 c
Perak	17.45 a	10.22 c
Thailand	14.28 b	8.65 d

(Along each column, means followed by the same letter are not significantly different at P≤0.05 level)

4.1.2 SIZE OF SEEDS

Means of seed length and width were obtained by measuring the total of 20 seeds in each replicate. Individual seed measurement was not carried out because a ruler was used and high precision was difficult. As such, determination of standard error for each mean was not possible (Tables 15 and 16).

Table 15. Means for length of seed (mm). (n=20)

Rep.	Sabah[1]	Perak[1]	Thailand
1	7.61	7.57	7.25
2	7.50	7.70	6.90
3	7.43	7.93	7.35
4	8.23	7.63	7.33
Mean±S.E.	7.69±.18	7.71±.08	7.21±.11

([1]In Malaysia)

Table 16. Means for width of seed (mm). (n=20)

Rep.	Sabah'	Perak'	Thailand
1	3.87	3.95	3.93
2	3.65	3.80	3.63
3	3.83	4.05	3.81
4	3.92	3.87	3.69
Mean±S.E.	3.82±.06	3.92±.05	3.77±.07

('In Malaysia)

Analysis of variance showed that there were significant differences among source means for seed length at the 0.05 level but no significant differences for seed width (Tables 17 and 18). Comparisons among means were performed using the S-N-K test ($P \leq 0.05$). The results showed that seeds from Sabah and Perak were significantly longer than the Thai source (Table 19). There were no significant differences for seed width among the three sources.

Table 17. ANOVA for sources (length of seed).

Sources of var.	df	S.S.	M.S.	F	Sig.
Bet.sources	2	.6412	.3206	4.70	0.05
Within	9	.6141	.0682		
Total	11	1.2553			

Table 18. ANOVA for sources (width of seed).

Sources of var.	df	S.S.	M.S.	F	Sig.
Bet.sources	2	.0468	.0234	1.6138	ns
Within	9	.1310	.0145		
Total	11	.1778			

(ns: not significant)

Table 19. Comparisons among source means for length and width of seeds using the S-N-K test.

Sources	Length(mm)	Width(mm)
Sabah	7.69 a	3.82 c
Perak	7.71 a	3.92 c
Thailand	7.21 b	3.77 c

(Along each column, means followed by the same letter are not significantly different at $P \leq 0.05$ level)

4.1.3 GERMINANTS FROM NUTS

The number of germinants produced from each nut varied from zero to four (Table 20). Total germination (%) was calculated by dividing the total number of germinants by 100 nuts. The results showed that over 50 percent of all the nuts did not produce any germinants. Most nuts produced only one germinant. In terms of total germination, the Perak source produced fewest germinants per nut (45%) compared to Thailand (66%) and Sabah (65%) which were probably not significantly different. Analysis of variance was not performed because no replicates were done. Only one nut was found to produce 4 germinants (Thailand). The distribution

of nuts with different numbers of germinants is illustrated in Figure 3.

Table 20. Distribution of nuts with different number of germinants (n=100).

Sources	Nuts	No. of germinants per nut 0	1	2	3	4	Total
Sabah	Nuts	46	45	7	2	0	100
	(Germinants)	0	45	14	6	0	65%
Perak	Nuts	60	36	3	1	0	100
	(Germinants)	0	36	6	3	0	45%
Thailand	Nuts	49	41	6	3	1	100
	(Germinants)	0	41	12	9	4	66%

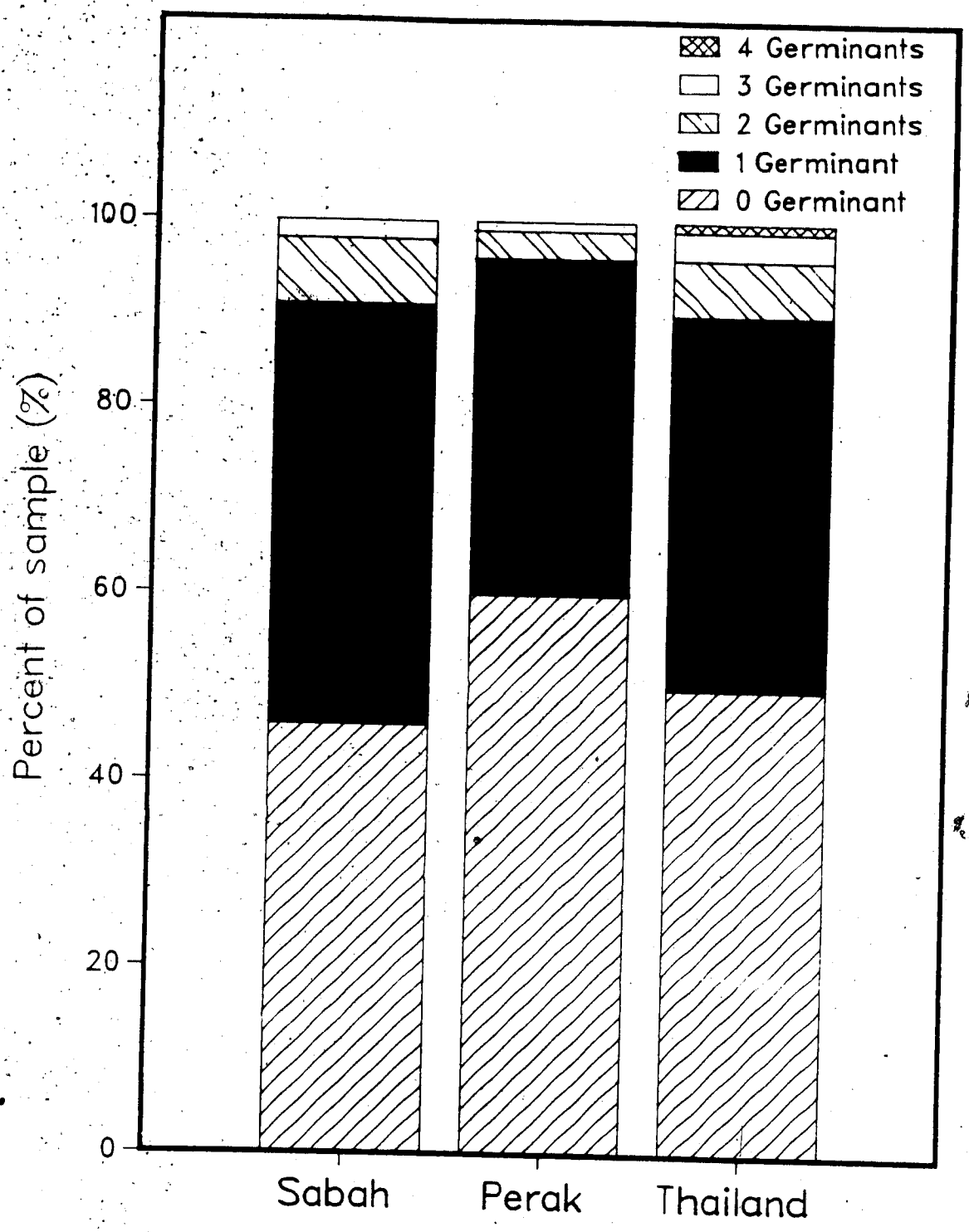

Figure 3. Percentage of nuts with different number of germinants.

4.1.4 SEED GERMINATION TEST

Highest total germination was obtained at 30°C and lowest at 19°C. There was no germination at 45°C. Seed source differences were also tested at each temperature and results showed that they were not significantly different from each other (Table 21). Arcsin transformation was not used because the percent data did not cover a wide range of values (Steel and Torrie 1980). Analysis of variance showed that there were significant differences among temperature treatments at 0.01 level. There were no significant differences among sources or in the interaction between temperatures and sources (Table 22).

Table 21. Means and S.E. of total germination (%) replicated four times.

Sources	Temperatures (°C) 19	24	30	36	45
Sabah	3.75±1.25	65.00±2.89	76.25±8.98	37.50±4.79	0
Perak	2.50±1.19	66.25±8.26	71.25±8.99	25.00±7.37	0
Thailand	3.75±3.75	72.50±7.22	78.75±5.54	30.00±8.90	0
Means	3.33±2.22	67.92±6.17	75.42±7.42	30.83±7.06	0

(ns: not significant)

Table 22. ANOVA for seed germination test.

Sources of var.	df	S.S.	M.S.	F	Sig.
Bet. sources	2	7.6	3.80	0.7197	ns
Bet. temp.	4	2381.2	595.31	112.75	0.01
Temp. x Sources	8	15.1	1.88	0.356	ns
Within	45	237.5	5.28		
Total	59	2641.4			

(ns: not significant)

Results in this study indicated that the lethal constant temperature for *Gmelina arborea* seeds was between 36°C and 45°C (some seeds died at 36°C and all died at 45°C). A second test was therefore carried out at temperatures of 38°C, 41°C, 46°C and 52°C to narrow down more closely what the lethal constant temperature might be. Because of insufficient seeds, only the Sabah source was used. The test can be assumed to represent all three sources because earlier analyses of variance showed that there were no significant differences among the three sources in regard to temperature effects on germination. Both results of the first and second run on temperatures were tested using multiple comparison analysis and were found not significantly different at $P \leq 0.05$ level (Table 23).

Table 23. Multiple comparison of germination tests between first and second run on temperatures.

Sources of var.	df	S.S.	M.S.	F	Sig.
Bet. 1st. & 2nd.	1	233.50	233.50	3.494	ns
Within	24	1604.04	66.84		

(ns: not significant)

The combined germination results were therefore pooled together (Table 24). Analysis of variance showed that temperature treatments were significantly different at a probability level of 0.01. The comparison of mean germination at different temperatures showed that total germination (%) at 24°C and 30°C were significantly

different from the others at $P \leq 0.01$ (S-N-K test) (Table 25). Germination results between 24°C and 30°C were similar ($P \leq 0.05$). The correlation between germination percentage and temperature had a coefficient of determination (R^2) of 0.77. The relationship showed that the constant temperature suitable for optimum germination was very narrow even though germination occured from 18.5°C to 40.5°C (Figure 5). There was a sharp drop in germination percentage with only slight changes from the optimum temperature (29.8°C). Arcsin transformations of the percentage data failed to lead to a better correlation.

The regression equation for the relationship between temperature and germination (%) is:

$$Y = -410 + 32.74X - 0.55X^2$$

$R^2 = 0.77$
Optimum temperature = 29.8°C
Maximum germination = 77.2%
(Y)= Germination percentage
(X)= Temperature(°C)

Table 24. Mean total percent germination at different temperature treatments.

Rep.	Temperature(°C) 19	24	30	36	38	41	46	52
1	8.33	75.00	70.00	25.00	45.00	15.00	0	0
2	3.33	73.33	61.67	23.33	30.00	0.00	0	0
3	1.67	68.33	80.00	30.00	20.00	0.00	0	0
4	0.00	55.00	90.00	45.00	55.00	15.00	0	0
Mean	3.33	67.92	75.42	30.83	30.00	7.50	0	0

Table 25. Comparisons of mean germination (%) at different temperature treatments using the S-N-K test.

No.	Temperature (°C)	Germination (%)	
1	52	0	c
2	46	0	c
3	41	7.5	c
4	38	30.00	b
5	36	30.83	b
6	30	75.42	a
7	24	67.92	a
8	19	3.33	c

(Means followed by the same letter are not significantly different at $P \leq 0.01$ level)

Cumulative germination percentage was plotted in order to determine the germinative rate at each temperature treatment (Figure 4). Highest germination occurred at 30°C with 50% of the seeds having germinated between days 6 and 7. Germination was very slow and low at 41°C and at 19°C. All seeds died at temperatures of 46°C and above. The germinative rates were also calculated and correlated to

temperatures. A regression equation was determined and germinative rate was found to be highly correlated to temperature (R^2=0.91) (see Figure 6). The germinative rate increased (less time needed) with temperature up to 33°C, and then decreased (more time needed).

The regression equation for the relationship between germinative rate and temperature is:

$$Y = 48.50 - 2.78X + 0.042X^2$$

R^2 =0.91
Optimum temperature = 33°C
Max. germinative rate = 2.5 days
(Y) = Days
(X) = Temperature(°C)

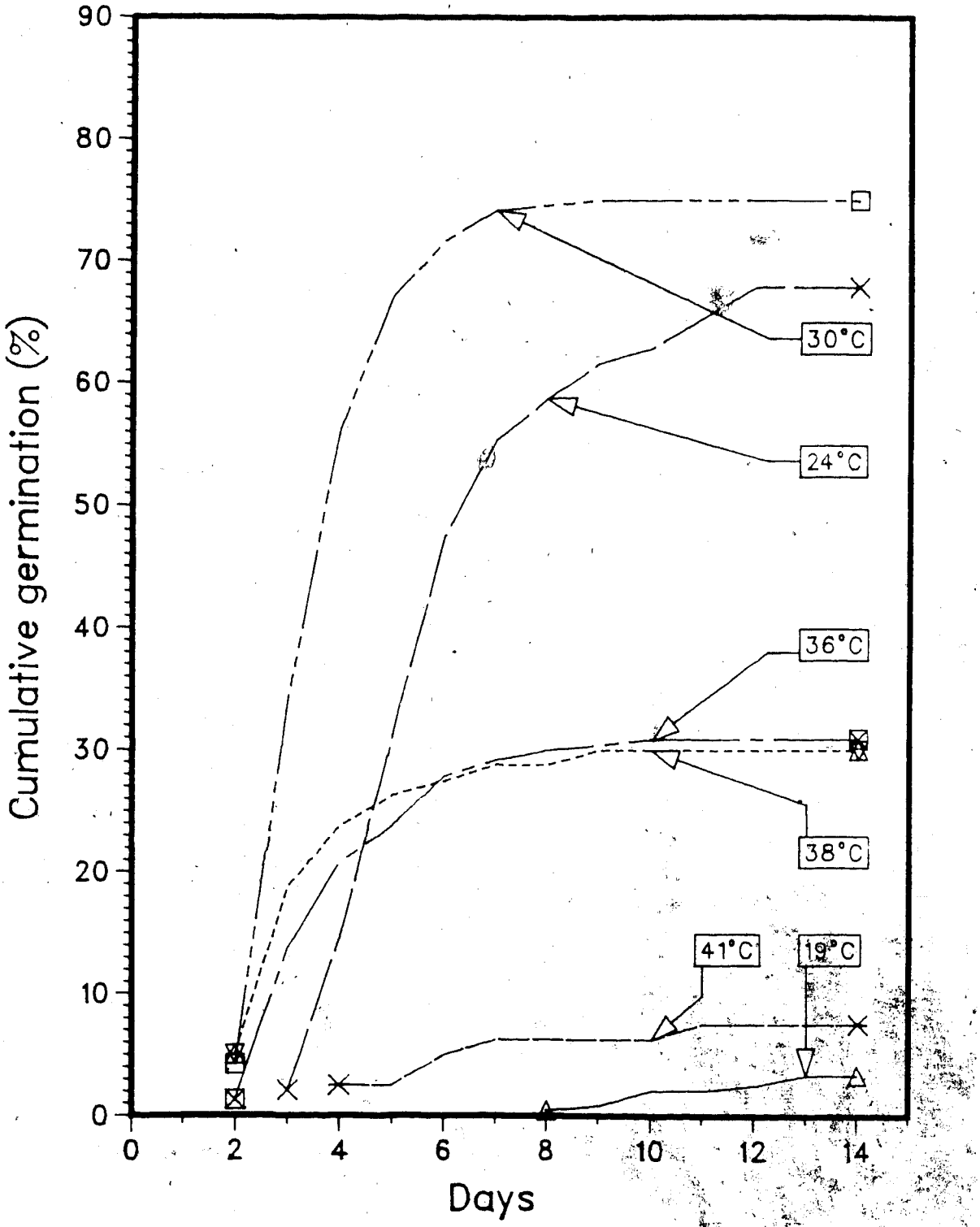

Figure 4. Cumulative germination percentage at different temperature treatments.

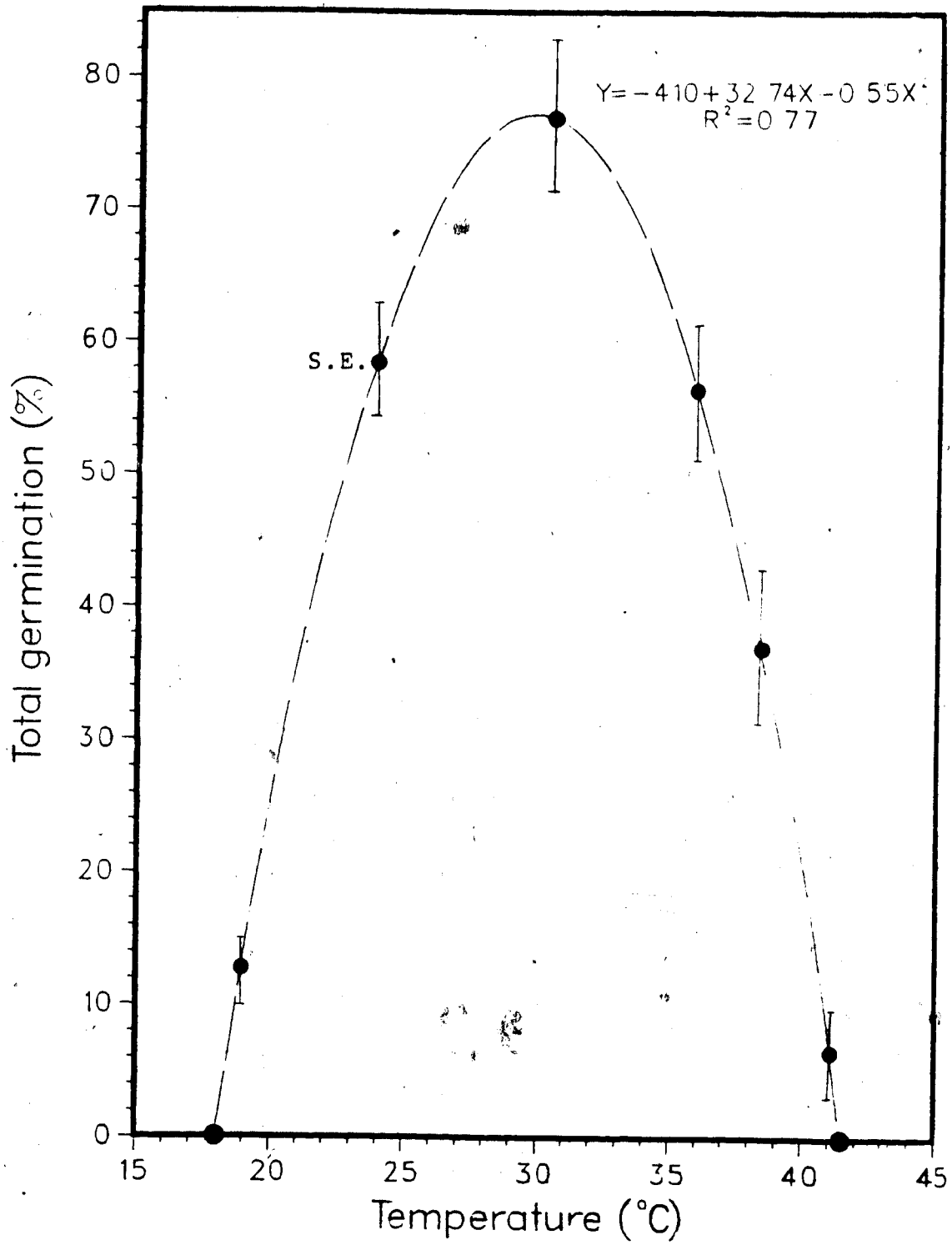

Figure 5. Total germination (%) at different temperature treatments.

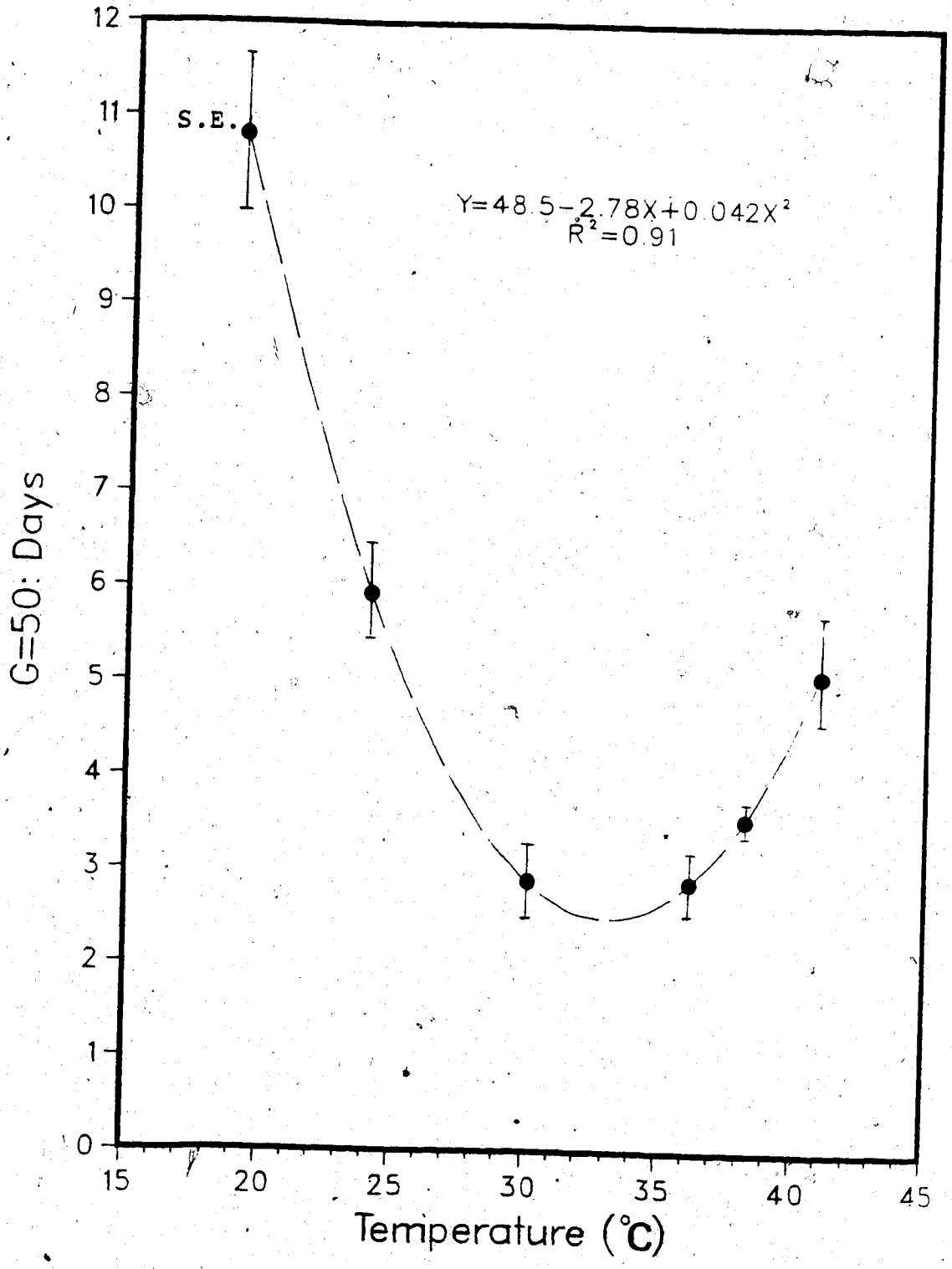

Figure 6. Germinative rate at different temperature treatments.

4.2 STUDY II: EFFECTS OF LIGHT QUALITY ON SEEDLING GROWTH

4.2.1 ROOT-SHOOT RATIO

Analysis of variance of root-shoot ratios showed that there were no significant differences among light quality, seed sources or their interactions (Table 26). However, there were indications of widening divergence after 48 days of growth. Plants under 3SON, 2S1M and 3MeS lights showed more rapid increase in root-shoot ratios than 3MeH and SM6I (Figure 7). After 60-day of growth, the largest ratio was obtained under 2S1M light (2 sodium and 1 mercury lamp) and lowest ratios were obtained under SM6I (most incandescent lamps) and 3SON light(3 sodium lamps).

Over the 60-day of growth, there was a definite trend in the root-shoot ratios under all light qualities. Root-shoot ratios decreased during the first 36 days. After 36 days, growth proceeded more rapidly in the roots than shoots, yielding increasing ratios. Root-shoot ratios among seedlings from different seed sources showed the same trend as seedlings grown under different light qualities over the 60-day of growth.

Since there were no significant differences among seedlings grown under different light quality in root-shoot ratios, a correlation between root-shoot ratios and days from planting was determined. A curvilinear relationship was obtained with a coefficient of determination (R^2) of 0.20. The results (Fig. 7) demonstrated a rapid change in

root-shoot ratios over the rearing period with no significant differences detected at each interval (Table 26). The standard error (±0.059) of the regression equation was high compared to the grand mean ratio of 0.229. Logarithmic transformations were tested but they did not produce any better correlation.

Relationship between root-shoot ratio and days from planting (up to 60 days) is:

$$Y = 0.324 - 0.00767X + 0.000145X^2$$

$R^2 = 0.20$
Standard error = ±0.059
(Y) = Root-shoot ratio
(X) = Days from planting

Table 26. ANOVA and comparisons of means for root-shoot ratio using the S-N-K test.

Treatments	Harvest interval(days) I(12)	II(24)	III(36)	IV(48)	V(60)
Lights	ns	ns	ns	ns	ns
3SON	.272 a	.205 a	.200 a	.184 a	.256 a
2S1M	.259 a	.207 a	.220 a	.229 a	.317 a
SM6I	.240 a	.196 a	.173 a	.226 a	.254 a
2M1S	.254 a	.208 a	.202 a	.202 a	.288 a
3MeH	.218 a	.210 a	.205 a	.241 a	.275 a
Sources	ns	ns	ns	ns	ns
Sabah	.252 a	.206 a	.212 a	.223 a	.290 a
Perak	.260 a	.205 a	.197 a	.213 a	.286 a
Thailand	.234 a	.206 a	.192 a	.212 a	.258 a
Interaction L x S	ns	ns	ns	ns	ns

(Along each column, means followed by the same letter are not significantly different at P≤0.05 level)
(ns: not significant)

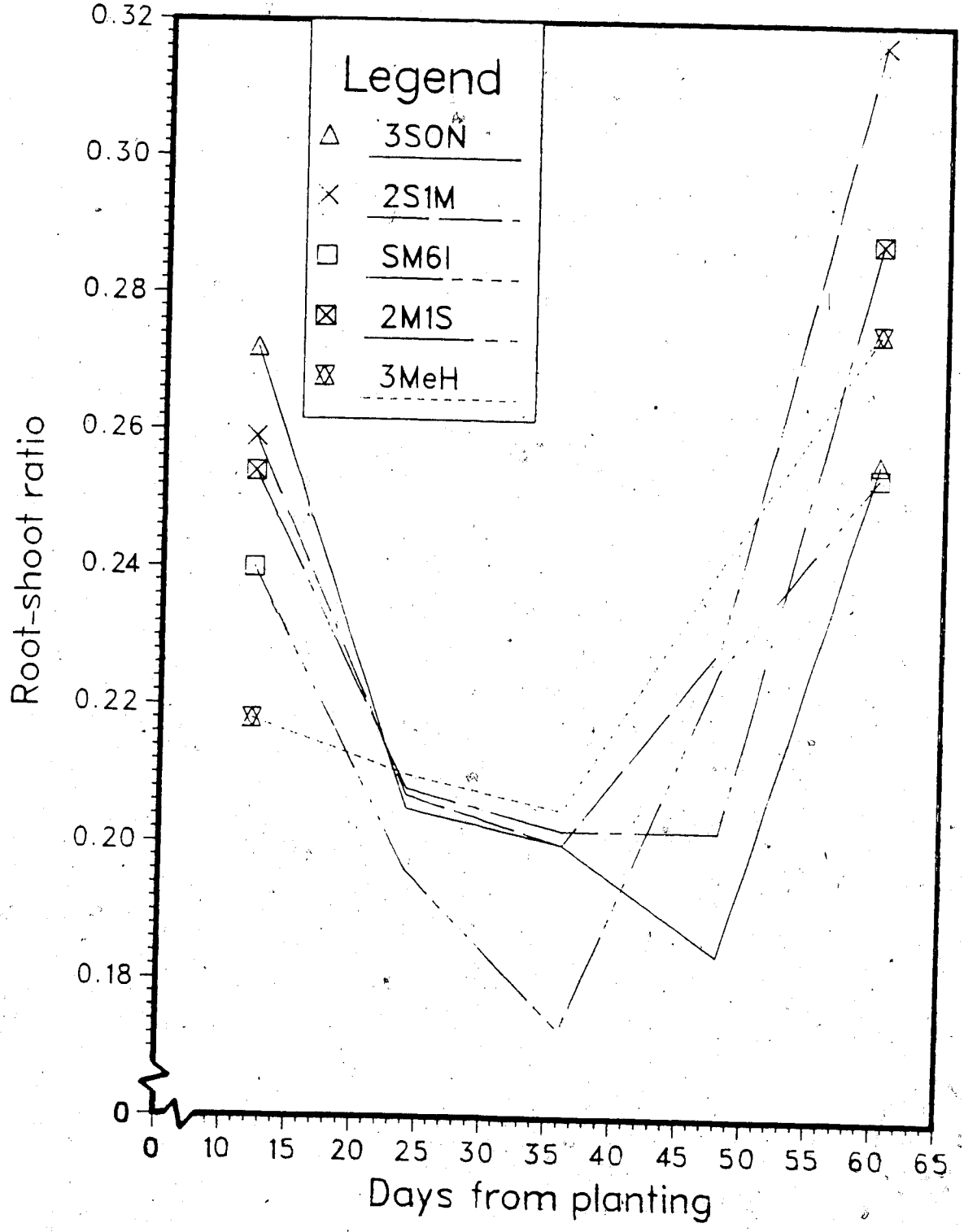

Figure 7. Root-shoot ratio under different light treatments.

4.2.2 ROOT COLLAR DIAMETER

There were no significant differences in root collar diameter among plants grown under different light qualities (Table 27). After 60 days of growth, plants under 3SON light produced larger root collar diameters and plants under SM6I light produced smaller diameters but differences were not significant. A correlation was determined between root collar diameters and days from planting for the five light qualities. A linear relationship was obtained with a coefficient of determination (r^2) of 0.96.

Linear relationship between root collar diameter and days from planting (up to 60 days) is:

$$Y = 0.297 + 0.1177X$$

r^2 =0.96
Standard error = ±.406 mm
(Y) = Root collar diameter (mm)
(X) = Days from planting

Significant differences in root collar diameter among seedlings from different seed sources were obtained at day 48 and 60. A widening trend among seed sources was indicated by increasingly significant differences from the 0.05 level (day 48) to the 0.01 level (day 60). Over the 60 days of growth, both sources from Sabah and Perak produced seedlings with much larger root collar diameters than the Thai source (Table 27). There was no significant difference between the Sabah and Perak sources. The results also showed no significant interactions between light quality and seed

source in root collar diameters.

Table 27. ANOVA and comparisons of means for root collar diameter(mm) using the S-N-K test.

Treatments	Harvest interval (days) I(12)	II(24)	III(36)	IV(48)	V(60)
Lights	ns	ns	ns	ns	ns
3SON	1.812 a	3.082 a	4.478 a	5.913 a	7.663 a
2S1M	1.806 a	3.238 a	4.506 a	6.170 a	7.566 a
SM6I	1.732 a	3.119 a	4.436 a	5.904 a	7.171 a
2M1S	1.714 a	3.021 a	4.420 a	5.999 a	7.222 a
3MeH	1.783 a	2.973 a	4.402 a	5.870 a	7.312 a
Sources	ns	ns	ns	*	**
Sabah	1.803 a	3.115 a	4.515 a	6.185 a	7.655 a
Perak	1.715 a	3.187 a	4.503 a	6.112 a	7.549 a
Thailand	1.791 a	2.958 a	4.327 a	5.617 b	6.957 b
Interaction L x S	ns	ns	ns	ns	ns

(Along each column, means followed by the same letter are not significantly different at P≤0.05 level)
(*: significant at 95%, **: significant at 99%)
(ns: not significant)

4.2.3 SHOOT HEIGHT

There were significant differences in shoot height among plants grown under different light qualities 24, 36 and 48 days after planting (Table 29). A trend clearly showed that plants under SM6I light were tallest among the five lights over the 60-day of growth. There were no significant differences among light qualities after 60 days even though shoot height was still tallest under SM6I light. The results also indicated that plants under 3MeH light produced the shortest plants. Correlations between shoot height and days from planting were determined for each light

quality (Figure 8). Coefficients of determination (r^2) were high for all tests. (Table 28). The linear relationships showed that height growth increased most rapidly under SM6I light and slowest under 3MeH light (indicated by the slope of each equation).

Table 28. Relationships between shoot height and days from planting (up to 60 days) under different light treatments.

Light	Regression	r^2	S.E.
3SON	Y = 0.7337X + 4.525	0.94	3.36
2S1M	Y = 0.6791X - 2.837	0.94	3.00
SM6I	Y = 0.7859X - 2.736	0.93	3.88
2M1S	Y = 0.6854X - 3.935	0.97	2.15
3MeH	Y = 0.6518X - 3.348	0.97	2.05

(Y) = Shoot height (cm)
(X) = Days from planting
S.E.= Standard error (±cm)

There were significant differences in shoot height among plants grown from different sources 12 and 24 days after planting. Both the Sabah and Perak sources produced taller plants than the Thai source (Table 29). A narrowing trend among seed sources on shoot heights was indicated by the lack of significant differences after 24 days. However, the Thai source produced the shortest plants at all intervals. The results showed no significant interactions between light quality and seed sources in shoot heights.

Table 29. ANOVA and comparisons of means for shoot height(cm) using the S-N-K test.

Treatments	Harvest interval (days) I(12)	II(24)	III(36)	IV(48)	V(60)
Lights	ns	**	**	**	ns
3SON	5.88 a	11.80 b	21.08 b	29.76 b	40.92 a
2S1M	6.01 a	12.25 b	22.02 b	29.81 b	37.97 a
SM6I	5.75 a	15.10 a	27.36 a	38.21 a	41.35 a
2M1S	5.28 a	10.62 b	20.73 b	30.68 b	36.38 a
3MeH	5.17 a	10.87 b	20.75 b	28.14 b	35.64 a
Sources	**	*	ns	ns	ns
Sabah	5.98 a	12.36 a	22.90 a	32.30 a	38.77 a
Perak	5.86 a	12.87 a	22.78 a	31.51 a	39.01 a
Thailand	5.02 b	11.15 b	21.49 a	30.15 a	37.58 a
Interaction L x S	ns	ns	ns	ns	ns

(Along each column, means followed by the same letter are not significantly different at P≤0.05 level)
(*: significant at 95%, **: significant at 99%)
(ns: not significant)

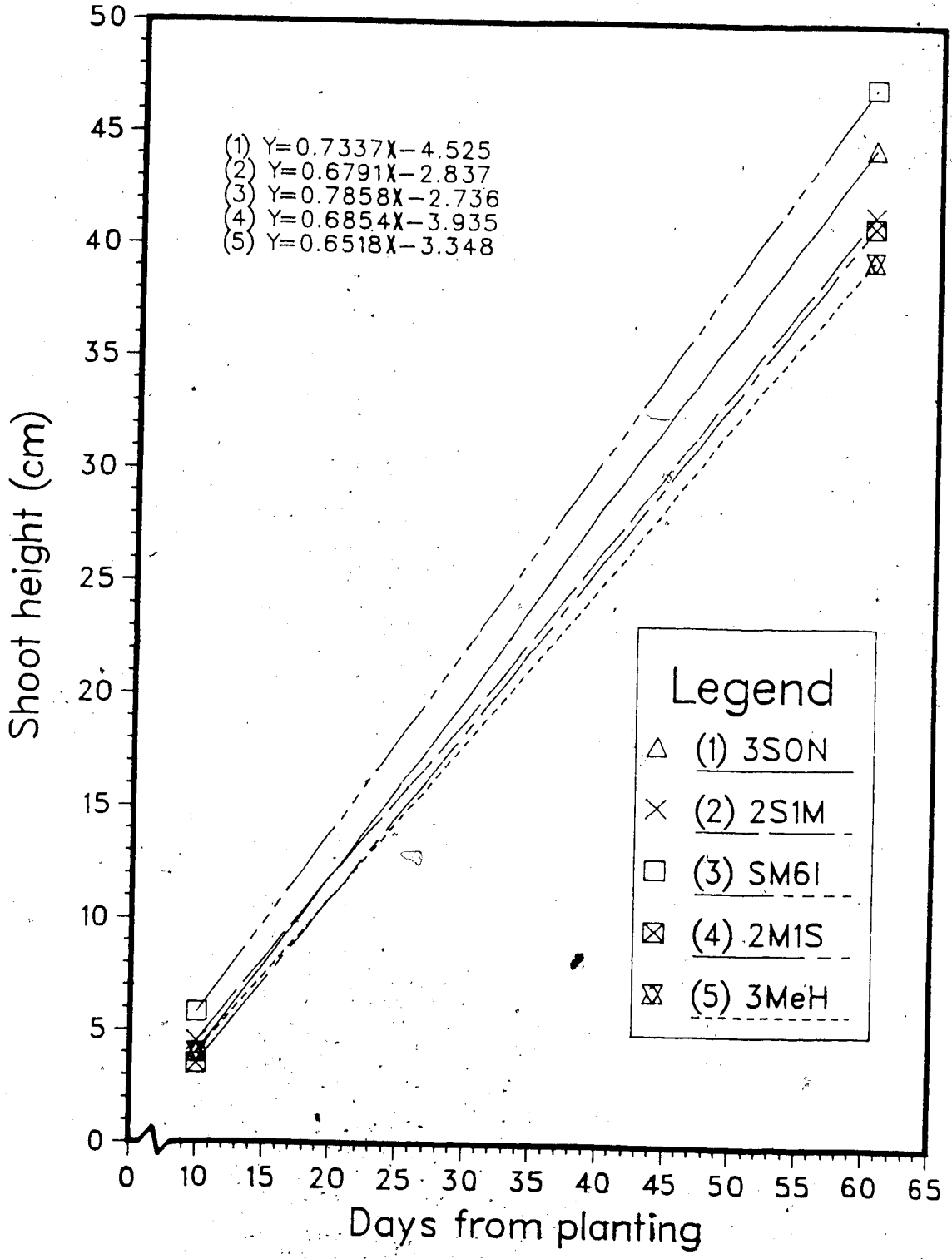

Figure 8. Shoot height under different light treatments.

4.2.4 TOTAL DRY WEIGHT

Analysis of variance showed that there were significant differences in total dry weights among plants grown under different light qualities 12, 24 and 60 days after planting (Table 30). A trend indicated that plants grown under 3SON and 2S1M lights produced higher dry weights than other light qualities. The results also showed that plants under SM6I light produced the lowest dry weights at all intervals over the 60-day of growth. Under all light qualities, total dry weights increased exponentially over the 60-day period. A widening trend was indicated particularly after 48 days where plants under 3SON light showed a more rapid increase in total dry weight as compared to other light qualities (Figure 9). After 60-day of growth, total dry weights under 3SON and 2S1M lights were significantly higher than those under SM6I light.

The results showed that different light qualities produced similar patterns in dry weight distribution within plant components (Figure 10). As the plants matured, the proportion of leaf dry weight decreased and the proportion of stem dry weight increased. The proportion of root dry weight decreased up to about 36 days and then increased. The shift in dry weight distribution within plants influenced the root-shoot ratios (Figure 7).

There were significant differences in total dry weights between the Malaysian sources (Sabah and Perak) and the Thai source 24, 48 and 60 days after planting. The Thai source

produced plants with lower total dry weights than sources from Sabah and Perak. A widening divergence over time was indicated by the increasing level of significant difference by day 60 (Table 30). The results showed no significant interactions between light quality and source in total dry weight.

Table 30. ANOVA and comparisons of means for total dry weight(g) per plant using the S-N-K test.

Treatments	Harvest interval(days) I(12)	II(24)	III(36)	IV(48)	V(60)
Lights	*	*	ns	ns	*
3SON	.175 a,b	.985 a,b	2.374 a	4.619 a	9.605 a
2S1M	.207 a	1.155 a	2.693 a	5.624 a	9.645 a
SM6I	.163 b	.879 b	2.146 a	5.064 a	7.990 b
2M1S	.169 b	.993 a,b	2.513 a	5.190 a	8.895 a,b
3MeH	.188 a,b	.950 b	2.495 a	4.840 a	8.312 a,b
Source	ns	*	ns	*	**
Sabah	.182 a	.994 a,b	2.431 a	5.266 a	9.079 a
Perak	.178 a	1.079 a	2.622 a	5.454 a	9.826 a
Thailand	.181 a	.905 b	2.280 a	4.482 b	7.764 b
Interaction L x S	ns	ns	ns	ns	ns

(Along each column, means followed by the same letter are not significantly different at P≤0.05 level)
(*: significant at 95%, **: significant at 99%)
(ns: not significant)

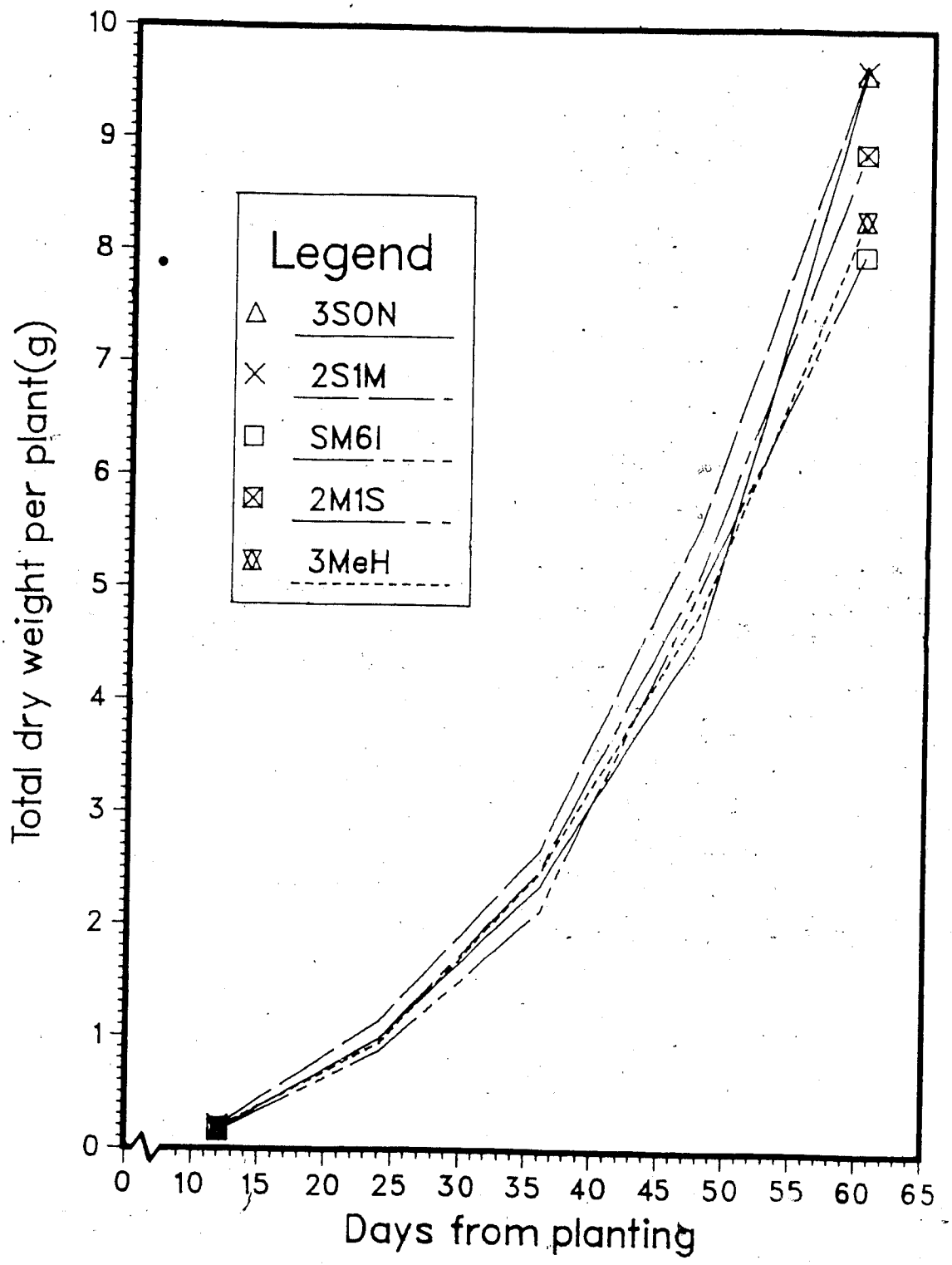

Figure 9. Total dry weight under different light treatments.

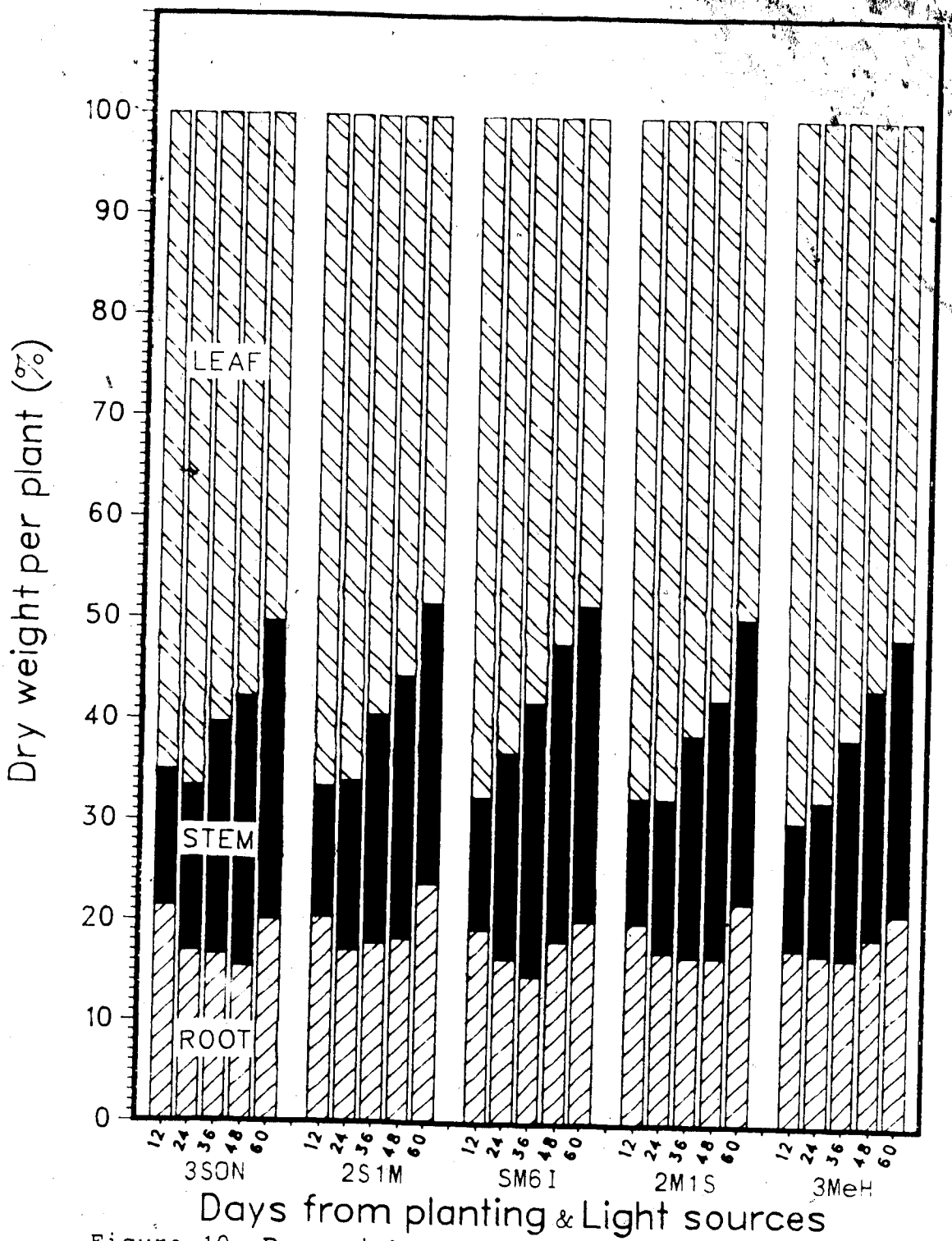

Figure 10. Dry weight distribution of plant components under different light treatments.

4.2.5 TOTAL LEAF AREA

The results showed that there were significant differences in total leaf area among plants grown under different light qualities 12 , 24 and 60 days after planting (Table 31). The plants demonstrated variations under different lights at different stages of growth. A widening divergence was indicated among light qualities particularly after 48 days (Figure 11). After 60 days, total leaf area was largest under 3SON light and smallest under SM6I light. There were also significant differences in total leaf area among seed sources after 24 and 48 days. A trend indicated that the Sabah and Perak sources had higher total leaf area than the Thai source. The results showed no significant interactions between light qualities and sources in total leaf areas.

Total dry weight was correlated with total leaf area for all light qualities. The relationship was linear with an r^2 of 0.90 (Figure 12). This relationship is a prerequisite for using the formula in calculating the net assimilation rate (Hunt 1978, Radford 1976, Sivakumar and Shaw 1978). As expected, variability in total dry weight increased with total leaf area as indicated by the greater dispersal of values (Figure 12).

The linear relationship between total dry weight per plant and total leaf areas per plant is:

$$Y = 0.00558X - 0.3968$$

$r^2 = 0.90$
Standard error = ±1.027 g
(Y) = Total dry weight per plant (g)
(X) = Total leaf area per plant (cm^2)

Table 31. ANOVA and comparisons of means for total leaf area(cm^2) per plant using the S-N-K test.

Treatments	Harvest interval(days) I(12)	II(24)	III(36)	IV(48)	V(60)
Lights	*	**	ns	ns	*
3SON	43.8 a,b	290.4 a,b	653.6 a	1106 a	1762 a
2S1M	52.0 a	314.4 a	625.0 a	1099 a	1525 a,b
SM6I	42.3 a,b	246.6 b	557.5 a	1087 a	1301 b
2M1S	37.1 b	273.0 b	615.0 a	1138 a	1422 a,b
3MeH	45.2 a,b	250.6 b	582.8 a	990 a	1434 a,b
Sources	ns	*	ns	*	ns.
Sabah	43.9 a	271.1 a,b	587.8 a	1063 a,b	1478 a
Perak	42.7 a	295.8 a	646.4 a	1172 a	1628 a
Thailand	45.6 a	258.2 b	586.2 a	1018 b	1370 a
Interaction L x S	ns	ns	ns	ns	ns

(Along each column, means followed by the same letter are not significantly different at P≤0.05 level)
(*: significant at 95%, **: significant at 99%)
(ns: not significant)

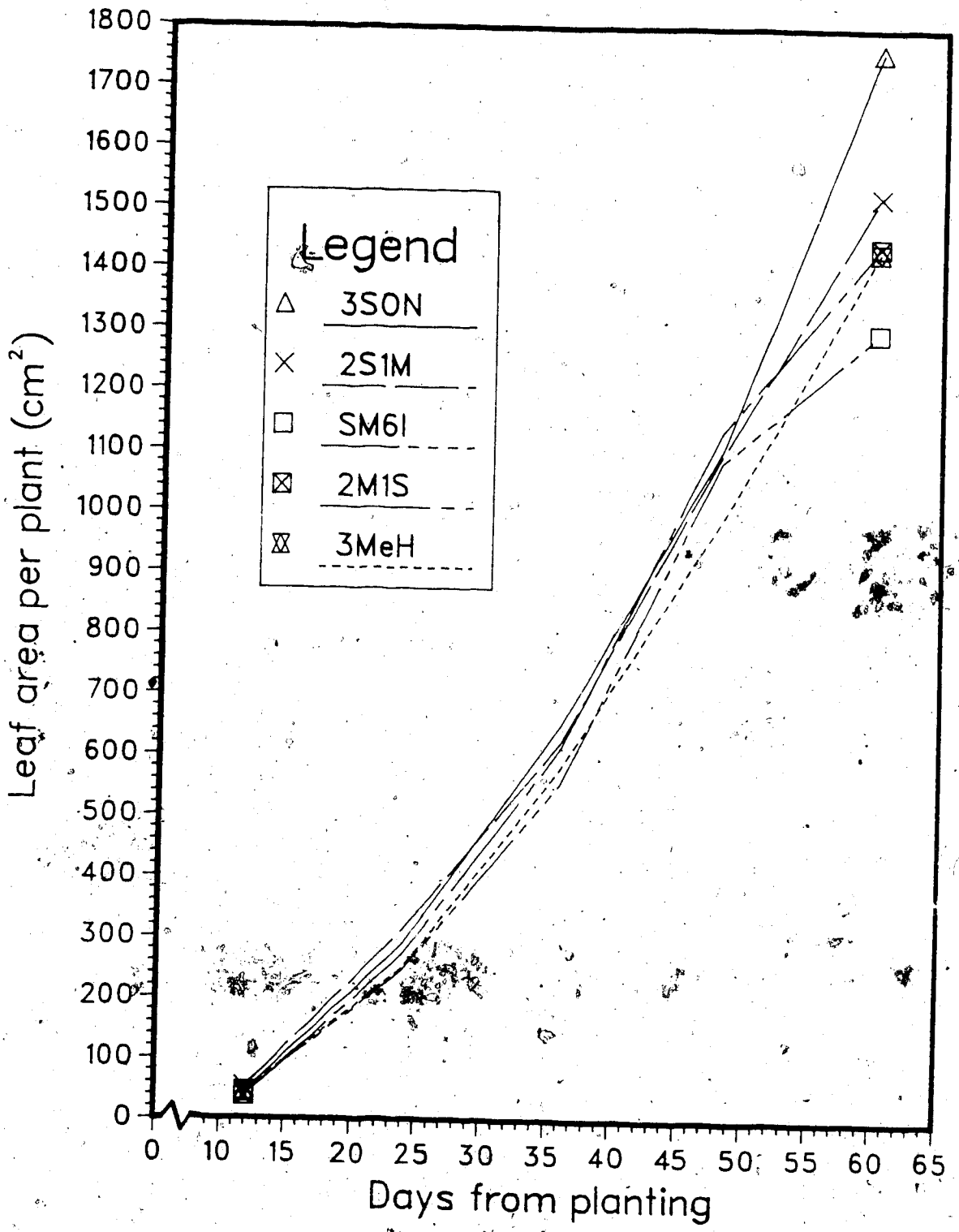

Figure 11. Total leaf area under different light treatments.

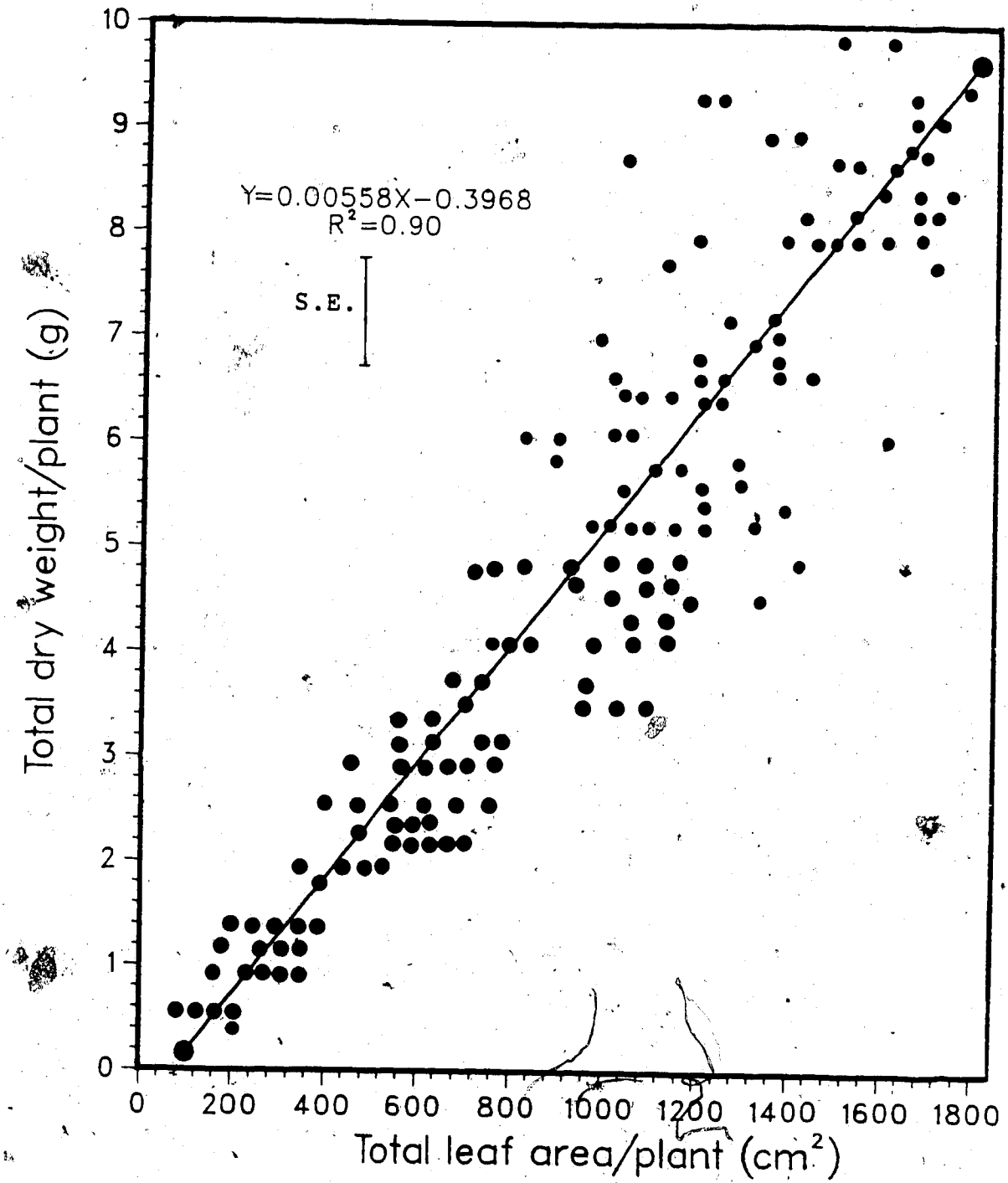

Figure 12. Regression between total dry weight and total leaf area (per plant basis).

4.2.6 RELATIVE GROWTH RATE

There were no significant differences in relative growth rates among plants grown under different light qualities (Table 32). The results showed that, under all light qualities, RGR decreased sharply from the first interval (12-24 days) to the second interval (24-36 days). After the third interval (36-48 days), only plants under 3SON light showed an increase in RGR while a sharp decrease was observed under SM6I light. By the fourth interval (48-60 days), a widening divergence in RGR was indicated among different lights but this trend was not statistically significant. A correlation between RGR and days from planting produced a curvilinear relationship (R^2=0.81). The relationship showed a rapid decrease in RGR up to about 50 days after which it stabilised.

The relationship between relative growth rate and days from planting is:

$$Y=0.274 - 0.0092X + 0.00009X^2$$

R^2=0.81
Standard error=±0.018 g $g^{-1}d^{-1}$
(Y)= Relative growth rate (g $g^{-1}d^{-1}$)
(X)= Days from planting

Significant differences in RGR among plants grown from different seed sources existed only in the first interval (12-24 days). Over the 60-day of growth, there was a narrowing of RGR among sources. The results also showed no

significant interaction between light quality and seed source in relative growth rates.

4.2.7 NET ASSIMILATION RATE

There were no significant differences in net assimilation rates among plants grown under different light qualities at all intervals (Table 33). Plants under all light qualities showed a sharp decrease in NAR from the first interval (12-24 days) to the second interval (24-36 days). After the third interval (36-48 days), plants under 3SON light (most sodium lamps) showed an increase in NAR as compared to other light treatments. There were indications of divergence after the second interval (24-36 days) but the trends reversed themselves after the third interval (36-48 days) and no clear effects of light quality could be described (Figure 13). In the last interval (48-60 days), the highest NAR was obtained under 3SON light and the lowest was under SM6I light. A correlation between NAR and days from planting produced a curvilinear relationship (R^2=0.68) for all light quality observations combined. The relationship showed that NAR decreased rapidly up to about 45 days after planting and then stabilised.

The relationship between net assimilation rate and days from planting is:

$$Y=105.70 - 3.646X + 0.0402X^2$$

$R^2=0.68$
Standard error=±9.62 mg $dm^{-2}d^{-1}$
(Y)= Net assimilation rate (mg $dm^{-2}d^{-1}$)
(X)= Days from planting

There were no significant differences in net assimilation rates among plants grown from different seed sources. The results also showed that there were no significant interactions between light quality and seed source in net assimilation rate.

Table 3. ANOVA and comparisons of means for relative growth rate ($mg\ g^{-1}\ d^{-1}$) using the S-N-K test.

Treatments	I(12-24)	II(24-36)	III(36-48)	IV(48-60)
		t. interval(days)		
Lights	ns	ns	ns	ns
SON	.143 a	.074 a	.054 a	.061 a
2S1M	.143 a	.071 a	.060 a	.046 a
SM6I	.140 a	.074 a	.072 a	.038 a
2M1S	.149 a	.078 a	.060 a	.045 a
3MeH	.135 a	.080 a	.057 a	.045 a
Sources	**	ns	ns	ns
Sabah	.142 a,b	.073 a	.064 a	.046 a
Perak	.151 a	.074 a	.061 a	.049 a
Thailand	.133 b	.078 a	.056 a	.046 a
Interaction				
L x S	ns	ns	ns	ns

(Along each column, means followed by the same letter are not significantly different at P≤0.05 level)
(**: significant at 99%, ns: not significant)

Table 33. ANOVA and comparisons of means for net assimilation rate(mg $dm^{-2}d^{-1}$) using the S-N-K test.

Treatments	Harvest interval (days) I(12-24)	II(24-36)	III(36-48)	IV(48-60)
Lights	ns	ns	ns	ns
3SON	52.53 a	26.20 a	22.13 a	29.27 a
2S1M	54.36 a	28.49 a	29.31 a	25.47 a
SM6I	52.68 a	28.18 a	30.87 a	20.21 a
2M1S	58.35 a	30.13 a	26.02 a	24.39 a
3MeH	53.13 a	32.82 a	25.62 a	25.10 a
Sources	ns	ns	ns	ns
Sabah	54.61 a	29.58 a	30.09 a	24.61 a
Perak	58.39 a	28.97 a	26.77 a	26.54 a
Thailand	49.63 a	28.94 a	23.51 a	23.52 a
Interaction L x S	ns	ns	ns	ns

(Along each column, means followed by the same letter are not significantly different at $P \leq 0.05$ level)
(*: significant at 95%, ns: not significant)

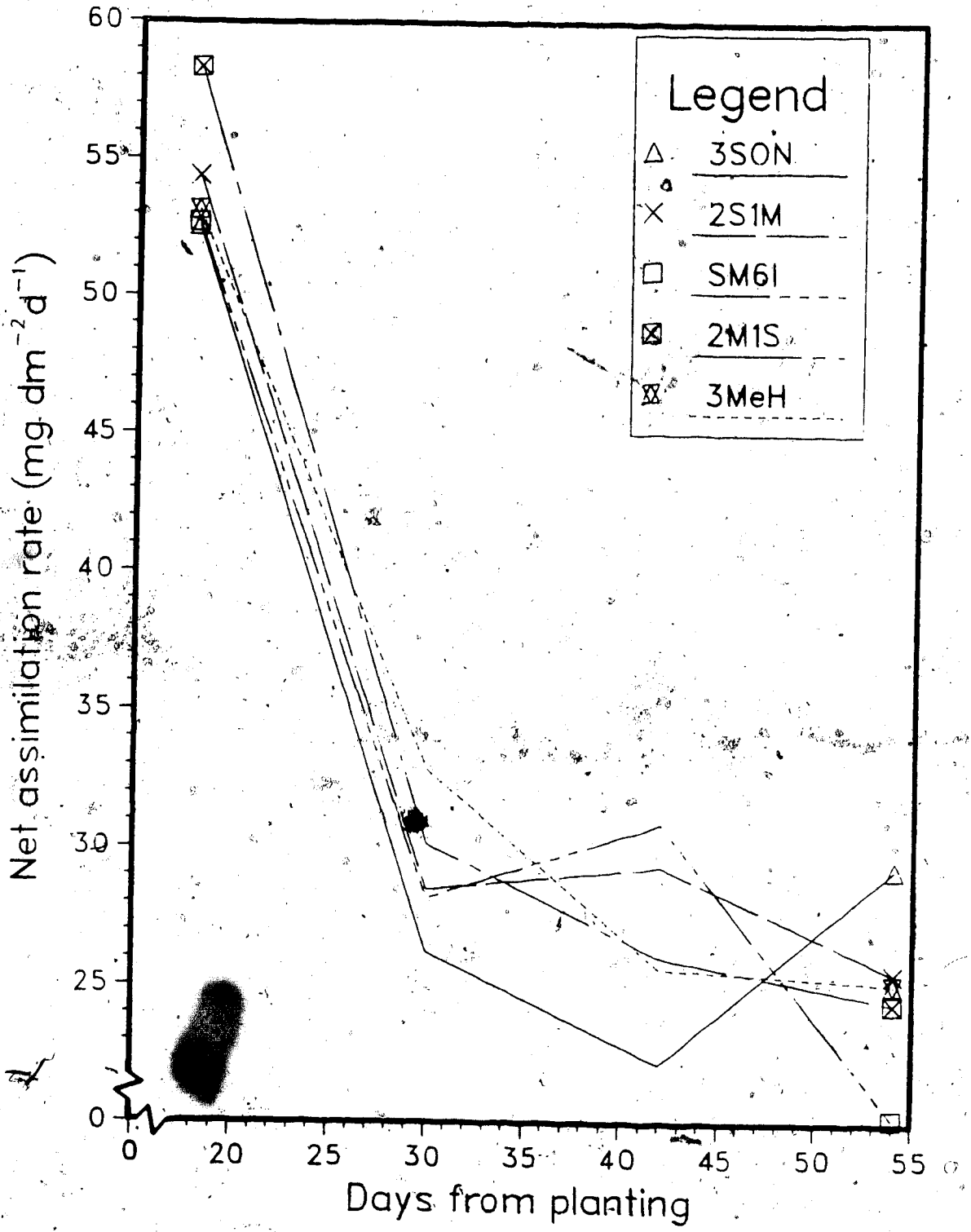

Figure 13. Net assimilation rate under different light treatments.

5. DISCUSSION

5.1 STUDY I

5.1.1 NUT AND SEED SIZE

The purpose of this study was to determine whether there are differences in nut and seed sizes among the three sources and also their relationships to subsequent germination. Nut and seed sizes are important ecological characteristics and are very constant parameters for a species within an ecotype (Harper et al. 1970). Nevertheless, they vary under different environmental conditions which affect fruit and seed development and also the whole plant.

There are several possible reasons for the differences in nut and seed sizes among sources. Seed size is dependent on nut size as reflected in the measurements in Tables 14 and 19. Possible factors influencing the fruit or nut size are:

(1) The results showed that there were no significant differences between the Sabah and Perak sources for either nut or seed sizes (see Table 14 and 19). The Thai source had significantly smaller nuts (length and diameter) at $P \leq 0.01$ and also for seed length at $P \leq 0.05$ as compared to the Malaysian sources. Sabah and Perak sources were within the range measured by

Bowen (1980) as shown in Table 1. The Thai source showed that nut sizes were in close agreement with measurements made by Wasuwanich (1984). He found that the mean length was 13.95 cm and mean diameter was 8.23 cm. There were no available data for Burmese or Indian sources for comparison with Perak or Sabah sources. Due to differences in genetic origins, different sources produced different size nut. *Gmelina arborea* is indigenous to Thailand and both Perak and Sabah sources probably originated from Burma or the same region. This may explain why there were no significant differences in seed and nut sizes between Sabah and Perak sources because of possible similar genetic origins.

(2) Another possible reason might be due to the different degree of maturity and age of the fruits between the Thai and the other sources. Nut and seed sizes are very much influenced by maturity and time of collection (Austin 1972). The timing and collection of *Gmelina arborea* fruits were different for the three locations. The Thai source produce smaller fruits and this could be due to the lower degree of maturity. The fruits might have dropped prematurely due to drastic climatic changes over the past 40 years (Hellum and Wasuwanich 1984). Seed size also varies with season and from year to year (Hellum 1976).

3) As pointed out by Stebbins (1974) and Harper (1977), seed size is an expression of the environmental factors under which it develops. It is an important adaptive and ecological feature of plants. The strategy for seed formation in a plant is a result of compromise among factors like seed number, size, dispersal and also seedling establishment (Thompson 1972). This compromise is critical for the survival and distribution of the species.

The diagrams in Figure 2 show the climatic distinctions between Thailand and Malaysia. The climates of Sabah and Perak are quite similar with high annual rainfall and without a distinct dry period. In Muak Lek, Thailand, the dry period may last from October to May and this affects plant growth adversely. Such a climate is less favorable for growth than those of Perak and Sa[redacted] *Gmelina arborea*, in the Muak-Lek area of Tha[redacted], may no longer be adapted to its own natural environment because of the extensive forest clearing over the last 40 years (Hellum and Wasuwanich 1984). As a result, this species may be out of phase with its own climate and fruits may develop under unfavorable conditions. The results in this study agree well with the findings and opinions of several workers that nut and seed sizes can vary considerably among environments (Yeatman 1965, Stebbins 1974, Harper

1977). Thus the results suggest that nut size is an important ecological expression of the environments under which the plants grow.

5.1.2 GERMINANTS FROM NUTS

The results in Table 20 showed that the number of germinants produced per nut was not related to nut size. Sabah and Thai sources produced higher total germination (65% and 66% respectively) than the Perak source (45%) even though both Sabah and Perak had significantly larger nuts than the Thai source (Table 14). About 50-60% of the nuts did not produce even one germinant. Most of the remaining 50-40% of the nuts produced only one germinant.

Several workers have shown that the actual number of seeds per nut was more than one as shown in Table 2 (Perak:2.2 seeds per nut, Sabah:1.5 seeds per nut, Thailand: no available data). Thus the total germination would be even lower if actual number of seeds per nut was considered in the calculation. The results were close to the means obtained by Okoro (1984) as shown in Table 3 but were much lower than results obtained by Woessner and McNabb (1979). A separate study by Wasuwanich (1984) using fresh and depulped nuts, showed that total germination percent was close to 60% after three weeks. This result agrees with those obtained for the Thai source (about 66%) in this study. The Perak source produced much lower results (45%) as compared to 70-80% obtained by Yap and Wong (1983). The lower results

obtained for the Perak source might be due to differences in the degree of maturity, collection, processing, drying procedures, storage conditions and age of the seed, all of which could reduce seed viability.

Several reasons may account for the low percent germination obtained in this study:

(1) In this study, the duration of germination was only 21 days which might be too short for all seeds to germinate. Studies have shown that germination of *Gmelina arborea* culminated after 30 to 40 days (Yap and Wong 1983, Wasuwanich 1984). Comparisons between published reports and results from this study cannot be made because age of nuts and conditions of germination were different.

(2) The protective flap covering each seed (see Fig. 1) might provide another reason for the low germination percent. The process by which the flap opens is not understood. Soaking for several days or drying in an oven for various time intervals did not produce any positive results (Bowen 1980). The delay or refusal of the flap to open and release the seed might have resulted in lower germination. It is also suspected that the flap prevented rapid water uptake by the seeds which may delay or inhibit germination. Even if water were imbibed by the seeds through the small

hole in the central cavity of the nut, seeds could not germinate fully due to possible insufficient oxygen supply and space for growth and expansion. As a result, seeds that had started active biochemical activities would eventually die when the flaps remained intact. The mechanism of how the flap opens needs further investigation.

3) Another reason for the overall low germination percent might be due to low viability of the three sources. Fruits were collected and processed differently and later flown to Edmonton. Due to variable conditions under which the nuts were exposed and stored, a high proportion of seeds inside the nuts might have lost their viability. Age of nuts and storage conditions have been found to be critical factors affecting germination performance (Woessner and McNabb 1979, Yap and Wong 1983, Wasuwanich 1984, Hellum and Wasuwanich 1984, Bonner 1983). Inadequate pollen shed and incomplete fertilization might also contribute to the low number and viability of the seeds.

4) The pH of the germinating medium might also have reduced the germination. Peat moss is acidic and may not be favorable for germination of *Gmelina arborea*. It has been found that nuts with a fermenting mesocarp, which is acidic, produced very low germination (Aminuddin and Zakaria 1980, Wasuwanich

1984, Woessner and McNabb 1979). The low pH of the fermenting mesocarp probably inhibited germination of the seeds. Nevertheless, no study has been done on the sensitivity of *Gmelina arborea* to different pH levels and this is an area for further investigation.

5.1.3 SEED GERMINATION

There were no significant differences in germination among the three sources (Table 22) even though the Thai source had significantly smaller seeds than the Malaysian sources (Table 19). Thus nut and seed sizes did not affect germination performance. It has also been pointed out that seed sizing should not be used for seedling production because of possible reduction in genetic base and also variability (Hellum 1976, Silen and Oosterhaus 1979).

The highest total germination, from the regression equation, was 77.2% obtained at an optimum temperature of 29.8°C. This is very close to the temperature of 30°C recommended by Bowen (1980) for best germination of *Gmelina arborea*. The relationship between total germination and temperature showed that the range suitable for germination was very narrow and specific for this species. A slight shift from the optimum temperature (29.8°C) reduced the total germination significantly. This study also indicated that *Gmelina arborea* seeds can tolerate only short periods of exposure to high temperatures. To obtain maximum

germination, temperature and the duration of exposure must be closely monitored. This study also showed that maximum germination dropped to nearly 0% within a 10-15°C range around the mean (29.8°C).

Such germination characteristics for *Gmelina arborea* have great ecological inplications. The narrow range of temperature tolerance for seed germination may explain the restricted and isolated distribution of the species under natural conditons (Troup 1921, Brandis 1972). As pointed out by several authors, germination response to temperature can influence survival and distribution of the species greatly (Townsend and McGinnies 1972, Thompson 1970, Mayer and Poljakoff-Mayber 1975, Koller 1972). A study on *Gmelina arborea* showed that nuts transferred from shade conditions to open sunlight produced a higher germination percentage (Aminuddin and Ng 1982). The observation might be due to changes in temperature rather than just a light effect as concluded in that paper.

In this study, germination was carried out under constant temperatures while one would expect temperatures to fluctuate between day and night under natural conditions. From this study, it is impossible to speculate whether alternating temperatures would affect the germination response of *Gmelina arborea* differently than did constant temperatures because available literature could support either view (Ellern and Tadmor 1967, Young et al. 1981, McElgunn 1974, Harty and Bulter 1975, Hsu et al. 1985).

Since the species is shade intolerant and grows best in open areas, germination might be expected to be best under alternating temperatures. This is another interesting field for further investigation.

5.2 STUDY II

5.2.1 LIGHT QUALITY AND IRRADIANCE

The five lamp combinations in this study produced different but overlapping spectral compositions and irradiances (Figure 14). As a result, it is difficult to determine which light quality was the predominant factor and which wavelengths contributed most to growth. The responses toward light also change with growth and age of plants (Leopold and Kriedeman 1975, Smith 1982, Walter 1979). Wavelengths in the red (600-700nm), blue (400-500nm) and far-red (700-800nm) parts of the spectrum are the most important for growth and development (Meijer 1971, Smith 1982, Morgan et al. 1983, Vokresenskaya 1979). The highest proportion of red light was obtained under the 3SON combination which had 3 sodium lamps and the highest proportion of blue light was obtained under the 3MeH combination which had 3 mercury lamps. The SM6I combination, which had 1 sodium lamp, 1 mercury lamp and 6 incandescent bulbs, produced the highest proportion of far-red light. Table 34 shows that irradiances and the proportion of red:far-red under each light treatment were not equal. The

differences in irradiance and spectral output were due to different radiant efficiencies of the lamps, the materials used and their wattages.

A preliminary Co_2-exchange measurement was carried out with five 20 day old *Gmelina arborea* seedlings to determine the light saturation level. Net assimilation was monitored by differential infrared gas analysis (Infrared gas analyzer-Model 865 Beckman Instr. Corp.). The results indicated that light saturation level was between 700 to 1000 μmol $m^{-2}s^{-1}$. Thus, the irradiance levels for the five light treatments were low for optimum photosynthetic potential of the plants. The differences in red to far-red ratio (zeta ratio) of the five light treatments also influence the developmental processes of the plants.

Table 34. Light irradiances and red:far-red ratios under different lamp combinations.

	Light Codes	Red:far-red ratios	Irradiances (μmol $m^{-2}s^{-1}$)
1.	3SON	2.51	462
2.	2S1M	2.43	420
3.	2M1S	2.21	394
4.	3MeH	2.07	374
5.	SM6I	1.24	356

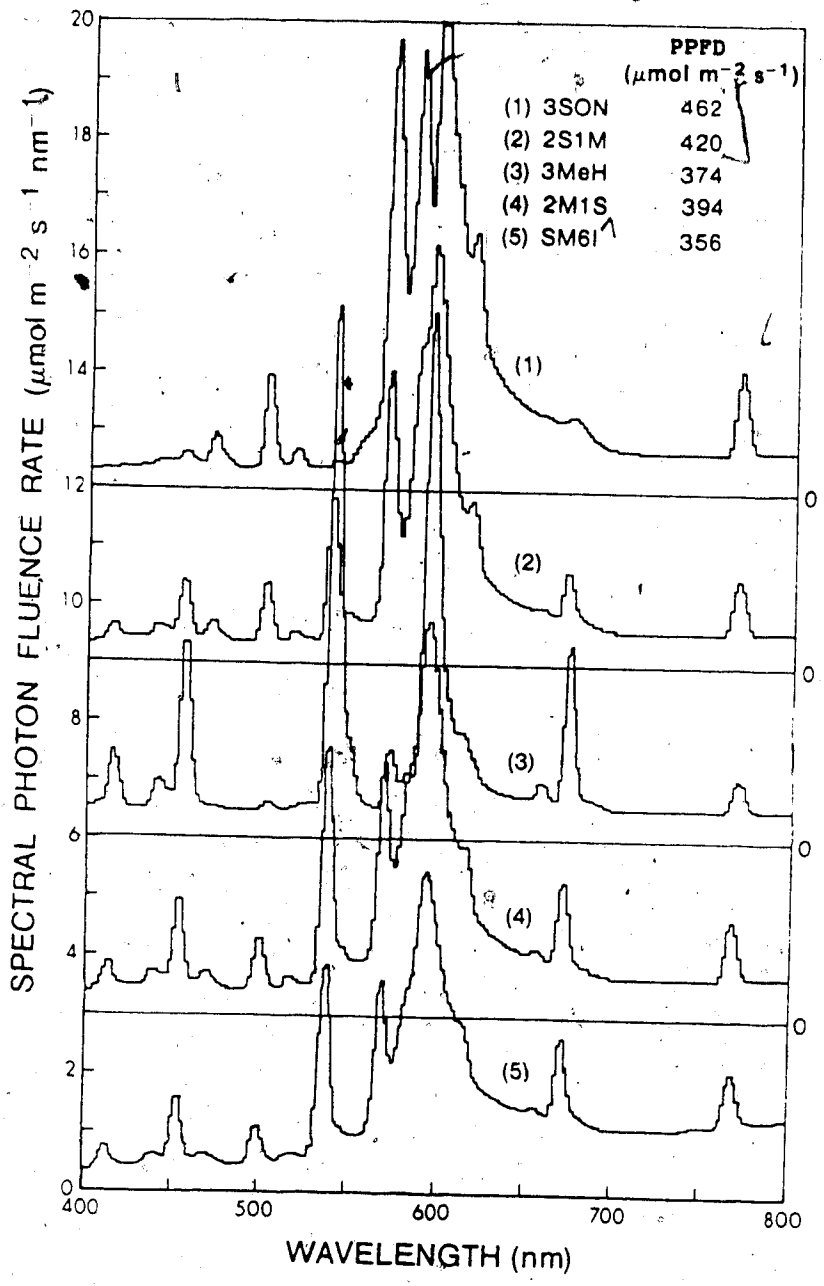

Figure 14. Spectral distribution of five light treatments using different lamp combinations.
1. 3SON: 3 units High Pressure Sodium lamps.
2. 2S1M: 2 units sodium + 1 unit metal halide.
3. 3MeH: 3 units High Pressure Metal Halide lamps.
4. 2M1S: 2 units metal halide + 1 unit sodium.
5. SM6I. 1 unit sodium + 1 unit metal halide + 6 units Incandescent Bulbs.

H.P. Sodium lamp =400W (SON/T Philips G/92/2)
H.P. Metal Halide=400W (HPI/T Philips G/92/2)
Incandescent Bulb=150W (Sylvania)

5.2.2 ROOT-SHOOT RATIO

Root-shoot ratio is an important factor affecting survival of seedlings after outplanting. The distribution of dry matter between the shoot (leaves and stem) and the root forms an important mechanism by which plants adapt to their environments. Plants must therefore strike a balance between the growth of shoot and root so that severe internal stresses are minimised. Under low light, plants produced larger but thinner leaves and had smaller root systems (Bormann 1958 , Sasaki and Mori 1981). Conversely, under high light intensities, plants are known to produced larger root system compared to the shoot (Kozlowski 1949, Steinbrenner and Rediske 1964). Leaf expansion, stem elongation and rate of photosynthesis also vary under different light qualities which in turn affect the root-shoot ratios.

Differences in light quality in this study did not bring about differences in root-shoot ratios in *Gmelina arborea*. Nevertheless, possible differences could not be ruled out because a widening divergence was indicated particularly after 48 days (Fig. 7). The 60-day test period might have been too short to produce any significantly different responses under the light treatments.

Plants under SM6I light generally produced lower root-shoot ratios compared to other light treatments. Irradiance under this light was lowest at 356 μmol $m^{-2}s^{-1}$ and was probably a reason which induced a greater allocation

of dry matter for leaf production and less for root growth. Another reason was probably due to the low red:far-red light ratio (1.24) compared to other light treatments. A low red:far-red ratio induces greater allocation of dry matter for stem growth and elongation (Morgan et al. 1983, Holmes et al. 1982, Axelson et al. 1979). Thus a greater amount of dry matter was distributed to above ground growth and this resulted in lower root-shoot ratios.

Higher root-shoot ratios were obtained under 3MeH compared to 3SON light even though no statistical significance was demonstrated. 3SON light produced plants with generally lower root-shoot ratios particularly after 24 days. Light irradiance under 3MeH was lower (394 μmol $m^{-2}s^{-1}$) than 3SON light (462 μmol $m^{-2}s^{-1}$). In this case, higher irradiance did not produce higher root-shoot ratios as expected. In term of light quality, 3SON light had a higher proportion of red light which promoted leaf growth and expansion (Axelson et al. 1979, Erner et al. 1972). Under 3MeH light, which had a higher amount of blue light, shoot and height growth were also inhibited to some extent (Gaba and Black 1983, Meijer 1971, Erez and Kadman-Zahavi 1972). Thus the differences in root-shoot ratios between 3SON and 3MeH were influenced more by different light qualities rather than irradiance. With larger leaf and shoot growth under 3SON light, root-shoot ratios were lower than under 3MeH light.

The results indicated that under equal energy input, 3SON light (more red light) would produce lower root-shoot ratios than 3MeH light (more blue light). The results of this study also agree with those found by Warrington and Mitchell (1976) where root-shoot ratios of seedlings were lowest under red-biased light and highest under blue-biased light. They also found that root-shoot ratios were generally higher under high irradiance as compared to low irradiance levels.

Over the 60-day of growth, root-shoot ratios changed rapidly in a similar trend under all light treatments (Fig. 7). It has also been suggested that the rapid change of root-shoot ratios might be adaptive in nature (Ledig et al. 1970, Kramer et al. 1960). Such developmental patterns allow the seedlings to pass most rapidly through any critical and vulnerable stages of growth. In this case, a high proportion of dry matter was invested in photosynthetic tissue production which caused a rapid drop in root-shoot ratios. Following increased leaf areas and carbon synthesis, the plants then shifted back to higher root growth as indicated by increasing root-shoot ratios after about 36 days (Fig. 7).

Seedlings with higher root-shoot ratios are preferred for outplanting so that survival and growth may be improved (Lopushinsky and Beebe 1976). A higher root-shoot ratio indicates greater root biomass and also better rooting potential. The ability of the root system to grow rapidly is

equally important when outplanted. In this study, the results showed that root-shoot ratios increased more rapidly under 3SON, 2S1M and 2M1S lights than 3MeH and SM6I lights after 48 days (Fig. 7). The more rapid increase in root-shoot ratios under 3SON, 2S1M and 2M1S lights was probably due to the higher red light content. Red light promotes shoot and leaf growth which, in time, also leads to greater dry matter for root growth.

5.2.3 ROOT-COLLAR DIAMETER AND SHOOT HEIGHT

Root-collar diameter and shoot height are closely related and are discussed together. There were no significant differences in root-collar diameters among light treatments (Table 27). Shoot height under SM6I light showed significant differences from other lights except on day 60. This was probably because the seedlings were already too close to the lamps (about 30cm away) and the effects of heat had reduced height growth. Other reasons for such growth characteristics under SM6I light were probably due to the low red:far-red light ratio and also the low irradiance.

Under SM6I light, red:far-red ratio was lowest at 1.24 and therefore shoot growth was greatly promoted. There were no significant differences among other light treatments probably because the differences in red:far-red light ratios were not large enough. Another reason was probably due to the low irradiance under SM6I light which promoted greater height growth. Photosynthetically active radiation (PAR) was

356 μmol $m^{-2}s^{-1}$ under SM6I light, which was lowest compared to the others. Plants under such light conditions allocated a greater proportion of their dry matter for height growth and less for diameter and root growth. This was indicated by generally lower values in root-shoot ratios and also root-collar diameters under SM6I light. Similar experiments with incandescent bulbs also produced seedlings with thinner stems and longer internodes (Garner and Allard 1931, Withrow and Withrow 1947).

The results showed that height growth was generally taller under 3SON (more red light) than under 3MeH (more blue light). Shoot height was also reported to be tallest under red-biased light and lowest under blue-biased light by Warrington and Mitchell (1976). The amount of blue light under 3MeH appeared to have a stronger effect than the red:far-red ratio on height growth. This was because the lower red:far-red light ratio of 2.07 under 3MeH did not produce taller plants than 3SON light which had a higher ratio of 2.51. In this case, the differences in red:far-red light ratios might be too small to cause any effect or the ratios had reached a saturation level which no longer affected height growth. Root-collar diameters were generally larger in all intervals under 3SON light compared to 3MeH light even though no statistical significances were detected. This was due to the more rapid growth of above ground biomass under 3SON than 3MeH.

The Thai seedlings generally had smaller root-collar diameters and less height growth than the plants from Malaysia given similar growth conditions. These differences cannot be explained but may be related to differences in genetic origins and climates. There were no differences between sources from Perak and Sabah.

5.2.4 DRY WEIGHT AND LEAF AREA

Total dry weight and total leaf area are closely related and are discussed together. Dry weight production is influenced by the photosynthetic leaf areas and net assimilation rates of the plant. Expansion of leaf area in turn provides larger surface area for photosynthesis and dry matter production. Leaf areas were linearly correlated to dry weights. Data scattering increased with increasing plant size which was particularly clear after 48 days of growth. The increase in scattering was probably due to the gradual appearence of growth responses and characteristics under different light conditions over time.

A rapid increase in leaf area and dry weight was obtained under 3SON (most red light) after 48 days. Leaf growth and expansion were greatly promoted which allowed greater energy capture and carbohydrate formation through photosynthesis. The increase in carbon synthesis in turn increased the total dry weight of the plants. Red light generally produces greater plant dry weight (Arthur and Harvil 1937, Stevenson and Dunn 1965, Dunn and Went 1959,

Morikawa et al. 1976). Warrington and Mitchell (1976) also found that dry weight of seedlings was at least twice as large under red-biased light compared to blue-biased light. Leaf areas increased up to 20 times when red-light was added to white light (Axelson et al. 1979). Red-light has also been found to promote carbohydrate synthesis in plants (Warrington and Mitchell 1976, Voskresenskaya 1967, Szasz and Barsi 1971).

Plants under 3MeH (most blue light) generally produced less leaf area and dry weight compared to 3SON light. This was probably due to the lower amount of red light in the 3MeH light treatment. The higher blue light content probably also had an inhibiting effect on shoot and leaf growth as suggested by Gaba and Black (1983) and Meijer (1971).

There was significantly lower dry weight and leaf area under SM6I light compared to 3SON light after 60-day of growth. A widening divergence was indicated in both parameters particularly after 48 days. The low values obtained under SM6I light were probably due to unfavorable light qualities for leaf expansion and the low light irradiance. As a result, energy capture and photosynthesis were reduced because of smaller leaf surface areas.

The distribution of dry weight of leaves, stems and roots showed similar patterns among the five light treatments (Fig. 10). The proportion of dry matter allocated to the leaves decreased steadily from about 65% to 50%. This indicated a high investment in photosynthetic tissues during

the early stages of growth which was neccessary for rapid carbon fixation. As the seedlings grew, more of photosyntates were allocated for stem and root growth which were needed to increase strength, support and translocation. Values quoted for young conifers (age not stated) in a study by Larcher (1980) also showed green mass (leaves) ranged from 50% to 60% of total weight. The proportion of stem dry matter increased steadily from about 15% to 30% over the growing periods. Because *Gmelina arborea* is a tree, it is expected that the proportion of stem weight should increase preferentially as the plant matures. The proportion of root dry weight also changed overtime as indicated by the root-shoot ratios. It depends very much on the environment and the water requirement of the above-ground biomass. According to figures quoted by Larcher (1980) for evergreen mature trees of tropical and subtropical forests, the final distribution of dry weights was about 2% for leaves, 78-88% for the trunk and 20-10% for roots. Results of this study indicated a steady decrease in the proportion of leaf dry weight and a steady increase in stem dry weight.

5.2.5 RELATIVE GROWTH RATE AND NET ASSIMILATION RATE

Relative growth rate (RGR) is a function of net assimilation rate (NAR) and leaf area ratio. NAR indicates the photosynthetic efficiency of the leaves and measures the rate of increase in dry matter per unit leaf area. Leaf area ratio measures the leaf area per unit dry matter of the

plant. RGR indicates the overall growth rate of the whole plant and measures the rate of increase in dry matter per unit of initial dry matter of the plant. In order to achieve a high relative growth rate, plants need a high photosynthetic efficency and also a large leaf area.

In this study, RGR and NAR did not show any significant differences among test seedlings grown under different light treatments. The relative growth rate seems to follow a similar trend to the net assimilation rate (Tables 32 and 33). The rapid decrease in NAR over the first 30 days of growth under all light treatments was due to rapid increase in leaf areas during early growth. High leaf expansion and growth were needed for photosynthesis and carbon production. There were indications of widening divergences among plants under different light treatments particularly after 42 days. Two lights (3SON and SM6I) produced contrasting trends after this period even though statistical significances were not demonstrated. NAR increased rapidly and was highest under 3SON light by day 54 but it was lowest under SM6I light.

The rapid increase in NAR under 3SON light after 42 days was probably due to increased carbon demand for root growth and leaf expansion. In the first 36 days, above-ground biomass increased more rapidly than root biomass as indicated by decreasing root-shoot ratios (Fig. 7). After this period, a shift in biomass to root growth was shown by increasing root-shoot ratios. Expansion of root was to increase support and water and nutrient uptake to the

expanded above-ground biomass. At the same time, leaf areas also expanded rapidly in order to maximise energy capture for carbon production. The net result was an overall rapid increase in dry weight (Fig. 9) with largest leaf areas and highest NAR by day 60.

Under SM6I light, NAR decreased sharply after day 42 and was lowest among the light treatments by day 54. Such a decrease was probably due to the low content of red light under SM6I which was lacking to promote leaf expansion and also the low irradiance which was insufficent for effective photosynthesis. As a result, the rate of dry weight increase also decreased after 48 days and was the lowest among light treatments by day 60 (Fig. 9).

NAR in this study ranged from 25 to 55 mg $dm^{-2}d^{-1}$. Larcher (1980) also quoted similar ranges for tropical and subtropical cultivated plants with rates during the main growing season ranging from 30 to 50 mg $dm^{-2}d^{-1}$. Jarvis and Jarvis (1964) presented data for maximum NAR of most woody plants from about 30 to 70 mg $dm^{-2}d^{-1}$. Okali (1971) also found NAR ranging from 20 to 70 mg $dm^{-2}d^{-1}$ for four tropical forest tree seedlings in Nigeria. RGR in this study ranged from 0.05 to 0.15 g $g^{-1}d^{-1}$. Okali (1971) found RGR ranging from 0.02 to 0.10 g $g^{-1}d^{-1}$ and Jarvis and Jarvis (1964) quoted values for tropical species from 0.02 to 0.12 g $g^{-1}d^{-1}$. However, comparisons of any results must be made with caution because conditions of growth and age of seedlings tested were different and can vary significantly.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 STUDY I

6.1.1 CONCLUSIONS

(1) Nuts from Perak and Sabah were significantly larger (both in length and diameter) than the Thai source ($P \leq 0.01$ level). The difference in sizes did not affect germination performance.

(2) The optimum constant temperature for total germination was 30°C and for the most rapid germinative rate, it was 33°C. Total germination at 30°C was 77.2% and the germinative rate at 33°C was 2.5 days.

(3) There was no germination at constant temperatures below 18°C or above 41.5°C.

(4) There were no significant differences in germination performance among seed sources in this study.

6.1.2 RECOMMENDATIONS

(1) In order to achieve highest total seed germination in *Gmelina arborea*, an incubation constant temperature of 30°C should be used, judging by this study.

(2) Seeds could not tolerate constant temperatures above 41.5°C. Therefore, care should be taken not to

expose the seeds or nuts for too long to temperatures above 41.5°C.

(3) Further investigaton should be carried out to determine the mechanism by which the flaps of the nuts protecting the seeds open. Further study should also be carried out to examine the sensitivity of *Gmelina arborea* seeds to alternating day-night tempeatures and to different pH levels.

6.2 STUDY II

6.2.1 CONCLUSIONS

(1) There were no significant differences among seedlings grown under different light treatments in root-shoot ratios, root-collar diameters, relative growth rates and net assimilation rates in this study. Nevertheless, indications of widening divergence were observed between high red light and low red light for all indices particularly after 48 days of rearing.

(2) There were significant but variable differences among seedlings grown under different light treatments in shoot heights, dry weights and leaf areas over the 60 days of growth.

(3) The 3SON light with 3 sodium lamps was most suitable for the production of seedlings up to 60 days old. Seedlings showed rapid increases in root-shoot

ratios, root-collar growth, height growth, leaf and dry weight increment after 60-day of rearing. Relative growth rates and net assimilation rates were also highest by day 60. The SM6I light (1 sodium lamp, 1 mercury lamp and 6 incandescent bulbs) gave rise to tallest seedlings but root-collar diameters were relatively small. Seedlings under SM6I light also had lowest root-shoot ratios, root-collar diameters, total dry weights, total leaf areas, relative growth rates and net assimilation rates by day 60.

(4) The Sabah and Perak seed sources grew significantly larger seedlings than the Thai source. Even where differences among sources were not significant, the Thai source generally produced the lowest values.

6.2.2 RECOMMENDATIONS

(1) In order to produce seedlings for outplanting under artificial light, high pressure sodium lamps should be used. Seedlings grew rapidly and indicated high potential for establishment after 60 days.

(2) The Malaysian (Sabah or Perak) sources grew more rapidly than the Thai source. They would therefore appear to be the better choices for reforestation where applicable.

(3) For future studies of this kind, all light

treatments should be adjusted to produce equal light irradiances. The duration of growth should be extended beyond 60 days because most plants only began to show significant divergence in their growth responses after 48 days. It is also recommended that seedlings produced in nurseries should be grown for more than 60 days to reach optimum plant size for either direct planting or stumping.

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