BIODIVERSITAS
Volume 20, Number 8, August 2019
Pages: 2110-2118

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d200803

Influences of inorganic and organic fertilizers to morphological quality attributes of *Shorea macrophylla* seedlings in a tropical nursery

MUGUNTHAN PERUMAL♥, MOHD EFFENDI WASLI, HO SOO YING
Faculty of Resource Science and Technology, Universiti Malaysia Sarawak. 94300 Kota Samarahan, Sarawak, Malaysia.
Tel. +60-16-8513690, ♥email: mugunthanperumal89@gmail.com

Manuscript received: 13 May 2019. Revision accepted: 10 July 2019.

Abstract. *Perumal M, Wasli ME, Ho SY. 2019. Influences of inorganic and organic fertilizers to morphological quality attributes of* Shorea macrophylla *seedlings in a tropical nursery. Biodiversitas 20: 2110-2118.* Better understanding and implementation of nursery cultural regimes to improve seedling quality with high survival capability and optimal growth potential are one of the pivotal aspects of a successful forest restoration program. An experiment was set to determine the influences of inorganic and organic fertilizers on the morphological quality attributes of *Shorea macrophylla* (de Vriese) P.S. Ashton seedlings. For seedling production, the pots were filled with a 1:1 mixture of topsoil and sand (v:v), following the standard forest nursery practice. Either a chemical fertilizer (CF, N: P: K = 10: 26: 10) or a blend of 360-day (80% elution of the ingredients at 25˚C) controlled-instant release fertilizer (CIRF, N: P: K = 10: 26: 10) or a jellyfish fertilizer (JF, N: P: K = 13.1: 1.7: 0.03) was applied at the rate of 5 g per pot. The findings revealed that the morphological quality attributes of *S. macrophylla* seedlings treated with JF were significantly higher ($P < 0.05$) than the seedlings treated with CF and CIRF at the end of nursery growing season. Notwithstanding, in terms of seedling quality indicators, seedlings from all the treatments were fit to the general expectations of a balanced root to shoot ratio values (RS < 2) and the seedlings raised in the nursery were of sub-optimal quality. Consequently, stock quality evaluation requires the integration of both morphological and physiological attributes of seedlings that provides a more effective appraisal of the fitness of seedlings to become established for field planting.

Keywords: Forest restoration, morphological quality attributes, nursery fertilization, Sarawak, *Shorea macrophylla*

INTRODUCTION

In the humid tropics of Borneo, *Shorea macrophylla* (de Vriese) P.S. Ashton is mainly chosen on the basis of its socio-economic and ecological importance as one of the common indigenous tree species used for tropical forest rehabilitation and reforestation programs in Sarawak, Malaysia (Perumal et al. 2015, 2017a, b). This endemic riparian species, locally known as "*Engkabang jantong*" (Light Red *Meranti*) (in Malaysia) and "*Tengkawang Hantelok*" (in Indonesia) belongs to the family of Dipterocarpaceae, the most important family of tropical rainforest trees in Southeast Asia (Utomo et al. 2018). *S. macrophylla* is commonly known in Sarawak as a medium to a large timber-sized tree and the seeds are highly valued for its oil-bearing fruits or known as the large-fruited species of illipe nuts, a substitute for cocoa butter, and sources of a fatty substance that can be used as medicine (Connell 1968; Tompsett and Kemp 1996; Ng et al. 2002). Under the natural condition in suitable areas, this climax species can attain a height of 50 m, 50-60 cm in diameter at breast height within 20-23 years (Newman et al. 1996) and 2.0 m in buttress height in the mixed dipterocarp forests of Sarawak and Brunei (Ashton 1964, 1982). This lowland tree species is one of the fastest-growing species in the genus (*Shorea*), and is found frequently in wet habitats, such as along the rivers and in areas which are periodically inundated (Ashton 1998; Perumal et al. 2017a, b; Mohamad Jaffar et al. 2018a, b, c). *S. macrophylla* flowers sporadically in mass flowering years (Appanah and Weinland 1993) and produces recalcitrant seeds with at most 1-month viability after collection (Ng 1976). Due to their fast growth and their hardiness, *S. macrophylla* is a prime candidate for reforestation programs in the humid tropics with poor soils.

Experimental reforestation programs using nursery-produced seedlings can be an effective means of ensuring successful establishment and rapid growth following outplanting (Pinto et al. 2011). According to Scagel et al. (1998), the success of reforestation regularly hinges on considerations and decisions made prior to plantings, such as seedling morphology, seedling stock-type, genetics, site preparation, site limiting factors, planting techniques, and the outplanting window. However, several constraints on dipterocarp seedling production due to irregular flowering and unpredictable fruiting intervals in the tropics had restricted the scale of reforestation programs (Tang and Tamari 1973; Chan and Appanah 1980; Lo 1985; Aminah et al. 1995). In particular, more than 70% of emergent trees of the family Dipterocarpaceae, which dominates the tropical rain forests of South East Asia are involved in mass flowering events, but seldom reproduce in other years (Sakai et al. 1999; Ichie and Nakagawa 2013). In Southeast Asia, reforestation using dipterocarps has been initiated by several researchers (Ådjers et al. 1995, 1996; Sakurai et al. 1999; Arifin et al. 2008; Wasli et al. 2014; Perumal et al. 2015, 2016, 2017a, b).

Seedling quality is generally defined as “fitness for purpose” (Mattsson 1997), which indicates that quality seedlings should meet the desired level of survival and growth upon outplanting. Despite advances in seedling quality testing and the prediction of field performance, no single characteristic or test has been proved suitable across a wide range of species and conditions (Dey and Parker 1997; Jaenicke 1999; Davis and Jacobs 2005). This suggests that superior seedling attributes that associate with survival and growth in the field need to be investigated and determined for any species intended for planting. Various seedling quality assessment methods and their importance in forecasting field performance have been developed and tested over the past two decades (Folk and Grossnickle 1997; Mattsson 1997; Mohammed 1997; Grossnickle and MacDonald 2018). Seedling morphological attributes are the most common attributes used in seedling quality assessment since they are cheap and easy to be measured (Mexal and Landis 1990), however, this is rarely done in Malaysia. Unlike physiological attributes, they do not require sophisticated equipment and advanced training to evaluate them (Nyoka et al. 2018). Seedling morphological attributes, such as shoot height, root collar diameter, sturdiness, root biomass, shoot biomass (Haase 2008), and root to shoot ratio are widely used to assess seedling quality in nursery and at the time of planting.

Proper application of fertilizer types is important for nursery productivity and seedling values. Fertilization is one of the essential cultural practices for seedling quality in reforestation as it can accelerate the growth of the shoots and roots of seedlings (Chun et al. 2012). Though, poor response of the dipterocarp seedlings to easily soluble or liquid fertilizer has been suggested (Turner et al. 1993; Lee and Alexander 1994). Fertilization affects root and shoot growth of plants, improves post-transplant rooting and growth capacity, and increases resistance to water stress, low temperature, and disease (van den Driessche 1991, 1992; Malik and Timmer 1998; Shaw et al. 1998; Grossnickle 2000; Fløistad and Kohmann 2004). These characteristics are of crucial importance for successful early establishment under unfavorable conditions (Puttonen 1997), and can be influenced substantially by alternative fertilization regimes.

Many studies have documented the influences of fertilization or mineral nutrition on seedling quality for reforestation, though most of these focus on conifers from wet, temperate forests, with emphasis on nitrogen additions (Green and Mitchell 1992; Green et al. 1994; Timmer and Aidelbaum 1996; Folk and Grossnickle 1997; Tan and Hogan 1997; Irwin et al. 1998; Quoreshi and Timmer 2000; Jose et al. 2003). Relatively very little is known and no clear consensus exists, whether seedling production based on different types of fertilization regimes influence initial seedling morphological quality attributes on the capacity of dipterocarp species from Malaysia to resist transplanting stress once outplanted. Although considerable studies on seedling quality have been carried out in temperate regions (Europe and North America) and in other tropical and subtropical regions in Australia and Asia, many of these studies have focused on seedlings for commercial plantations with very little work on seedlings destined for restoration and agroforestation (Nyoka et al. 2018). Nonetheless, previous studies also reported that simple fertigation did not improve the growth of pot grown dipterocarp seedlings in the nursery (Turner et al. 1993; Lee and Alexander 1994). Thus, the effective methods of fertilizer application under nursery and field conditions have not been thoroughly developed and quantified.

The objective of the present study was to determine the influences of inorganic and organic fertilizers on the seedling morphological quality attributes of *S. macrophylla* in a tropical nursery as to develop a practical technique for producing healthy and quality seedlings in ensuring better field performance. The assessment focused on the influences of different types of fertilizers on the morphological attributes, which collectively provide adequate information on the quality of seedlings as well as their likelihood of survival and growth upon outplanting. Notwithstanding, the results of the present study could provide some useful applied information as well as guidelines to the nursery community and forest managers towards improving the current nursery management practices and physical seedling quality assessment which may enhance seedling survival and productivity for future successful reforestation programs in Sarawak, Malaysia. We, specifically, addressed the following question in this study: To what extent do fertilizer regimes affect seedling performance of *S. macrophylla* at the end of nursery culture prior to outplanting?

MATERIALS AND METHODS

Study site

This study was conducted in the Universiti Malaysia Sarawak forest research nursery (N01˚27’820”, E110˚27’079”) located in Kota Samarahan, Sarawak, Malaysia from February-November 2015. During 2015, the study site received 2,898.0 mm of rain (Drainage and Irrigation Department 2017). Monthly average air temperature and relative humidity were 27.0˚C and 83.4%, respectively (Meteorological Department 2017).

Seed collection and seedling production

Seeds of *S. macrophylla* were collected from Sampadi Forest Reserve, Lundu, Sarawak (N01˚34’13”, E109˚53’12”) during a masting event, which began in late January-February 2015. On February 7, 2015, visibly healthy (i.e., free of fungus, decay, and herbivore damage) and uniform sized seeds were selected, dewinged, and sown directly into black, perforated, polyethylene bags (15.2 cm in diameter, 22.9 cm in deep) with several drainage holes at the bottom. Bags were placed bare ground under a white transparent net. To maintain optimum soil moisture, seedlings were watered once a day in the beginning and then as required. Hand weeding was done regularly.

Table 1. Initial and final (270 DAS) chemical characteristics of the growing medium.

Soil chemical parameters		Soil chemical properties			
		Initial	Final (270 DAS)		
			CF	CIRF	JF
pH (H_2O)		5.30 ± 0.12	5.58 ± 0.26	4.79 ± 0.25	5.23 ± 0.28
EC[1]	(μS cm^{-1})	28.2 ± 1.2	40.1 ± 8.2	52.8 ± 18.6	17.3 ± 8.8
Total C[2]	(g kg^{-1})	26.0 ± 1.8	17.6 ± 2.5	16.5 ± 1.9	10.1 ± 3.3
Total N[3]	(g kg^{-1})	0.63 ± 0.19	0.33 ± 0.11	0.19 ± 0.07	0.18 ± 0.06
Available P	(mg P kg^{-1})	1.30 ± 0.09	73.5 ± 29.2	128.3 ± 70.8	1.4 ± 0.4
Exch. K^+	($cmol_c$ kg^{-1})	16.3 ± 2.6	0.09 ± 0.08	0.14 ± 0.04	0.03 ± 0.03

Note: Values in the same column indicate means ± standard deviation, [1] EC: Electrical Conductivity, [2] Total C: Total Carbon, [3] Total N: Total Nitrogen

Preparation of growing medium and fertilization treatments

The controlled-instant release fertilizer (CIRF) treatment used in this study was a blend of 80% polyurethane coated controlled-release fertilizer (CRF) with 20% uncoated instant release fertilizer. The CRF was designed by the manufacturer which consists of prills that expected to display an 80% elution of its nutrients within 360 days assuming a soil temperature of 25˚C at position of fertilizer placement. The uncoated fertilizer disperses its nutrients instantly under normal watering condition (once daily). For seedling production in the nursery, the pots were filled with about 2.0 kg of 1:1 mixture of topsoil and sand (v:v), following the standard forest nursery practice for dipterocarp species adapted in Sarawak. The initial and final (270 Days After Sowing) chemical characteristics of the growing medium are presented in Table 1. The three fertilizer formulations, either a chemical fertilizer (CF, N: P: K = 10: 26: 10) (control) or a controlled-instant release fertilizer (CIRF, N: P: K = 10: 26: 10), SK Cote™ Plus or a jellyfish fertilizer (JF, N: P: K = 13.1: 1.7: 0.03), Marutomo Corporation, Japan was applied at the rate of 5 g per pot. The CF, CIRF, and JF fertilizer was applied as a top dressing of the polyethylene bags. These application rates corresponded to 0.855 kg ha^{-1} at a density of 171 seedlings ha^{-1} for CF, CIRF, and JF treatments.

Methods for subsequent seedling survival rate and growth assessment

A sample of 57 seedlings from each fertilizer treatment was selected for seedling survival rate and subsequent growth assessment. Seedling survival rate, shoot height, root collar diameter, and number of leaves were recorded and monitored every 30 days commencing 45 Days After Sowing (DAS) until the end of the nursery growing season (270 DAS). Relative growth rate (RGR) for shoot height and root collar diameter was calculated using the following equation (Kramer and Kozlowski 1979):

$$RGR = (\ln X_2 - \ln X_1)/ \Delta t \quad \text{……………………………e1)}$$

Where, X_1 and X_2 denote variables measured at the time of the first and second assessments, respectively and Δt is the time interval between the two measurements. Seedling total leaf surface area estimation was adapted following the method of Blanco and Folegatti (2003). At 90 DAS, a total of five leaves were collected from each of 12 seedlings per fertilizer treatment and measurements of the leaf length and leaf width were taken. The actual surface area of each leaf was measured using a portable LI-COR leaf surface area meter conveyor. A mathematical model was obtained by correlating the parameters of leaf length (L), width (W), length x width (LW), length + width (L+W), length x length (L^2) or width x width (W^2) to the actual leaf area (LA) of the total 60 leaves sample using regression analysis. The regression equation with the highest R^2 values was selected to construct the mathematical formula for leaf surface area estimation in each of the treatment. Thus, the fitted regression equations for leaf surface area estimation of seedlings were as follows: -

Chemical Fertilizer (CF) treatment:

$$LA_{est} = -20.9 + 4.68\,W + 0.664\,(LW), \text{ where } R^2 = 0.98, n = 60 \quad \text{……………………………e2)}$$

Controlled-Instant Release Fertilizer (CIRF) treatment:

$$LA_{est} = 2.4 + 0.960\,(LW) - 0.102\,L^2, \text{ where } R^2 = 0.95, n = 60 \quad \text{……………………………e3)}$$

Jellyfish Fertilizer (JF) treatment:

$$LA_{est} = -199 + 14.9\,(L + W) - 0.215\,L^2, \text{ where } R^2 = 0.96, n = 60 \quad \text{……………………………e4)}$$

Where,
LA_{est} = estimated leaf area (cm^2)
W = width of leaf (cm)
LW = product of leaf length and leaf width (cm^2)
L+W = sum of leaf length and leaf width (cm)
L^2 = square product of leaf length (cm^2)

Therefore, in order to estimate the total leaf surface area of seedlings, a subsample of five seedlings per treatment per block (15 seedlings from the total of 57 seedlings of growth assessment in each treatment) was randomly selected for detailed measurements of leaf length and leaf width at an interval of every 30 days until the end of the nursery growing season (270 DAS). The leaf length and leaf width measurements were then inserted into the mathematical formula of each treatment as to estimate the leaf surface area of *S. macrophylla* seedlings.

Methods for seedling biomass production

Following the final measurements at the end of the nursery growing season (270 DAS), a subsample of four seedlings per treatment per block (12 seedlings from the total of 57 seedlings in each treatment) was randomly selected and harvested using destructive sampling techniques for seedling biomass production. Each seedling was tagged and then washed with tap water carefully to remove any remaining growing medium and other debris. Each plant part including the leaves, stems, and roots was partitioned and the measurement of biomass was performed. All the plant parts were oven-dried to a constant weight at 60˚C for five days (120 hours) and their biomass were recorded. Total biomass was obtained by adding dry weights of leaves, stems, and roots.

Experimental design and statistical analysis

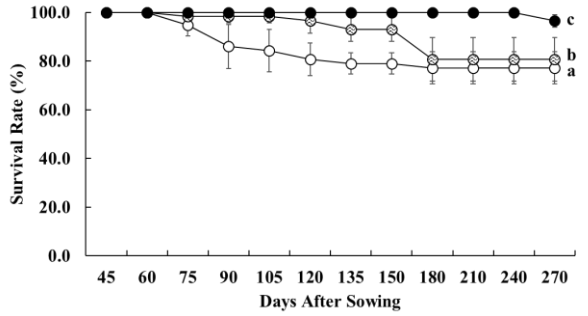
The three fertilizer treatments (CF, CIRF, and JF) were randomly assigned to each seedling and arranged in a randomized complete block design with three replicate blocks. Each fertilizer treatment had 19 seedlings per block, and thus a total of 57 seedlings per fertilizer treatment were used for subsequent seedling survival and growth assessment in the experiment. Treatments and replications were rearranged monthly and placed on bare ground of the nursery to ensure that the seedlings were subjected to a similar growing environment. In order to compare and determine whether survival rate and morphological quality attributes of seedlings under nursery conditions were significantly affected among different types of fertilizer treatments, a one-way Analysis of Variance (ANOVA) for a randomized complete block design was performed at the end of the nursery growing season (270 DAS). Tukey's Honest Significant Difference (HSD) test was chosen as post-hoc test to compare mean values of the treatments at 5% significance level ($P < 0.05$). All the statistical analyses were performed using Statistical Software Package for the Social Sciences (IBM, Version 24.0 for Windows) (SPSS Inc., 2016) and the results are reported as mean ± standard deviation.

RESULTS AND DISCUSSION

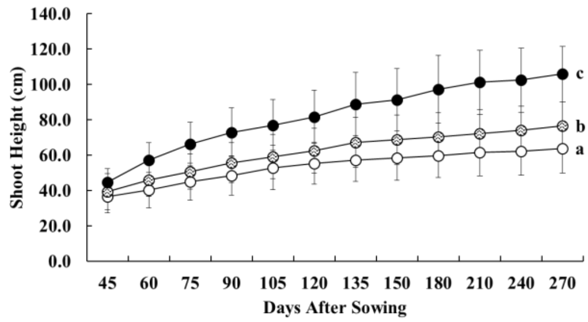
Effects of inorganic and organic fertilizers on subsequent seedling survival rate and morphological quality attributes at the end of nursery growing season

The cumulative seed germination percentage of *S. macrophylla* among different types of fertilization were similar (data not shown) and this indicated that uniform seeds were used for the experiment. One-way analysis of variance showed that mean survival rate of *S. macrophylla* seedlings was significantly influenced ($P < 0.05$) by fertilizer regimes at the end of nursery culture (270 DAS) as shown in Figure 1.A. Fertilization apparently had a minor effect on mean seedling survival because survival was > 75% throughout the experiment in all treatments. At 270 DAS, JF treatment depicted the highest mean survival rate followed by CIRF and CF treatments with 96.5%, 80.7%, and 77.2%, respectively.

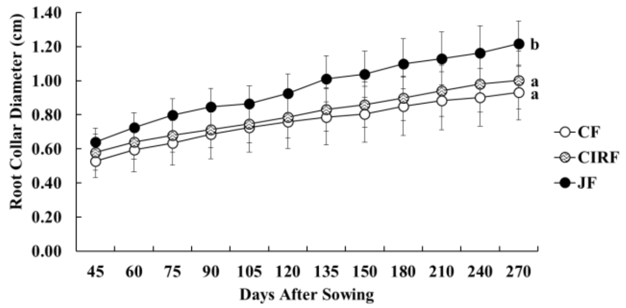
Figures 1.B and 1.C display the mean shoot height and root collar diameter growth trends among different fertilizer treatments. The effects of fertilizer regimes on morphological quality attributes of *S. macrophylla* seedlings at the end of nursery growing season were variable among different treatments. The fertilizer treatments had significant effects ($P < 0.05$) on all the seedling morphological quality attributes except for root to shoot ratio (Table 2).



A



B



C

Figure 1. Effects of inorganic and organic fertilizers on mean survival rate and growth trends of *S. macrophylla* seedlings at the end of nursery growing season (270 DAS). A. Survival rate, B. Shoot height, C. Root collar diameter. Different letter(s) indicate significant differences among treatments at $P < 0.05$ using Tukey's HSD test for 270 DAS

Table 2. Effects of inorganic and organic fertilizers on the seedling morphological quality attributes of *S. macrophylla* at the end of nursery growing season (270 DAS)

Treatments/ Morphological quality attributes		**Chemical fertilizer (CF)**	**Controlled-instant release fertilizer (CIRF)**	**Jellyfish fertilizer (JF)**
Shoot height	(cm)	63.8 ± 13.7 a	76.8 ± 13.5 b	105.9 ± 15.6 c
Root collar diameter	(cm)	0.93 ± 0.16 a	1.00 ± 0.17 a	1.22 ± 0.13 b
Sturdiness quotient		6.91 ± 1.29 a	7.74 ± 1.22 b	8.78 ± 1.55 c
RGR_{sh}	(cm cm^{-1} day^{-1})	0.110 ± 0.054 a	0.167 ± 0.061 b	0.272 ± 0.065 c
RGR_{cd}	(cm cm^{-1} day^{-1})	0.0017 ± 0.0007 a	0.0019 ± 0.0008 a	0.0025 ± 0.0005 b
Number of leaves		7 ± 3 a	7 ± 3 a	11 ± 4 b
Total leaf surface area	(cm^2 $seedling^{-1}$)	1106.5 ± 374.1 a	1038.7 ± 378.2 a	2353.7 ± 455.5 b
Shoot biomass	(g)	17.1 ± 7.1 a	16.2 ± 9.3 a	32.9 ± 11.6 b
Root biomass	(g)	14.1 ± 7.1 a	12.9 ± 6.3 a	31.0 ± 20.2 b
Total biomass	(g)	31.2 ± 13.6 a	29.2 ± 15.0 a	63.9 ± 30.0 b
Root to shoot ratio		0.81 ± 0.29 ns	0.83 ± 0.19 ns	0.92 ± 0.38 ns

Note: Means ± standard deviation values in the same row followed by different letter(s) indicate significant differences among treatments at $P < 0.05$ using Tukey's HSD test; ns: no significant differences; RGR_{sh}: Relative Growth Rate of Shoot Height; RGR_{cd}: Relative Growth Rate of Root Collar Diameter

Figure 2. Selected root and shoot development of *S. macrophylla* seedlings at the end of nursery growing season (270 DAS). A. Chemical fertilizer treatment (CF); B. Controlled-instant release fertilizer treatment (CIRF); C. Jellyfish fertilizer treatment (JF)

Morphologically, all the seedling quality attributes were significantly higher for jellyfish fertilizer treatment as compared to controlled-instant release and chemical fertilizer treatments. However, there were no significant differences ($P > 0.05$) detected between the inorganic fertilizers (CF and CIRF treatments) for root collar diameter, relative growth rate of root collar diameter, number of leaves, total leaf surface area, shoot biomass, root biomass, and total biomass. The selected root and shoot development of *S. macrophylla* seedlings at the end of nursery growing season (270 DAS) for all the fertilizer treatments are shown in Figure 2. Based on Table 2, although there were no significant differences ($P > 0.05$) obtained among different fertilizer treatments at the end of nursery culture for mean root to shoot ratio, the seedlings of *S. macrophylla* in all the treatments were fit to the general expectations of a balanced root to shoot ratio. Likewise, the mean sturdiness quotients presented in Table 2 does not meet the ideal expectations among all the fertilizer treatments throughout the experiment, which postulates greater values than 6 (Gregorio et al. 2004).

Discussion

The survival of *S. macrophylla* seedlings in the CF treatments was depleted approximately 14% within 90 days after fertilization due to foliar and root necrosis. This mortality is possibly due to the higher salinity induced by CF, due to its fast release of nutrients which could have slightly worsened the root conditions. A similar trend was reported by Irino et al. (2004) where 40% of the *Dryobalanops lanceolata* seedlings died within 30 days after treated with chemical fertilizer due to foliar and root necrosis. Previous study concluded that dipterocarp seedlings were less responsive to easily soluble or liquid fertilizers since most of the dipterocarp species are characterized by relatively slow growth (Turner et al. 1993, Lee and Alexander 1994). In the present study, the CIRF and JF treatments promoted higher seedling survival at (75 to 270 DAS) as compared to CF treatment.

In our study, seedling morphological quality attributes were found to be significantly higher when treated with jellyfish fertilizer as compared to those treated with chemical fertilizer and controlled-instant release fertilizer. Findings from this study clearly revealed that the application of jellyfish fertilization had enhanced and yielded better seedling growth performance of *S. macrophylla*, i.e. they have a beneficial influence on the improvement of growth parameters of seedlings as compared to chemical fertilization.

The findings indicated that seedlings of *S. macrophylla* raised in the nursery were of sub-optimal quality since their sturdiness quotient values exceeded 6 (Gregorio et al. 2004). A sturdiness quotient of less than 6 has been recommended as a desired characteristic of high-quality seedlings in tropical systems (Jaenicke 1999). Previous studies by several researchers have also found sturdiness quotient to correlate with seedling survival rate and initial growth following outplanting (Mexal and Landis 1990; Ivetić et al. 2017). According to Takoutsing et al. (2014), seedlings with sturdiness ratio greater than six were basically tall and thin (lanky) and etiolated, whereas a small quotient indicates sturdy plants with a higher chance of survival, particularly on windy or dry sites.

Nonetheless, seedlings from CF, CIRF, and JF treatments were found to have a root to shoot ratio values within the acceptable range (RS < 2) and generally these seedlings are likely to withstand the adverse conditions in most planting sites due to the adequate root system that will not impede the growth of the plant. Root to shoot ratio of ≤ 2 have been suggested by Jaenicke (1999), Haase (2007), and Nyoka et al. (2018) as the desired threshold characteristic of the high and good quality of container seedlings. According to Hasse (2007), the ratio measures the balance between the transpirational area (shoot) and the water absorbing area (root) of the seedlings. This ratio is premised on the fact that well-developed roots are important to the seedlings to absorb sufficient amount of water and nutrients, while shoots provide for a pathway through which water and nutrients absorbed by roots are pumped to the leaves for photosynthesis purposes and cooling the plant through transpiration (Nyoka et al. 2018). In addition, the findings also substantiate those of Gregorio et al. (2005) who found that seedlings with a low root to shoot ratio have a greater survival rate than the seedlings with higher root to shoot ratios. Several factors which influenced the root to shoot ratio are cultural practices (Johnson and Cline 1991; Ericsson 1995), genetics, seedlings age, container size, and the species.

Since the present study was the first to examine the influences of CF, CIRF, and JF fertilizers on the morphological quality attributes of *S. macrophylla* seedlings as to develop a practical technique for producing healthy and quality seedlings in ensuring better field performance, our results clearly showed that all types of fertilizers are beneficial in raising the seedlings. Based on the root development of seedlings as shown in Figure 2, *S. macrophylla* seedlings in CF and CIRF treatments could be raised over a much longer period (even after more than 9 months as stock in the nursery) until the initiation of transplantation in rehabilitation programs. However, for seedlings in JF treatment, it should be outplanted at 270 DAS (9 months) at the field as to avoid root deformations in the polyethylene bags. According to Takoutsing et al. (2014), root deformations sometimes are attributed to the duration of the seedlings and the type of substrate used in the nurseries. Previous study by Irino et al. (2004) suggested that dipterocarp seedlings could be raised to 16 months, as observed in their experiment. The use of controlled-release fertilizer (CRF) had enabled to maintain the raised *Dryobalanops lanceolata* seedlings under good conditions even after more than 1 year as stock in the nursery (Irino et al. 2004).

Several researchers emphasized that the production of seedlings with a large, vigorous root system and a root to shoot ratio to match the needs of the outplanting site is a significant factor in the successful seedling establishment (McDonald 1991; Barnett and McGilvray 1993; South et al. 2005). Edwards (1998) added that seedlings with large root systems are better able to withstand outplanting stock and usually grow well in the year following outplanting as compared to seedlings with high root to shoot ratios. Likewise, a study by Nyoka et al. (2018) in Malawi reported that seedlings with small root systems in relation to shoot were not able to adequately supply sufficient water to shoots during the long dry season.

In this study, *S. macrophylla* seedlings treated with jellyfish fertilizer seemed to show slightly better and favorable growth performance at the end of nursery growing season (270 DAS). This was presumably due to the absorption of water and nutrients from the soils in the growing medium to the fertilizer and return carbon and nutrient contents to a balance and more favorable state which is readily available for the uptake of seedlings (Caravaca et al. 2002). In addition, jellyfish can be used as a source of organic fertilizer for enhancing tree growth as well as for improving soil properties in terms of physical and chemical properties. Theoretically, jellyfish fertilizer comprises of high organic matter (approximately 81%), which plays an essential role in improving the physical structure of the soil; and consequently, increases the soil moisture. It creates a vapor barrier between the soil and the atmosphere, resulting in a decrement in soil temperature and evaporative water loss when jellyfish fertilizer is distributed over the soil surface (Power 2002). Likewise, Nyoka et al. (2018) pointed out that amendments using organic matter can help in maintaining or improving soil properties including soil bulk density, soil structure, water and nutrient holding capacity, and the environment for the growth of beneficial rhizosphere microorganisms. Nevertheless, the improvement in soil aggregation by organic matter addition positively affects the seeds germination as well as the growth and development of shoots and roots (Noordwijk et al. 1993).

Numerous studies have demonstrated and discussed that nursery cultural practices including types of fertilizations strongly have a substantial influence on seedling quality and performance after outplanting (Liu et al. 2000; Gao et al. 2007; Wang et al. 2007; Li et al. 2011, 2012; Takoutsing et al. 2012). However, most of these studies did not combine nursery cultivation treatments with planting site conditions. Field trials are essential for validating the suitability of nursery techniques and the identification of the seedling functional attributes which forecast outplanting performance (Andivia et al. 2019). Takoutsing et al. (2014) suggested that the only way to fully comprehend the behaviors of seedling promoted by nursery techniques and its productivity is to consider the outplanting site condition since nursery cultural practices vary by species, nursery, and outplanting environments.

In conclusion, the present study found out that different types of nursery fertilizations revealed significant differences in morphological quality attributes of *S. macrophylla* seedlings at the end of nursery growing season (270 DAS). All types of fertilizers are beneficial in raising the seedlings in the nursery. In particular, seedlings treated with jellyfish fertilizer was significantly higher than chemical fertilizer and controlled-instant release fertilizer for all the morphological quality attributes, except for root to shoot ratio. Notwithstanding, findings from the present study also revealed that *S. macrophylla* seedlings from all the treatments were fit to the general expectations of a balanced root to shoot ratio values (RS < 2) and the seedlings raised in the nursery were of sub-optimal quality. While defining the appropriate seedling stock-type to meet the needs that can be achieved through the variety of methods, including the Target Plant Concept, an understanding of the interplay of nursery production techniques and factors influencing outplanting sites is necessary to ensure forest restoration is most effective. Consequently, it is recommended that evaluation of stock quality requires the integration of both morphological and physiological attributes of seedlings that provides a more effective appraisal of the fitness of seedlings to become established for field planting. Since most studies did not combine nursery techniques with planting site conditions and limited research has been done on the seedling quality of indigenous species in Malaysia, development of species and site-specific targets for seedling shoot and root system quality assessment is required and subsequently tested as to ensure they meet the set standards.

ACKNOWLEDGEMENTS

This study was financially supported by Ministry of Higher Education, Malaysia under the Research Acculturation Grant Scheme (RAGS) (RAGS/g(2)/914/2012(15)) and Grant-in-Aid for scientific research purpose by the Japan-Malaysia Association (JMA) and NPO Rainforest Sarawak. The authors wish to express gratitude to the Director and staff of the Forest Department, Sarawak for their supportive assistance during the duration of this study. The authors would also like to extend thanks to local villagers, especially Jebeng for their kind cooperation and assistance during the field survey. The authors are grateful to the anonymous reviewers for their constructive comments and suggestions that helped to improve the quality of the manuscript.

REFERENCES

Ådjers G, Kuusipalo J, Hadengganan S, Nuryanto K, Vesa L. 1995. Enrichment planting of dipterocarps in logged-over secondary forest, effects of width, direction and maintenance method of planting line on selected *Shorea* species. For Ecol Manag 73 (1-3): 259-270.

Ådjers G, Kuusipalo J, Hadengganan S, Nuryanto K, Vesa L. 1996. Performance of ten dipterocarp species in restocking logged-over forest areas subjected to shifting cultivation. J Trop For Sci 9 (2): 151-160.

Aminah H, Dick JMP, Leakey RRB, Grace J, Smith RI. 1995. Effect of indole butyric acid (IBA) on stem cutting of *Shorea leprosula*. For Ecol Manag 72 (2-3): 199-206.

Andivia E, Villar-Salvador P, Oliet JA, Puértolas J, Dumroese RK. 2019. How can my research paper be useful for future meta-analyses on forest restoration plantations? New For 50: 255-266.

Appanah S, Weinland, G. 1993. Planting Quality Timber Trees in Peninsular Malaysia- Review. Malaysian Forest Record No. 38, Forest Research Institute Malaysia, Kuala Lumpur.

Arifin A, Tanaka S, Jusop S, Majid NM, Ibrahim Z, Sakurai K. 2008. Rehabilitation of degraded tropical rainforest in Peninsular Malaysia with a multi-storied plantation technique of indigenous dipterocarp species. Jpn J For Env 50 (2): 141-152.

Ashton PS. 1964. Ecological Studies in the Mixed Dipterocarp Forests of Brunei State. Clarendon Press, Oxford.

Ashton PS. 1982. Dipterocarpaceae. Flora Malesiana Ser I 9: 237-552.

Ashton PS. 1998. *Shorea macrophylla*. The IUCN Red List of Threatened Species. e.T33620A9798047, DOI: 10.2305/IUCN. UK.1998.RLTS.T33620A9798047.en

Barnett JP, McGilvray JM. 1993. Performance of container and bareroot loblolly pine seedlings on bottomlands in South Carolina. South J Appl For 17 (2): 80-83.

Blanco FF, Folegatti MV. 2003. A new method for estimating the leaf area index of cucumber and tomato plants. Horticultura Brasileira 21 (4): 666-669.

Caravaca F, Garcia C, Hernandez MT, Roldan A. 2002. Aggregate stability changes after organic amendment and mycorrhizal inoculation in the afforestation of a semiarid site with *Pinus halepensis*. Appl Soil Ecol 19 (3): 199-208.

Chan HT, Appanah S. 1980. Reproductive biology of some Malaysian Dipterocarps. I. flowering biology. Malays For 43 (2): 132-143.

Chun KW. 2012. Effect of jellyfish fertilizer application on seedling growth. J Jpn Soc Reveg Tech 37 (1): 155-158.

Connell M. 1968. Report on the Sarawak Illipe Nut Trade- A Post Harvest Study. Tropical Products Institute, Ministry of Overseas Development, London.

Davis AS, Jacobs DF. 2005. Quantifying root system quality of nursery seedlings and relationship to outplanting performance. New For 13 (2-3): 121-138.

Dey D, Parker W. 1997. Morphological indicators of stock quality and field performance of red oak (*Quercus rubra* L.) seedlings

underplanted in a central Ontario shelterwood. New For 14 (2): 145-156.
Drainage and Irrigation Department. 2017. Weather Data (Rainfall) 1995-2016. Drainage and Irrigation Department, Kuching, Sarawak, Malaysia.
Edwards C. 1998. Testing Plant Quality: Information Note. Issued by forestry practice, Forestry Commission, Edinburg, November 1998.
Ericsson T. 1995. Growth and shoot: root ratio of seedlings in relation to nutrient availability. Plant Soil 168 (1): 205-214.
Fløistad IS, Kohmann K. 2004. Influence of nutrient supply on spring frost hardiness and time of bud break in Norway spruce (*Picea abies* (L.) Karst.) seedlings. New For 27 (1): 1-11.
Folk RS, Grossnickle SC. 1997. Determining field performance potential with the use of limited environmental conditions. New For 13 (1-3): 121-138.
Gao ZG, Liu JL, Zheng GX, Zhong ZL. 2007. Study on effect of PP333 on *Pinus massoniana* seedling quality. J Zhejiang For Sci Tech 27 (2): 55-56.
Green TH, Mitchell RJ, Gjerstad DH. 1994. Effects of nitrogen on the response of loblolly pine to drought. II. biomass allocation and C: N balance. New Phytol 128 (1): 145-152.
Green TH, Mitchell RJ. 1992. Effects of nitrogen on the response of loblolly pine to water stress. I. photosynthesis and stomatal conductance. New Phytol 122 (4): 627-633.
Gregorio NO, Herbohn JL, Harrison S. 2004. Small-scale forestry development in Leyte, Philippines: the central role of nurseries. Small-scale For Econ Manag Pol 3 (3): 337-351.
Gregorio NO, Herbohn JL, Harrison S. 2005. Germplasm access and planting stock quality in smallholder forest nurseries in Leyte, The Philippines. In: Harrison, Steve R, Herbohn J, Suh, Jungho, Mangaoang, Eduardo, Vanclay, Jerry (eds) Redevelopment of A Timber Industry following Extensive Land Clearing. Proceedings from the end-of-project workshop, ACIAR Smallholder Forestry Project, Ormoc City, The Philippines, 19-21 August 2004.
Grossnickle SC, MacDonald JE. 2018. Seedling quality: history, application, and plant attributes. Forests 9 (5): 283-305.
Grossnickle SC. 2000. Ecophysiology of Northern Spruce Species: The Performance of Planted Seedlings. NRC Research Press, Ottawa, Ontario, Canada.
Haase DL. 2007. Morphological and physiological evaluations of seedling quality. In: Riley LE, Dumroese RK, Landis TD (eds) National Proceedings of Forest and Conservation Nursery Associations. United States Department of Agriculture, Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-50, USA, December 2007.
Haase DL. 2008. Understanding forest seedling quality: measurements and interpretation. Tree Plant Notes 52 (2): 24-30.
Ichie T, Nakagawa M. 2013. Dynamics of mineral nutrient storage for mast production in the tropical emergent tree *Dryobalanops aromatica*. Ecol Res 28 (2): 151-158.
Irino KO, Iba Y, Ishizuka S, Kenzo T, Ripot S, Kendawang JJ, Miyashita N, Nara K, Hogetsu T, Ninomiya I, Iwasaki K, Sakurai K. 2004. Effects of controlled-release fertilizer on growth and ectomycorrhizal colonization of pot-grown seedlings of the dipterocarp *Dryobalanops lanceolata* in a tropical nursery. Soil Sci Plant Nutr 50 (5): 747-753.
Irwin KM, Duryea ML, Stone EL. 1998. Fall applied nitrogen improves performance of 1-0 slash pine nursery seedlings after outplanting. Southern J Appl For 22 (2): 111-116.
Ivetić V, Grossnickle S, Škorić M. 2017. Forecasting the field performance of Austrian pine seedlings using morphological attributes. iForest 10 (1): 99-107.
Jaenicke H. 1999. Good Tree Nursery Practices: Practical Guidelines for Research Nurseries. World Agroforestry Centre (ICRAF), Nairobi, Kenya.
Johnson JD, Cline ML. 1991. Seedling quality of southern pines. In: Duryea ML, Dougherty PM (eds) Chapter 8: Forest Regeneration Manual. Kluwer Academic, Netherlands.
Jose S, Merritt S, Ramsey CL. 2003. Growth nutrition photosynthesis and transpiration responses of longleaf pine seedlings to light water and nitrogen. For Ecol Manag 180 (1-3): 335-344.
Kramer PJ, Kozlowski TT. 1979. Physiology of Woody Plants. Academic Press, New York.
Lee SS, Alexander IJ. 1994. The response of seedlings of two dipterocarp species to nutrient addition and ectomycorrhizal infection. Plant Soil 163 (2): 299-306.
Li GL, Liu Y, Zhu Y, Yang J, Sun HY, Jia ZK, Ma LY. 2011. Influence of initial age and size on the field performance of *Larix olgensis* seedlings. New For 42 (2): 215-226.
Li GL, Zhu Y, Li QM, Liu Y, Zou SQ, Huang YL. 2012. Effect of seedling age on the seedling quality and field performance of *Pinus koraiensis*. Scientia Silvae Sinicae 48 (1): 35-41.
Liu Y, Chen Y, Zhang ZY, Li XG. 2000. Effects of fertilizer treatments on seedling growth and cold resistance of triploid *Populus tomentosa*. J Beijing For Univ (Nat Sci Edu) 22 (1): 38-44.
Lo YN. 1985. Root initiation of *Shorea macrophylla* cuttings: effects of node position, growth regulators and misting regime. For Ecol Manag 12 (1): 43-52.
Malik V, Timmer VR. 1998. Biomass partitioning and nitrogen retranslocation in black spruce seedlings on competitive mixed wood sites: a bioassay study. Can J For Res 28 (2): 206-215.
Mattsson A. 1997. Predicting field performance using seedling quality assessment. New For 13 (1-3): 227-252.
McDonald PM. 1991. Container seedlings outperform bareroot stock: survival and growth after 10 years. New For 5 (2): 147-156.
Meteorological Department. 2017. Weather Data (Surface Air Temperature and Relative Humidity) 2010-2016. Meteorological Department, Kuching, Sarawak, Malaysia.
Mexal JG, Landis TD. 1990. Target seedling concepts: height and diameter. In: Rose R, Campbell SJ, Landis TD (eds) Target Seedling Symposium: Proceedings: Combined Meeting of Western Forest Nursery Associations. RM-GTR-200, USDA Forest Service.
Mohamad Jaffar ANN, Wasli ME, Perumal M, Lat J, Sani H. 2018a. Effects of soil compaction and relative light intensity on survival and growth performance of planted *Shorea macrophylla* (de Vriese) in riparian forest along Kayan Ulu River, Sarawak, Malaysia. Intl J For Res 2018: 11.
Mohamad Jaffar ANN, Wasli ME, Perumal M, Sani H, Lat J. 2018c. Assessment of soil hardness expressed by one drop penetrability at forest restoration sites along Kayan Ulu River, Sarawak, Malaysia. In: Ibrahim N, Che Othman MH, Feroz SR, Sairi F, Senen MA (eds) Translating Applied Biology for Future Sustainability: The 15th Symposium of Malaysian Society of Applied Biology. Melaka, Malaysia.
Mohamad Jaffar ANN, Wasli ME, Perumal M. 2018b. Evaluation on soil hardness in riparian forest restoration along Kayan Ulu River, Sarawak, Malaysia. Trends Undergrad Res 1 (1): 33-39.
Mohammed GH. 1997. The status and future of stock quality testing. New For 13 (1-3): 491-514.
Newman MF, Burgess PF, Whitmore TC. 1996. Borneo Island Light Hardwood- Manual of Dipterocarps for Foresters. CIFOR, Bogor, Indonesia.
Ng FSP. 1976. Gregarious flowering of dipterocarps in Kepong. Malays For 40 (3): 126-137.
Ng KKS, Ang KC, Lee SL. 2002. Mating system in a planted population of *Shorea macrophylla* (Dipterocarpaceae). J Trop For Sci 14 (1): 145-149.
Noordwijk VM, Schhonderbeek D, Kooistra MJ. 1993. Root-soil contact of field-grown winter wheat. Geoderma 56 (1-4): 277-286.
Nyoka BI, Kamanga R, Njoloma J, Jamnadass R, Mng'omba S, Muwanje S. 2018. Quality of tree seedlings produced in nurseries in Malawi: an assessment of morphological attributes. For Trees Livelihoods 27 (2): 1-15.
Perumal M, Wasli ME, Ho SY, Sani H. 2015. Soil morphological and physicochemical properties at reforestation sites after enrichment planting of *Shorea macrophylla* in Sampadi Forest Reserve, Sarawak, Malaysia. Borneo J Res Sci Tech 5 (2): 28-43.
Perumal M, Wasli ME, Ho SY, Sani H. 2017a. Survivorship and growth performance of *Shorea macrophylla* (de Vriese) after enrichment planting for reforestation purpose at Sarawak, Malaysia. OnLine J Biol Sci 17 (1): 7-17.
Perumal M, Wasli ME, Ho SY, Sani H. 2017b. Association between soil fertility and growth performance of planted *Shorea macrophylla* (de Vriese) after enrichment planting at rehabilitation sites of Sampadi Forest Reserve, Sarawak, Malaysia. Int J For Res 2017: 16.
Perumal M, Wasli ME, Lat J. 2016. Effects of enrichment planting on the soil physicochemical properties at reforestation sites planted with *Shorea macrophylla* de Vriese in Sampadi Forest Reserve, Sarawak, Malaysia. In: Sakai S, Pungga RS, Meleng P, Itioka T (eds) Proceedings of the International Symposium on Frontier in Tropical Forest Research: Progress in Joint Projects between the Forest Department Sarawak and the Japan Research Consortium for Tropical

Forests in Sarawak. Forest Department Sarawak (FDS) and Japan Research Consortium for Tropical Forests in Sarawak (JRCTS), Malaysia.

Pinto JR, Marshall JD, Dumroese RK, Davis AS, Cobos DR. 2011. Establishment and growth of container seedlings for reforestation: a function of stock-type and edaphic conditions. For Ecol Manag 261 (11): 1876-1884.

Power RT. 2002. Effects of soil disturbance on fundamental sustainable productivity of managed forests. In: Verner J (ed) Proceedings of the Symposium on the Kings River Sustainable Forest Ecosystem Project: Progress and Current Status. Gen Tech Rep. PSW-193, US Department of Agriculture Forest Service Pacific Southwest Forest and Range Experimental Station, Berkeley, California.

Puttonen P. 1997. Looking for the "silver-bullet"- can one test do it? New For 13 (1-3): 9-27.

Quoreshi AM, Timmer VR. 2000. Early outplanting performance of nutrient-loaded containerized black spruce seedlings inoculated with *Laccaria bicolor*: a bioassay study. Can J For Res 30 (5): 744-752.

Sakai S, Momose K, Yumoto T, Nagamitsu T, Nagamasu T, Hamid AA, Nakashizuka T. 1999. Plant reproductive phenology over four years including an episode of general flowering in a lowland dipterocarp forest, Sarawak, Malaysia. Am J Bot 86 (10): 1414-1436.

Sakurai K, Ninomiya I, Harada K, Kendawang JJ, Lee HS, Ogino K. 1999. Role of Tree Planting as Ecosystem Rehabilitation on the Degraded Land after Shifting Cultivation at Bakam Forest Reserve, Sarawak, Malaysia. Can Biological Production Harmonize with Environment? -reports from Research Sites in Asia-, The United Nations University, Tokyo.

Scagel R, Bowden R, Madill M, Kooistra C. 1998. Provincial Seedling Stocktype Selection and Ordering Guidelines. Ministry of Forests, Victoria.

Shaw TM, Moore JA, Marshall JD. 1998. Root chemistry of Douglas-fir seedlings grown under different nitrogen and potassium regimes. Can J For Res 28 (10): 1566-1573.

South DB, Harris SW, Barnett JP, Hainds MJ, Gjerstad DH. 2005. Effect of container type and seedling size on survival and early height growth of *Pinus palustris* seedlings in Alabama, U.S.A. For Ecol Manag 204 (2-3): 385-398.

Takoutsing B, Degrande A, Tchoundjeu Z, Asaah E, Tsobeng A. 2012. Enhancing farmers access to quality planting materials through community-based seed and seedling systems: experiences from the western highlands of Cameroon. Middle-East J Sci Res 12 (4): 455-463.

Takoutsing B, Tchoundjeu Z, Degrande A, Asaah E, Gyau A, Nkeumoe F, Tsobeng A. 2014. Assessing the quality of seedlings in small-scale nurseries in the highlands of Cameroon: the use of growth characteristics and quality thresholds as indicators. Small-scale For 13 (1): 65-77.

Tan W, Hogan GD. 1997. Physiological and morphological responses to nitrogen limitation in jack pine seedlings: potential implications for drought tolerance. New For 14 (1): 19-31.

Tang HT, Tamari C. 1973. Seed description and storage tests of some dipterocarps. Malays For 36 (2): 38-53.

Timmer VR, Aidelbaum AS. 1996. Manual for Exponential Nutrient Loading of Seedlings to Improve Outplanting Performance on Competitive Forest Sites. Natural Resources Canada, Canadian Forest Service Sault Ste, Marie ON, Canada.

Tompsett PB, Kemp R. 1996. DABATTS: Database of Tropical Tree Seed Research with Special Reference to the Dipterocarpaceae, Meliaceae and Araucariaceae. Royal Botanic Gardens, Kew.

Turner IM, Brown ND, Newton AC. 1993. The effect of fertilizer application on dipterocarp seedlings growth and mycorrhizal infection. For Ecol Manag 57 (1-4): 329-337.

Utomo S, Uchiyama S, Ueno S, Matsumoto A, Widiyatno, Indrioko S, Na'iem M, Tsumura Y. 2018. Effects of Pleistocene climate change on genetic structure and diversity of *Shorea macrophylla* in Kalimantan rainforest. Tree Gen Genomes 14 (4): 44.

van den Driessche R. 1991. Effects of nutrients on stock performance in the forest. In: van den Driessche (ed) Mineral Nutrition of Conifer Seedlings. CRC Press Inc, Boca Raton, Florida.

van den Driessche R. 1992. Changes in drought resistance and root growth capacity of container seedlings in response to nursery drought, nitrogen, and potassium treatments. Can J For Res 22 (5): 740-749.

Wang F, Yu CL, Liu D. 2007. Effects of plant growth regulators on drought resistance of shrub seedlings. For Sci Tech 32 (3): 56-60.

Wasli ME, Sani H, Ho SY, Perumal M, Zainudin ZA, Lat J, Lee PS. 2014. Preliminary assessment on the growth performance of *Dryobalanops beccarii* Dyer planted under enrichment planting technique at Gunung Apeng Forest Reserve, Sarawak, Malaysia. Kuroshio Sci 8 (1): 45-52.