PHYSIOLOGICAL PERFORMANCE OF *SHOREA LEPROSULA* FOR REHABILITATION OF A DEGRADED FOREST IN JANDA BAIK, MALAYSIA

Ho Wai Mun,
Forest Plantation Programme
Forestry Biotechnology Division
Forest Research Insitute Malaysia (FRIM)
52109 Kepong, Selangor, Malaysia
Email: howaimun@frim.gov.my

Daniel Weber
Phytoprove Pflanzenanalytik UG
Georg-Voigt-Str.14, 60325 Frankfurt am Main, Germany
Email: weber@phytoprove.com

Mohamad Fakhri Ishak
Forest Plantation Programme
Forestry Biotechnology Division
Forest Research Insitute Malaysia (FRIM)
52109 Kepong, Selangor, Malaysia
Email: mohamadfakhri@frim.gov.my

Faridah Ahmad Azam
Forest Plantation Programme
Forestry Biotechnology Division
Forest Research Insitute Malaysia (FRIM)
52109 Kepong, Selangor, Malaysia
Email: faridahahmad@frim.gov.my

Sik Huei Shing
Wood Drying Laboratory,
Forest Products Division
Forest Research Insitute Malaysia (FRIM)
52109 Kepong, Selangor, Malaysia
Email: sik@frim.gov.my

ABSTRACT

A Restoration, Reclamation and Rehabilitation Programme (3RSM) was implemented in the 11th Malaysia Plan to restore degraded permanent reserved forests in Peninsular Malaysia caused by natural disasters as well as anthropogenic disturbances. One of the selected areas for this programme was Lentang Forest Reserve (LFR) in Janda Baik, Pahang, Malaysia. In LFR, various indigenous rainforest tree species were planted. Among these, Shorea leprosula was selected for this study. Besides growth data, physiological parameters including leaf area, leaf chlorophyll and chlorophyll fluorescence were also collected and analysed. The influence of shade and gap on the growth and physiological performance of S. leprosula was evaluated. Our findings revealed that this species preferred a more opened canopy by exhibiting better growth and considerably better overall photosynthetic performance. Therefore, S. leprosula can be a recommended species from the Dipterocarpaceae family for future restoration projects in similar degraded forests with considerable growth achieved through efficient photosynthetic activity even when planted in gaps created within the forests.

Keywords: *degradation, indigenous species, stress, photosystem, electron transport*

INTRODUCTION

Land degradation, including forest areas, is a global threat that is taking place at an alarming rate as influenced by natural and anthropogenic factors. It has been defined as “reduction or loss of the biological or economic productivity and complexity of land” (UNCCD 2016) causing reduced food production, exacerbate natural disasters, biodiversity loss, besides loss of soil organic carbon and ecosystem services (IUCN 2015, Gilbey *et al*. 2019). Across the world, land degradation and desertification has caused huge economic loss estimated at US$ 6.3 to 10.6 trillion or US$ 870 to 1,450/person/year (ELD 2015).

The State of the World’s Forests reported that from 2015 to 2020, the rate of deforestation was estimated at 10 million ha/year, down from 16 million ha/year in the 1990s (FAO & UNEP 2020). Forest degradation, in particular, will become a stumbling block towards achieving sustainable development, conservation of biodiversity, and climate change mitigation and adaptation. This will eventually increase vulnerability to climate change stressors and natural hazards which undermines the livelihood of forest-dependent communities. In addition, many countries, both tropical and temperate, forests are being cleared for intensive agricultural activities. In some of these areas, abandoned lands have also increased when farming activities turned unsustainable or unproductive. Therefore, halting and reversing forest degradation must be put on high priority by restoring degraded forest areas in order to enhance forest ecosystem services and functions.

Although some degraded forests may recover naturally, it is unfortunate that many do not where the system has crossed an ecological threshold. This can be due to inadequate original plant and animal biota, change of soil fertility and repeated disturbances (Lamb & Gilmour 2003). Human intervention may be necessary in some areas to start off and/ or accelerate recovery process. In this context, different terms have been used to describe the approaches used. 'Restoration' is used for recreation of an ecosystem as close as possible to that which originally existed at the site, 'rehabilitation' is used where the original productivity or structure is regained as well as some of the original biodiversity while 'reclamation' is used for situations where productivity or structure is regained but biodiversity is not (Lamb & Gilmour 2003).

Most degraded forests are a mosaic of land uses which may include patches of residual forest, agricultural land, settlement or abandoned area. It may not be feasible to restore the whole landscape but can be done by concentrating on certain areas for instance buffer zone of rivers and forest corridors. The most common effort to overcome restoration is by tree planting. One of the approaches is to increase populations of commercially valuable timber species in secondary forests by enrichment planting (planting under canopy gaps or along cleared strips) which can also be used to improve biodiversity by introducing species that are unable to colonise and regenerate or are ecologically threatened or vulnerable (Lamb *et al*. 2005).

Under the 10th Malaysia Plan (2011−2015), a program for restoration of degraded and poorly stocked forest areas was initiated in Peninsular Malaysia which had successfully planted various tree species over 4,477 ha in permanent reserved forests. This effort continued through the 11th Malaysia Plan (2016−2020) through a Restoration, Reclamation and Rehabilitation of Degraded Forests Programme (3RSM) by planting selected species and silvicultural treatment. A total of 1,640 ha of degraded forests were identified in this programme including in Cameron Highlands, Riverbank of Kelantan River and Janda Baik.

Lentang Forest Reserve (LFR) is located in Janda Baik, state of Pahang, Malaysia. Part of the forest was cleared as a result of illegal farming. The affected forest area has been planted with over 30,000 trees from various local species including *Aquilaria malaccensis*, *Dipterocarpus cornutus*, *Dryobalanops aromatica*, *Shorea parvifolia*, *S. leprosula* and *S. platyclados*, since 2017 by Forest Department of Peninsular Malaysia (FDPM) and silvicultural treatments were prescribed at regular intervals. LFR has a mosaic landscape with some previously planted areas and existence of pioneer species providing some shade for the new plantings. Meanwhile, opened canopy areas created gaps between these areas thus giving the planted trees in this area more ambient light.

Among the planted trees is *S. leprosula* or locally known as *meranti tembaga*, a Dipterocarpacea. According to the IUCN Red List of Threatened Species, the status of *S. leprosula* has changed from 'endangered' in 1998 to 'near threatened' in 2017 while the Malaysia Plant Red List 2021 has enlisted it as 'least concern'. This species is of particular interest to the authors as it is an emergent tree with high economic value due to its good quality timber. This species is a popular dipterocarp used for enrichment planting and reforestation in Malaysia (Lee & Alexander 1996). *Shorea leprosula* is one of the promising native tree species for forest rehabilitation (Pamoengkas *et al*. 2020) that grows fast with the potential to be developed for plantation forestry (Soekotjo 2009)

Leaves growing under light, or sun leaves, have shown to display higher mesophyll width, higher leaf mass per area (LMA) and therefore higher photosynthetic rate compared to shade leaves. Although shade leaves have lower LMA, more nitrogen is found in the chlorophyll to enhance light capture, compensating for lower irradiance to achieve photosynthetic capacity similar to that of sun leaves (Poorter *et al*. 2009) Leaves from high light or sun plants have shown to possess increased number of reaction centers, capacity of electron transport and number of PSII units. The measurement of chlorophyll fluorescence (ChlF) provides information on the photosynthetic mechanism of plants. It is a non-intrusive tool that allows the study of photosynthetic process without destroying the plant sample. This physiological parameter can be rapidly used to detect changes in Photosystem II (PSII) under stress using intact leaves. ChlF has been used as an indicator for various plant stress factors including high and low temperatures, drought, salinity, nutrient deficiencies and heavy metals. As such, ChlF can also be used to determine the status of photosynthetic apparatus of plants grown in sun or shade areas as in light acclimation studies.

This paper presents on part of the findings from a research project conducted in LFR in collaboration with FDPM through the 3RSM Programme. The aim is to determine the effect of shade and gap on the growth and physiological performance of *S. leprosula*. These parameters were examined in order to understand the suitability of *S. leprosula* for rehabilitation when planted under shade and in open gap.

MATERIALS AND METHODS

The site is located in Lentang Forest Reserve, Pahang, Malaysia (101°54'9.279" E, 3°17'59.627" N) with an elevation of 538 m to 585 m above sea level. *Shorea leprosula* trees chosen for this study were planted in 2018 under existing naturally regenerated trees and in gaps. Throughout this paper, former trees will be referred to as those planted under 'shade' and the latter in 'gap'.

Microclimate of the study site was monitored using HOBO MX2301 (ONSET, United States) with air temperature and air humidity data logged at an interval of every 15 minutes. One unit of HOBO sensor was placed, by tying to a wooden pole at 1 m above ground, each in the shade and in the gap. The data obtained were averaged for each month. Measurements of tree growth (height and diameter at breast height-dbh) were carried out on three selected *S. leprosula* trees planted under shade and in open.

For all physiological parameters, measurements were made on first fully expanded leaves on *S. leprosula* planted under shade (shade leaf) and in gap (sun leaf). For determination of leaf area, leaves were selected and leaf margins were traced on papers. The papers were then cut according to shape of leaves and measured using a leaf area meter (Delta T). The selected leaves were kept in air-tight bags and weighed immediately after reaching the laboratory. Subsequently, the leaves were oven dried until constant weight at 80°C and dry weight of leaves were measured again. Leaf chlorophyll was measured with the portable SPAD-502 Chlorophyll Meter (Minolta Camera Co., Japan).

Measurements of chlorophyll fluorescence was conducted using Handy Plant Efficiency Analyser (PEA) portable fluorometer (Hansatech Instruments Ltd., King's Lynn, United Kingdom) after 30 minutes of dark adaptation using leaf clips. Maximum quantum yield for primary photochemistry (F_v/F_m) and performance index (PI_{ABS}) measured were analysed and discussed in this paper.

Table 1: Definition of terms of the JIP-test parameters from the Chl a fluorescence transient OJIP emitted by dark-adapted leaves

Fluorescence Parameters	Description
Basic JIP-test parameters derived from the OJIP transient	
$t(F_m)$	Time (in ms) to reach the maximal fluorescence intensity F_m
F_0	Minimum fluorescence in dark-adapted leaves
F_m	Maximum fluorescence in dark-adapted leaves
S_m	Normalized area
Quantum yields and probabilities	
$\Phi_{Do} = F_0/F_m$	Quantum yield of energy dissipation (at t = 0)
$\Phi_{Po} = F_v/F_m$	Related to maximum photochemical efficiency of PSII
Φ_{Eo}	Quantum yield of electron transport (at t = 0)
Φ_{Ro}	Quantum yield of reduction of end electron acceptors at the PSI acceptor side
Ψ_{ETo}	Probability with which trapped electron is passed beyond Q_A
Ψ_{REo}	Probability with which trapped electron is passed beyond PSI
δ_{Ro}	Efficiency/probability with which an electron from the intersystem electron carriers moves to reduce end electron acceptors at the PSI acceptor side
Specific energy fluxes expressed per active PSII reaction center (RC)	
ABS/RC	Apparent antenna size of active PSII RC
TR_0/RC	Maximal trapping rate of absorbed photons in RC
ET_0/RC	Electron transport flux from reduced QA to QB in active RC
DI_0/RC	Effective dissipation of energy in active RC
RE_0/RC	Electron flux reducing end electron acceptors at the PSI acceptor side in active RC

Note: Adapted from Zivcak *et al.* 2014 and Kalaji *et al.* 2014. All parameters are expressed in relative units.

RESULTS AND DISCUSSION

Throughout the monitoring duration of 12 months, it was found that mean air temperature was lowest in the month of December whereas June recorded the highest mean readings. On the other hand, relative humidity recorded an inverse trend compared to air temperature. The results also showed that air temperature in area shaded by trees had a mean difference of about 3°C at noon time compared to gap area.

Observation on the growth of *S. leprosula* was only conducted for a total of seven months (July 2019 − February 2020) as some of the selected trees were unfortunately destroyed by wild animals during the project period. The relative growth rates of height and dbh are presented in Table 2. Trees growing in gap were found to have twice the relative height growth of those under gap. Trees growing in gap also displayed slightly better relative dbh growth. Some studies have shown that *Shorea* species suffer leaf damage due to high temperature or strong light irradiance in large gaps (Turner *et al*. 1990) but naturally-regenerated *S. curtisii* seedlings may require relatively high photosynthetically active radiation (Turner 1989). In addition, seedlings of *Shorea* may need moderate shading in terms of survival and growth from seedling to tree stage (Hoshino *et al*. 2016). Results from this study indicated that *S. leprosula* did not present any damages in gap but showed superior height and dbh growth when relatively more ambient light was available. A study in Indonesia showed that the best height growth for *S. leprosula* occurred in stand with planting distance of 4x6 m with the largest increment for diameter and height of 1.49 cm/year and 0.82 m/year, respectively (Pamoengkas 2020). The same study recommended the planting distance of 4x6 m for plantation forestry to produce construction and furniture wood.

Table 2: Average relative growth rate of *Shorea leprosula* planted in gap and under shade

	N	Gap	Shade
Relative height growth (cm/month)	3	15.24 ± 2.40	6.90 ± 1.39
Relative dbh growth (mm/month)	3	1.44 ± 0.99	1.37 ± 0.54

In this study, leaves growing on trees planted in gap are referred as sun leaves while leaves of trees from shade area are shade leaves. Our results found that shade leaves have slightly higher average dry leaf weight, leaf area as well as LMA although the differences with sun leaves were insignificant (Table 3). Although LMA of sun leaves were usually reported to be higher compared to shade leaves, findings from this study showed contrasting results. The average values of LMA for *S. leprosula* in this study were also lower than the range as reported for humid tropical forests at 113–446 g/m^2 (Asner & Martin 2016). The differences may probably be due to the young age of trees in this study. Nevertheless, similar to a study (Roberta *et al*. 2020), leaf chlorophyll SPAD values that we measured were higher in shade leaves than in sun leaves but differences were insignificant (Table 3). The decline in the amount of light received by shade leaves thus appeared to be balanced by a gradient in chlorophyll concentration (Cui *et al*. 1991).

Table 3: Leaf dry weight, area, area per mass and chlorophyll of *Shorea leprosula* planted in gap and under shade

	N	Gap	Shade
Leaf dry weight (g)	22	0.68 ± 0.16^a	0.72 ± 0.12^a
Leaf area (m^2)	22	0.0079 ± 0.0017^a	0.0083 ± 0.0013^a
Leaf area per mass (LMA) (g/m^2)	22	86.57 ± 8.29^a	87.06 ± 8.69^a
Leaf chlorophyll	60	34.18 ± 7.46^a	36.06 ± 4.22^a

Note: Values represent the mean ± standard deviation. Same letters in a row indicate insignificant differences at P<0.05 according to Student's T-test.

Table 4: Selected parameters calculated from fast fluorescence kinetic measurements in sun and shade leaves of *Shorea leprosula*

	Sun leaf	Shade leaf
F_0	$3,391.22 \pm 323.24^a$	$4,116.63 \pm 391.81^b$
F_m	$18,964.81 \pm 2,121.71^a$	$22,432 \pm 1,905.78^b$
F_v/F_m	0.82 ± 0.01^a	0.82 ± 0.01^a
S_m	22.62 ± 3.07^a	19.54 ± 1.98^b
Ψ_{Eo}	0.48 ± 0.05^a	0.48 ± 0.05^a
Ψ_{REo}	0.22 ± 0.04^a	0.20 ± 0.03^a
RC/CS_0	$3,396.39 \pm 575.90^a$	$4,011.41 \pm 626.90^b$
ABS/RC	1.03 ± 0.20^a	1.04 ± 0.15^a
PI_{ABS}	4.49 ± 1.66^a	4.33 ± 1.77^a
PI_{Total}	3.78 ± 1.42^a	3.05 ± 1.10^b

Note: Values represent the mean ± standard deviation (n = 27). Different letters in the same row indicate significant differences at P<0.05 according to Student's T-test.

Of all the JIP-test parameters examined in this study, only F_0, F_m, S_m, RC/CS_0 and PI_{Total} were significantly different (P<0.05) between sun and shade leaves. When comparing between leaves from trees grown in gap (sun leaf) and shade (shade leaf), fast ChlF induction curve showed significant differences in F_0 and F_m values (Table 4). The lower F_0 in sun leaves could be due to the loss of PSII reaction centre (RC) and their inactivation. F_m also had a similar fate with F_0 suggesting that under optimal exposure to ambient light, sun leaf could capture maximize light and lower F_m indicates the energy dissipation via non-photochemical pathways [Zhang *et al*. 2020, Bolhar-Nordenkampf *et al*. 1989]. This is supported by the lower RC/CS_0 in sun leaves which suggests inactivation of the RCs which can be considered as a down-regulation mechanism to dissipate excess absorbed light (Kalaji *et al*. 2014). RC/CS_0 is defined as the density of reaction centers per excited cross section. This parameter is higher in shade leaves and corresponds with the higher leaf chlorophyll SPAD values. The absorbed energy by reaction centers (ABS/RC) was also similar for both sun and shade leaves. S_m is a measure of the energy needed to close all reaction centers and was found to be significantly higher in sun leaves.

The maximum quantum yield of PSII photochemistry ($\Phi_{Po} = F_v/F_m$) was, however, insignificantly influenced (P<0.05) by the growing conditions (gap and shade) of the trees. The shape of fast ChlF induction (Figure 1) is identical in sun and shade leaves suggesting similarity in energy fluxes at the donor as well as at the acceptor side of PSII. However, O-P normalized curves revealed only a slight increase of fluorescence in P step in sun leaves. The probability of the fraction of PSII trapped electrons that are transferred further than Q_A in the electron transfer chain (Ψ_{ETo}) as well as the probability of electron transport from the PSII to the PSI acceptor side (Ψ_{REo}) were similar between sun and shade leaves. These showed that there was no limitation of electron transport from reduced Q_A beyond PSI.

Although there were no indication on limitation of electron transfer from the reduced Q_A to Q_B (Ψ_{Eo}) and the probability of electron transfer from Q_A to beyond the PSI (Ψ_{REo}) between sun and shade leaves, there was a significant decrease in the pool size of electron acceptors (by about 14%), as indicated by measurements on the normalized area over the ChlF curve (S_m), related to the number of electron carriers. It was reported that one of the most important differences between ChlF transient in the sun and the shade leaf is a higher relative variable fluorescence at 30 ms (V_I) (Cascio *et al*. 2010)

PI_{ABS} and PI_{Total} indicate the overall photosynthetic performance associated with the electron transfer capacity of leaf. In this study, the former value was insignificantly different between sun and shade leaves. The latter index, PI_{Total}, is a measure for the performance up to the reduction of PSI end-electron acceptors. We found significantly lower PI_{Total} values in shade leaves which suggested a decrease in photosynthetic performance associated usually with decrease of leaf electron transport capacity which also reflected inhibition of PSI (Figure 2). Nevertheless, this result cannot be confirmed as Ψ_{REo} values in both sun and shade leaves were insignificantly different.

There are, nonetheless, some limitations associated with the using of JIP-test. The information from JIP parameters do not present a detailed interpretation of the adaptive strategies adopted when plants are in stressful conditions (Ripoll *et al*. 2016). In order to fully understand plant responses to heat stress, for instance, the JIP-test should be used in combination with other techniques such as gas exchange measurements.

Figure 1: Chlorophyll a fluorescence induction curves at 3,500 µmol photons/m²/s of continuous red light up to 1s for the sun and the shade leaves. Circle marker – sun leaf, triangle marker – shade leaf.

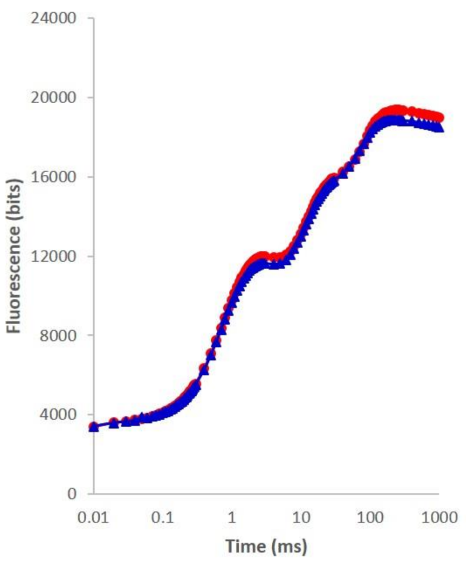
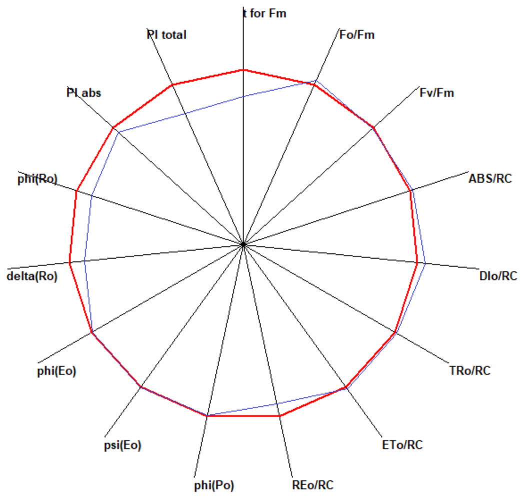


Figure 2: Differences of shape of spider plot JIP-test parameters' images of sun (red) and shade leaf (blue). t — time to reach maximum F_m,



CONCLUSION

Our study found that *S. leprosula* responded with much higher relative growth rate when planted in gap compared to under shade in LFR. This finding, however, was not strongly supported by the evidences of physiological parameters studied on leaves as both shade and sun leaves exhibited similar shape in ChlF induction curve. Thus, other environmental factors including soil physical and chemical properties along with a longer monitoring period need to be considered in order to ascertain the growth promoter(s) of this species. Nevertheless, *S. leprosula* has shown to be a suitable species for restoration of the study site, particularly with a certain level of canopy openness. The authors suggest that if this species is further used for restoration programmes in the future, it may need some protection against disturbances caused by wild animals.

ACKNOWLEDGEMENTS

The authors would like to thank Forest Department of Peninsular Malaysia (FDPM) and Forest Research Institute Malaysia (FRIM) for the financial support to conduct the study. The authors are also grateful to Bentong District Forest Office for permission to enter Lentang Forest Reserve and on-site support rendered throughout the duration of this project.

REFERENCES

Asner, G. P. & Martin, R. E. (2016). Convergent elevation trends in canopy chemical traits of tropical forests *Global Change Biology,* 22, 2216–27.

Bolhar-Nordenkampf, H. R., Long, S. P., Baker, N. R., Oquist, G., Schreiber, U. & Lechner, E. G. (1989). Chlorophyll fluorescence as a probe of the photosynthetic competence of leaves in the field: A review of current instrumentation. *Functional Ecology,* 3, 497–514.Cascio, C., Schaub, M., Novak, K., Desotgui, R., Bussotti, F. & Strasser, R. J. (2010). Foliar responses to ozone of *Fagus sylvatica* L. seedlings grown in shaded and in full sunlight conditions. *Environmental and Experimental Botany,* 68, 188–97.

Cui, M., Vogelmann, T. C. & Smith, W. K. (1991). Chlorophyll and light gradients in sun and shade leaves of *Spinacia oleracea Plant, Cell & Environment,* 14(5), 493–500.

Economics of Land Degradation (ELD) Initiative. (2015). *Report for Policy Aand Decision Makers: Reaping Economic and Environmental Benefits from Sustainable Land Management*. Bonn: ELD Initiative. p. 26.

FAO & UNEP. (2020). *The State of the World's Forests 2020. Forests, Biodiversity and People.* Rome: FAO and UNEP. p. 214.

Gilbey, B., Davies, J., Metternicht G. & Magero, C. (2019). Taking land degradation neutrality from concept to practice: Early reflections on LDN target setting and planning *Environmental Science and Policy*, 100, 230–7.

Hoshino, D., Tani, N., Niiyama, K., Otani, T., Aida, D., Shamsuri, M., Azizi, R., Abd Rahman, K., Nur Hajar, Z. S. & Ismail, H. (2016). Site effects on survival and growth of planted *Shorea curtisii* in a logged-over hill forest in Peninsular Malaysia *Journal of Tropical Forest Science,* 28, (Special Issue), 342–52.

International Union for Conservation of Nature (IUCN) (2015). *Land Degradation Neutrality: Implications and Opportunities for Conservation.* Gland: IUCN. p. 20.

Kalaji, H. M., Oukarroum, A., Alexandrov, V., Kouzmanova, M., Brestic, M., Zivcak, M., Samborska, I. A., Cetner, M. D., Allakhverdiev, S. I. & Goltsev, V. (2014). Identification of nutrient deficiency in maize and tomato plants by in vivo chlorophyll *a* fluorescence measurements *Plant Physiology and Biochemistry,* 81, 16–25.

Lamb, D. & Gilmour, D. (2003). *Rehabilitation and restoration of degraded forests.* Gland: IUCN. p. 122.

Lamb, D., Erskine, P. D. & Parrotta, J. A. (2005). Restoration of degraded tropical forest landscapes *Science,* 310, 1628–32.

Lee, S.S. & Alexander I.J. (1996). The dynamics of ectomycorrhizal infection of *Shorea leprosula* seedlings in Malaysian rain forests. *New Phytologist,* 132(2), 297–305.

Pamoengkas, P., Rachmat T.T & Khalifa N. (2020). The growth of *Shorea leprosula* at various planting distances and slopesin Gunung Dahu Research Forest, Bogor, Indonesia, *Biodiversitas*, 21(9), 439–6404.

Poorter, H., Niinemets, U., Poorter, L., Wright, I. J. & Villar, R. (2009). Causes and consequences of variation in leaf mass per area (LMA): a meta-analysis. *New Phytol*ogist, 182, 565–88.

Ripoll, J., Bertin, N., Bidel, L.P.R. & Urban, L. (2016). A user's view of the parameters derived from the induction curves of maximal chlorophyll *a* fluorescence: perspectives for analyzing stress. *Frontiers in Plant Science,* 7, 1679.

Roberta, E. M., Gregory, P. A., Bentley, L. P., Shenkin, A., Salinas, N., Huaypar, K. Q., Pillco, M. M., Álvarez, F. D. C., Enquist, B. J., Diaz, S. & Malhi, Y. (2020). Covariance of sun and shade leaf traits along a tropical forest elevation gradient *Frontiers in Plant Science,* 10, 1810.

Soekotjo. (2009). *Teknik Silvikultur Intensif (SILIN)*. Yogyakarta: Gadjah Mada University Press. [in Indonesian].

Turner, I. M. & Newton, A. C. (1990). The initial responses of some tropical rainforest tree seedlings to a large gap environment *Journal of Applied Ecology,* 27, 605–8.

Turner, I. M. (1989). A shading experiment on some tropical rain forest tree seedlings. *Journal of Tropical Forest Science,* 1, 383–9.

United Nations Convention to Combat Desertification (UNCCD). (2016). *Land Degradation Neutrality Target Setting Programme Land Degradation Neutrality Target Setting: A Technical Guide*. Bonn: UNCCD. p. 68.

Zhang, B., Zhang, H., Jing, Q. & Wang, J. (2020). Light pollution on the growth, physiology and chlorophyll fluorescence response of landscape plant perennial ryegrass (*Lolium perenne* L.) *Ecological Indicators,* 115, 106448.

Zivcak, M., Brestic, M., Kalaji, H. M. & Govindjee. (2014). Photosynthetic responses of sun- and shade-grown barley leaves to high light: is the lower PSII connectivity in shade leaves associated with protection against excess of light? *Photosynthesis Research,* 119, 339–54.