Effect of perlite for soil improvement and on growth characteristics of teak seedling planted in sandy soil in Northeast Thailand

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Abstract

When teak (*Tectona grandis* L. f.) is planted in sandy soil in Northeast Thailand, its growth is suppressed by low pH, poor fertility, and low water holding capacity. To examine materials capable of increasing water holding capacity and nutrients in the soil in order to improve teak growth, we conducted an experiment with teak seedlings. We used perlite and added at a rate of 4% to sandy soil from northeast Thailand. Teak seedlings were potted in these soils and raised from July 2013 to July 2014. We compared growth, photosynthetic rate, leaf water potential, and concentrations of elements in plant organs between the perlite and no addition (control) treatments.

Water content in the soils was increased with the perlite treatment from December 2013; however, this effect decreased after March 2014. Comparing the growth traits of the teak seedlings, perlite treatment produced larger growth and promoted the uptake of phosphorus, calcium, and magnesium. These trends originated from the presence of these nutrients in perlite. We concluded that perlite had a role as a fertilizer, and was a useful material to improve teak growth in sandy soil.

Keywords: Acrisols, Photosynthesis, Nutrients, Soil improvement

Introduction

Teak (*Tectona grandis* L. f) is one of the most valuable timber species in Thailand (Tewari 1992). Since 1994, a tree plantation promotion project has been conducted and teak had been planted in throughout Thailand (Furuya et al. 2012). However, teak planted in Northeast Thailand showed suppressed growth (Tangmitcharoen et al. 2012). Farmers living in this district are interested in the farming of teak (Himmapan et al. 2010). Thus, we sought to develop methods to accelerate the growth of teak in Northeast Thailand.

The representative soil in Northeast Thailand is described as a "light textured sandy soil" (abbreviated to sandy soil) that is categorized in the acrisols (ultisols in USDA soil taxonomy) (Kyuma 2003; Suzuki et al. 2007). This sandy soil is characterized by a low content of clay, low pH, poor fertility, and low water holding capacity (Suzuki et al. 2007). The growth of teak is restricted by nutrient limitation, and deficiency of nutrients, especially nitrogen (N), calcium (Ca), and phosphorus (P), affects its growth drastically (Tanaka et al. 1998, Barroso et al. 2005; Zhou et al. 2012). Moreover, the growth of teak showed a negative correlation with the content of sand, and a teak plantation in soil with a high content of sand showed poor growth (Tanaka et al. 1998; Salifu 2001).

To improve this sandy soil, the correction of acidity, fertilization, and improvement water holding capacity is essential for the acceleration of teak growth. Kayama et al. (2016) reported that charcoal and bentonite had an ability to increase the soil water content. In addition, charcoal contained nutrients, such as N, Ca, and magnesium (Mg), and the root growth of teak was accelerated with this treatment (Kayama et al. 2016). However, charcoal treatment did not show obvious growth acceleration for other organs. By contrast, bentonite did not contain nutrients, and the growth of teak was not enhanced. Thus, growth acceleration of teak needs not only improvement of low water holding capacity but also increases in nutrient concentrations. As another potentially useful material to improve sandy soil, perlite has also been shown to increase water holding capacity (Özenç 2003; Samadi 2011). Moreover, perlite is produced in Thailand, and large amount of various nutrients are contained within it (Saisuttichai and Manning 2007). We hypothesized that the use of perlite could improve the low water holding capacity and poor fertility of sandy soil. However, research has not yet been carried out to examine the effects of perlite on the growth of teak.

The aim of our research was to examine the ability of perlite to improve water holding capacity and increase teak growth. We conducted a pot experiment with teak seedlings in sandy soil with the addition of perlite. To verify the effects of perlite, we examined ecophysiological traits of the teak seedlings. These parameters were compared with seedlings potted in sandy soil without perlite.

Materials and methods

Study site

Our experiment was conducted at the Northeast Forest Seed Center located in Khon Kaen Province in northeastern Thailand (16°16′ N, 102°47′ E, 191 m a.s.l.). This centre conducts measurements of meteorological data: mean annual precipitation was 1,104 mm, and annual mean, maximum, and minimum temperatures were 28.3°C, 40°C, and 13°C, respectively (from 2008 to 2012, Northeast Forest Seed Center, unpublished data). Precipitation is concentrated from May to October (Northeast Forest Seed Centre, unpublished data). During the experimental period, monthly precipitation and average maximum and minimum temperatures were as report by Kayama et al. (2016).

In Khon Kaen Province, we previously published a soil suitability map of teak plantation for farmers (Wichiennopparat et al. 2015). Sandy soil in Khon Kaen Province is distributed over a large area (13.5%). These areas are categorized as moderately suitable for teak planting.

Preparation of materials, soil, and teak seedlings

For the ratio of perlite, a previous study showed that 8% was effective in increasing water holding capacity (Özenç 2003). However, when we analysed the nutrients in perlite, a large amount of nutrients, especially Ca, was detected. There was a possibility that excess use of perlite may result in fertilizer spoilage of teak. Thus, we decided to decrease the use of ratio of perlite to 4%. In July 2013, we prepared 7 kg of perlite from a market in Lopburi province, Thailand. We also collected 300 kg of sandy soil from the Northeast Forest Seed Center. Our experiment was conducted without fertilization because we had to examine the effects of nutrients in perlite.

The teak seedlings were prepared by a tissue culture technique. The teak clone was from Mae Hong Son Province (clone number 21), and this clone has been planted in various places (Royal Forest Department, unpublished data). Teak seedlings were raised from March to June 2013 at the Teak Improvement Center, Lampang, Thailand. In July 2013, 74 teak seedlings were transported to the Northeast Forest Seed Centre, Khon Kaen. In addition, we prepared eight tables for raising the teak seedlings.

Establishment of the pot experiment

We established the perlite treatment by adding it at a rate of 4% into the sandy soil. We mixed the components, and the total weight of the mixed soil was 153 kg per treatment. These mixed soils were put into 17 pots (depth: 22.5 cm, diameter: 27 cm, volume: 8.5 L), and the soil weight per pot was 9 kg. We also prepared 17 pots filled with 9 kg of sandy soil alone as the control treatment. Before transplantation, 50 g of soil samples were collected from 4 pots for each treatment.

We potted 32 teak seedlings into 32 pots in July 2013. We also set a soil sensor (ML2, Delta-T Devices Ltd., Cambridge, UK) into one pot per treatment. The water content of the soil was measured continuously. Each pot was put onto the tables, and these tables were established in the field in sunny conditions. The two pots containing the soil sensors were also put onto the tables. The logger connected to the soil sensor was fixed to a pole made of concrete.

After being set up, all pots (including pots with soil sensors) were irrigated with 1 L of water in the morning of every day. On rainy days, irrigation was not conducted. Irrigation was carried out until the end of the experiment (July 2014).

Soil analysis

We measured soil texture and chemical properties including pH and concentrations of carbon (C), N, exchangeable P, and base cations. Four soils samples for each treatment from before transplantation were used. To determine the pH of the soil, 25 ml of distilled water was added to 10 g fresh soil to make a homogenized mixture (van Reeuwijk 2002). This mixture was then shaken for 1 h and the pH was measured using a pH meter (SG2, Mettler Toledo, Zürich, Switzerland). Prior to chemical analysis, we conducted air-drying of the soil samples.

The soil texture was determined by the hydrometer method (Klute 1986). The concentrations of C and N in dried soils were determined using a nitrogen and carbon analyzer (Flash 2000, Thermo Fisher Scientific, Waltham, MA). Exchangeable P was separated using dilute acid fluoride (Sparks et al. 1996) by shaking for 1 minute. P in the extracted solution was determined by the molybdenum blue method (American Public Health Association et al. 1998) using a spectrophotometer (U-1800, Shimadzu, Kyoto, Japan). Exchangeable base cations (Ca, Mg, potassium [K], and sodium [Na]) were quantified by mixing 4 g of dry soil with 100 ml of 1 M ammonium acetate solution, and shaking for 1 h (Sparks et al. 1996). Base cations in the extracted solutions were analyzed using an atomic absorption spectrophotometer (AAnalyst 300, Perkin-Elmer, Norwalk, CT).

Measurement of teak seedlings

For the measurement of teak seedlings, eight seedlings for each treatment were used for growth measurements. We measured tree height and basal diameter at six time points (July 2013, October 2013, December 2013, February 2014, April 2014, and July 2014). We also measured length and width for all leaves of the teak seedlings. The leaf area of teak seedling was calculated using the equation of Tondjo et al. (2015), as follows:

$A = 0.60 \times L \times \mathrm{Wi}$

where A is the leaf area, L is the leaf length, and Wi is the leaf width.

Measurement of photosynthetic rate and nitrogen

We measured the area-based photosynthetic rate at light saturation (P_{sat}) and stomatal conductance (gs) for teak leaves located second from the top. From our observations, leaves of teak seedlings had been foliating in response to continuous irrigation, and the average of longevity of teak leaves was 99 days (Kayama et al. 2016). We observed foliation of teak seedlings in every week. Based on these observations, we selected teak leaves for measurement of photosynthetic rate that passed one month after foliation.

For the measurement of photosynthetic rate and leaf water potential, eight teak seedlings not used for the measurement of growth parameters were used per treatment. There was no irrigation to eliminate the effects of water in the pot on the day when the measurements were conducted.

When we measured photosynthetic rates, the leaves of some seedlings were immature or senescent. To provide uniformly mature teak leaves, we selected four teak leaves from among eight seedlings. We measured P_{sat} five times (October 2013, December 2013, February 2014, April 2014, and July 2014), and the measurements were always performed between 09:00 and 11:00.

Measurements were made using a portable gas analyzer (LI-6400, LiCor, Lincoln, NE, USA) in steady-state conditions, at an ambient temperature of 27°C and ambient CO_2 concentration of 38.0 Pa. The LED light source was adjusted to a saturation light level of 1,800 $\mu mol\ m^{-2}s^{-1}$ PPF.

Measurement of leaf water potential and concentration of nitrogen

After measurement of photosynthetic rate, we measured the leaf water potential of teak leaves at five times (October 2013, December 2013, February 2014, April 2014, and July 2014). The leaf used to measure water potential was the same as that used to measure photosynthetic rate. In general, leaf water potential showed the lowest value in the afternoon by transpiration, and showed the highest value by recovery of water during the night (Larcher 2003). We measured leaf water potential in the afternoon and predawn. Four teak leaves for each treatment were sampled at 13:00–14:00 and 5:30–6:00 the next day. Sampled shoots were put in a plastic bag that contained a wet filter paper, and kept in a refrigerator. We measured leaf water potential using a pressure chamber (Model 600, PMS Instrument Co., Albany, OR, USA).

After measuring leaf water potential, we analyzed the concentration of nitrogen. Photosynthetic rate is closely related to concentrations of nitrogen (Evans 1989; Larcher 2003; Kayama et al. 2007). Leaf samples were oven-dried at 70°C for 3 days, and LMA ($g\ m^{-2}$) measured by the method of Larcher (2003). Leaf samples were ground to a fine powder using a sample mill (WB-1; Osaka Chemical Co., Osaka, Japan). The concentration of N was determined using an NC analyzer (Sumigraph NC-220F, Sumika Chemical Analysis Service, Tokyo, Japan). The results of the concentration of N were calculated from the area based on N (N_{area}) from the data of LMA.

Analysis of biomass and element concentrations of teak seedlings

To determine the biomass of teak seedlings, we measured the dry mass of leaves, stems and branches, and roots. In July 2014, eight teak seedlings from each treatment used for growth measurements were sampled. Roots of seedlings were washed twice with water to remove soil. The washed seedlings were divided into leaves, stems and branches, and roots. Each component was put into its own envelope and oven-dried at 70°C for 3 days. After drying, the dry mass of each component was determined. We also examined the root/shoot ratio as an indicator of teak growth (Gopikumar and Varghese 2004; Rao et al. 2008, Zhou et al. 2012).

Of the elements in the plant organs, we measured the mass base of concentrations of N, P, K, Ca, and Mg in leaves and roots. Dried samples were ground to a fine powder, and N concentration was determined using an NC analyzer. The remaining samples were digested by the HNO_3-HCl-H_2O_2 method (Goto 1990). Concentrations of K, Ca, and Mg, were analyzed using an ICP analyzer (ICPE-9000, Shimadzu, Kyoto, Japan), and the concentration of P was determined by the molybdenum blue method using a spectrophotometer (UV-2500PC, Shimadzu, Kyoto, Japan).

Statistical analysis

Significant pairwise differences for each variable were tested by t-test using Stat View 5.0 (SAS Institute Inc.). Comparisons were made between the perlite and control treatments.

Results

Water contents in soil

To examine the minimum water content in soil for each season, we collected the lowest water contents before irrigation and rainfall. Averages of these values for each month are shown in Fig. 1. The water content was low for the perlite treatment until October 2013. From December 2013 to February 2014, water content increased for the perlite treatment compared with the control treatment. From March 2016, water content showed a similar trend between the two treatments.

Water contents of the perlite and control treatments were increased by rainfall in September 2013. The value of maximum water content in this month was 0.62 m^3 m^{-3} for perlite treatment, and 0.28 m^3 m^{-3} for control treatment.

Soil properties

For soil texture, the content of sand was over 90.0% for each treatment (Table 1). The contents of silt and clay were low for each treatment. Comparing with two treatments, there was no significant difference.

The pH value was significantly higher for the perlite treatment than that for the control treatment (P<0.01). The concentrations of P, Ca, Mg, and K for the perlite treatment were also significantly higher than those for the control treatment (P<0.01). There was no significant difference in the concentrations of C, N, and Na between the two treatments.

Growth characteristics

Tree height and diameter did not show significant differences between the two treatments (Fig. 2, P>0.05). The growth pattern of teak seedlings was similar between the two treatments (Fig. 3). Tree height and diameter showed remarkable increases, but these increases weakened from February 2014.

Total leaf area showed a seasonal increase from April 2014 (Fig. 4). Comparing the two treatments, leaf area in April 2014 was significantly larger for the perlite treatment than for the control treatments (P<0.01). The average of total number of leaves in July 2014 was 9.5 for perlite treatment, and 6.5 for control treatment. The total number of leaves showed significantly difference between two treatments (P<0.01).

Photosynthetic rate, leaf water potential, and concentration of nitrogen

The P_{sat} was not significantly different between the two treatments (Fig. 5, P>0.05). The P_{sat} in each treatment was highest in February 2014; however, P_{sat} decreased drastically from April 2014.

gs in the perlite treatment was significantly higher than in the control treatments in February 2014. The gs value decreased in December 2013 and July 2014.

Leaf water potential in the afternoon and predawn was highest in December 2013 (Fig. 6). In contrast, these values were decreased from February 2014. The predawn leaf water potential in July 2014 showed significantly difference between perlite and control treatments (P<0.05).

N_{area} showed the highest value in February 2014; however, N_{area} decreased from April 2014 (Fig. 7). Comparing with treatments, N_{area} did not show the significantly difference. The average of LMA for teak leaves showed 93 g m^{-2}. The value of LMA did not change during the experimental period, and there was no significantly difference between two treatments.

Biomass of teak seedling

In July 2014 the dry mass of roots was significantly higher for the perlite treatment than for the control treatment (Fig. 8, P<0.01). Total dry mass of teak seedlings was also significantly higher for the perlite treatment than for the control treatment (P<0.05). For the dry masses of leaves and stems and branches, there were no significant differences between the two treatments. The root:shoot ratio was 1.37±0.09 for the perlite treatment and 1.29±0.09 for the control treatment. There was no significant difference in the root:shoot ratio between the two treatments.

Concentration of elements in plant organs

The concentrations of P in the leaves and roots of teak seedlings were significantly higher for the perlite treatments than for the control treatment (Table 2, P<0.05). In the perlite treatment, the concentration of Mg in leaves and Ca in roots was also significantly higher compared with the control treatment (P< 0.05). By contrast, the concentration of K in roots was significantly higher for the control treatment than that for the perlite treatment (P<0.05). In terms of the concentration of N, there were no significant differences between the two treatments.

Discussion

Based on the results of the water content before irrigation, perlite treatment showed high values from December 2013 to February 2014 (Fig. 1). These materials probably have the ability to increase water holding capacity temporarily. In contrast, the water content of perlite treatment did not show high value until October 2013 (Fig. 1). The perlite used for our experiment was granule (2-4 mm), and easy to break. On the water holding substances, increase of water holding capacity was less for granule than that for powder (Yabashi and Konko 1989). There is a possibility that granule of perlite may be low capacity to increase soil water. We also confirmed that granule of perlite was broken from December 2013. Thus, water holding capacity of perlite may be increased after break of granule. Meanwhile, leaf water potential is little difference between perlite and control treatments (Fig. 6). Low value of water content is little effect for the trait of water availability of teak seedlings.

Moreover, gs was high in February 2014 (Fig. 5). This trend showed that stomata in the perlite treatment were harder to close with abundant water in the soil. However, water content was not high from March 2014 (Fig. 1). Thus, the ability of perlite to increase water holding capacity did not last for prolonged period. Compared with other experiments, the period of the experiment was 4 month in Özenç (2003) and 8 weeks in Samadi (2011). Perlite has a capacity to increase water holding capacity for a short period; however, this capacity was probably decreased from 8 months.

Comparing growth between the two treatments, growth of aboveground organs did not show obvious growth acceleration from the perlite treatment (Fig. 2, 8). In contrast, root growth with the perlite treatment was accelerated, as a result, total dry mass for the perlite treatment showed large growth compared with control treatment (Fig. 8). Thus, the use of perlite contributed to root development. A similar trend was confirmed with the use of charcoal (Kayama et al. 2016). Compared with total dry mass, use of perlite (ave. 73.5 g) was larger than that of charcoal (ave. 53.9 g), bentonite (ave. 46.8 g) and corncob (ave. 36.5 g; Kayama et al. 2016). Thus, use of perlite affect obvious growth acceleration of teak seedlings compared with other materials.

Moreover, the concentrations of P, Ca, and Mg were increased in all organs of teak with the perlite treatment (Table 2). These nutrients showed high concentrations in the soil with the perlite treatment (Table 1). Thus, the increased uptake of P, Ca, and Mg originated from these nutrients in perlite. In addition, the observed enhanced root development may be related to the uptake of these nutrients.

Comparing our results with previous reports, when the growth of teak seedlings was suppressed drastically, the value of the root:shoot ratio increased over 1.0 (Gopikumar and Varghese 2004; Rao et al. 2008, Zhou et al. 2012). In the present study, the root:shoot ratios were over 1.0 for both treatments. We considered that teak seedlings showed suppressed growth, and one of the causes of this was N deficiency. The concentration of N in leaves at the end of the experiment (average 683 μmol g^{-1}) indicated N deficiency (<857 μmol g^{-1}, Zech and Drechsel 1991). In contrast, the concentration of P in leaves at this time (average 401 μmol g^{-1}) was much higher and did not indicate any deficiency (<32 μmol g^{-1}, Zech and Drechsel 1991). Thus, sandy soil was considered as a rather infertile environment and especially for N. In addition, P_{sat} was also lower from April 2014 (Fig. 5). Photosynthetic rate shows a positive correlation with the concentration of N (Gopikumar and Varghese 2004; Evans 1989; Kayama et al. 2007), and these decreases were related to decreased N in leaves (Fig. 7). In terms of gs, a leaf suffering from N deficiency can readily suffer from a decrease in leaf water potential (Radin and Ackerson 1981). Thus, N deficiency negatively affects physiological parameters in teak seedlings. These trends were also confirmed by Kayama et al. (2016).

Despite the N deficiency, we confirmed that leaf area of teak seedlings were increased from April to July 2014 (Fig. 4). In particular, the perlite treatment showed obvious increases in leaf area in April 2014 (Fig. 4). In teak, various nutrients are important for leaf production (Barroso et al. 2005; Zhou et al. 2012). Our results showed that the concentration of P and Mg in leaves were significantly higher for perlite treatment that those for control treatment (Table 2). In the perlite treatment, the abundant supply of P and Mg may contribute to develop leaves in April 2014.

In addition, P_{sat} and gs in December 2013 were low (Fig. 5). The date of measurement of P_{sat} showed that the minimum temperature was 11°C in the morning (Kayama et al. 2016). There is a possibility that the leaves of the teak seedlings in December 2013 were suffering from low temperature in the morning, and as a result P_{sat} and gs could not recover in the morning.

Finally, we concluded previously that charcoal was a useful material to improve seedling growth of teak in sandy soils in northeast Thailand. Teak seedlings grown with perlite exhibited accelerated root growth. Perlite produced in Thailand contained P, Ca, and Mg, and we confirmed the effects of fertilizer of these nutrients. In particular, Ca was an essential nutrient for growth acceleration in teak (Barroso et al. 2005; Zhou et al. 2012), and perlite showed a role as a Ca fertilizer. However, this experiment also showed N deficiency in this treatment. Our experiment did not use fertilizer to examine nutrients in perlite. We confirmed that perlite did not contain N (Table 1). If we apply perlite in the raising of teak, we should also use another N-containing fertilizer.

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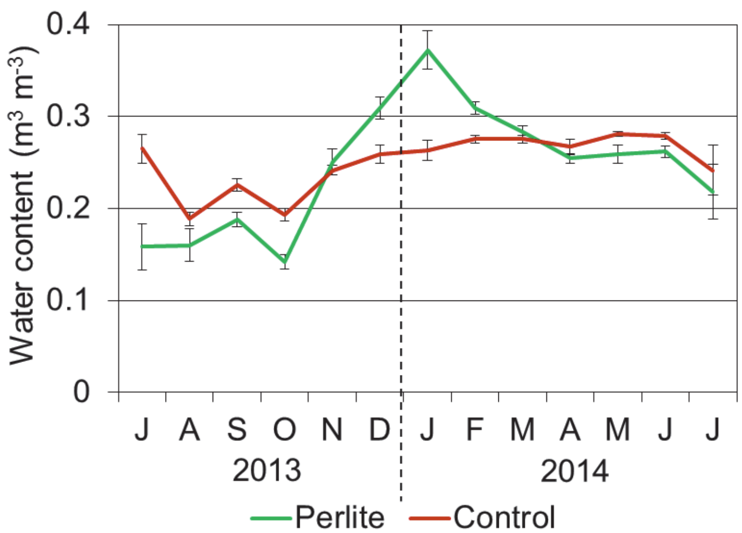

Fig. 1. Average soil water content in the two treatments before irrigation or rainfall (from July 2013 to July 2014, mean ± SE). Note. The values of water content were averaged among several dates with low values before irrigation.

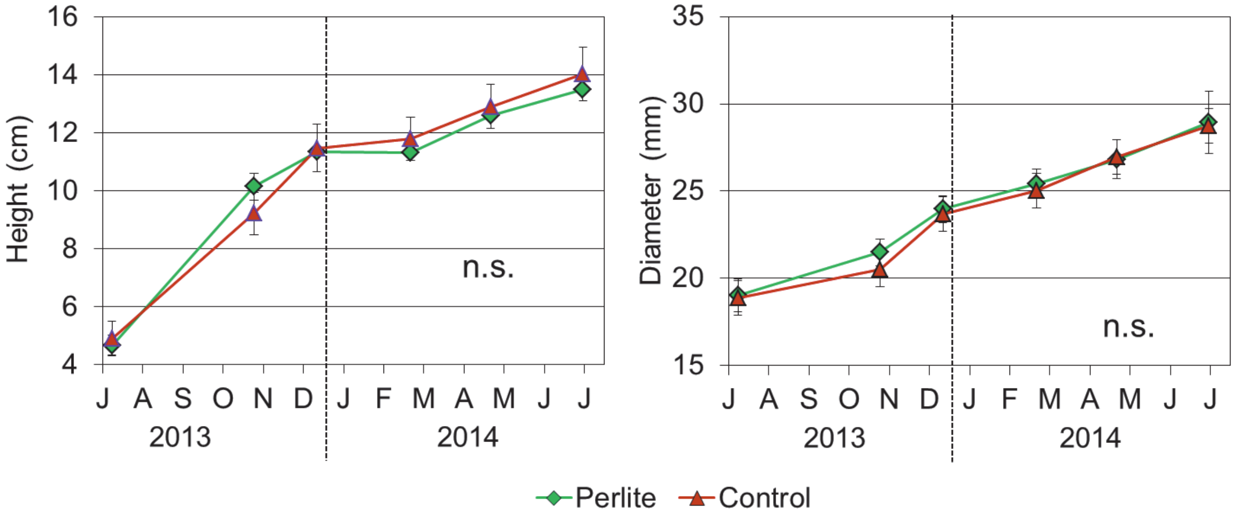

Fig. 2. Tree height and basal diameter of teak seedlings grown in the two treatments (mean ± SE, n=8). Mean values of each parameter were analyzed by t-test (not significant).

Note. Divisions on the horizontal axis over the letters are the first day of each month. The same format is used in subsequent figures.

Fig. 3. Pictures of teak seedlings grown in the perlite (left) and control (right) treatments (April 2014). Tree height and basal diameter did not show obvious difference between the two seedlings. However, total leaf area was larger for the seedling in the perlite treatment (1,369 cm^2) than in the control treatment (1,188 cm^2).

Note. Yellow bars the pictures showed the scale (10 cm).

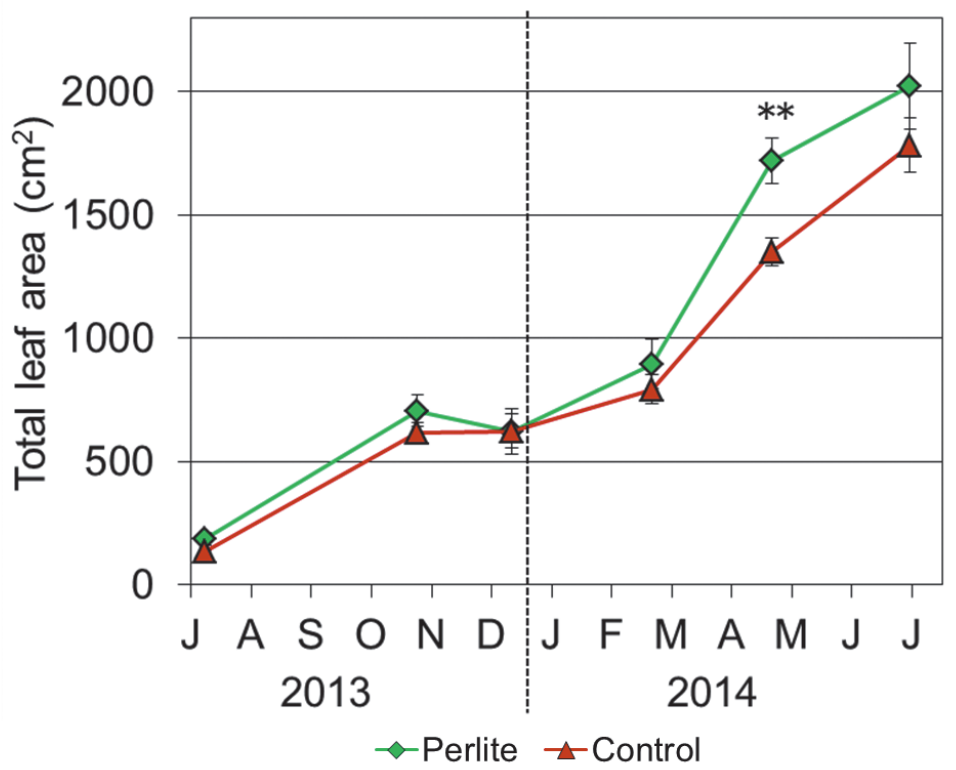

Fig. 4. Total leaf areas for teak seedlings grown in the two treatments (mean ± SE, n=8). Mean values of each parameter were analyzed by t-test. ** P<0.01.

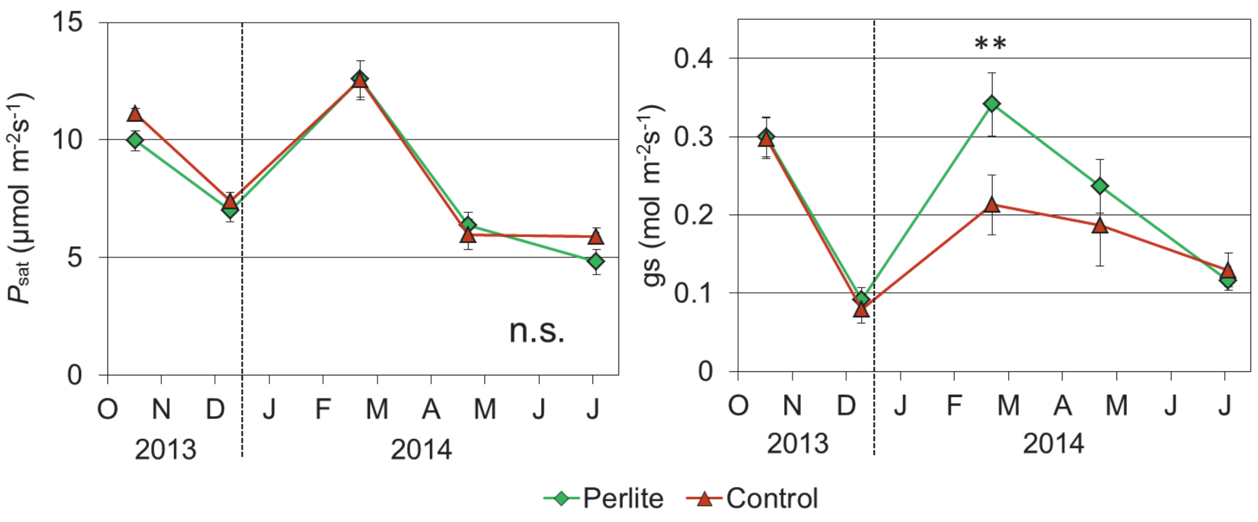

Fig. 5. Photosynthetic rate at light saturation (Psat) and stomatal conductance (gs) for teak seedlings grown in the two treatments (9:00–11:00, mean ± SE, n=4). Mean values of each parameter were analyzed by t-test (not significant).

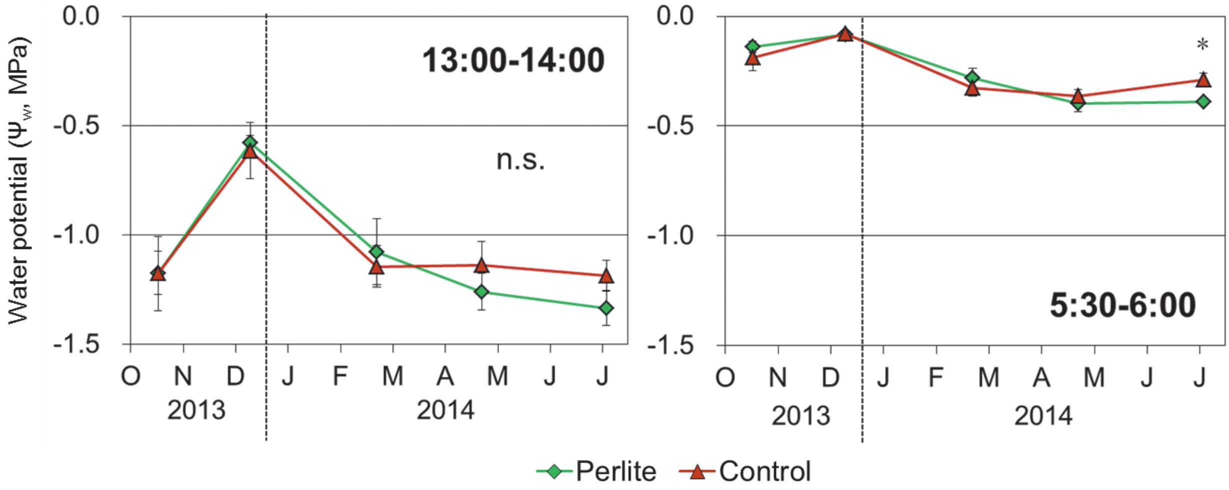

Fig. 6. Leaf water potential in the afternoon (13:00–14:00) and predawn (5:30–6:00) for teak seedlings grown in the two treatments (Mean ± SE, n=4). * $P<0.05$.

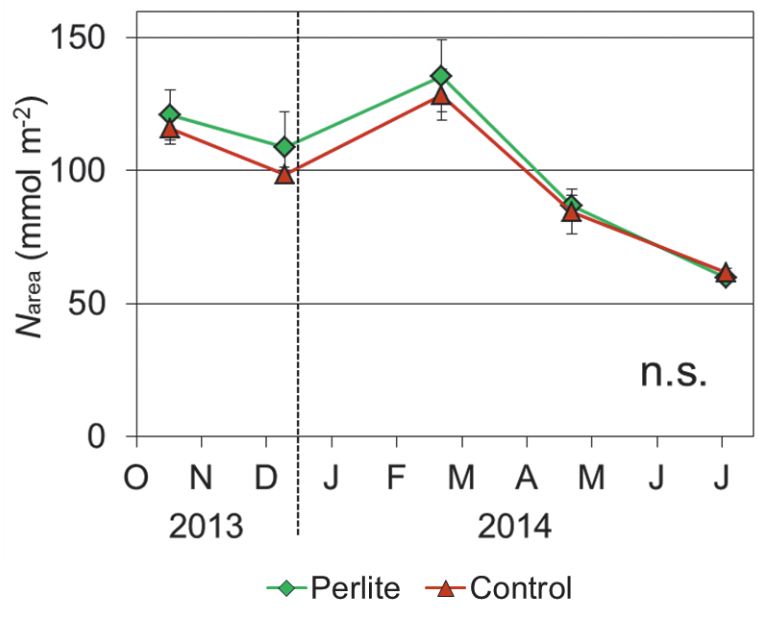

Fig. 7. Concentrations of area-based nitrogen (Narea) and for teak seedlings grown in the two treatments (Mean ± SE, n=4). Mean values of each parameter were analyzed by t-test (not significant).

Table 1. Texture and chemical properties of soils in the two treatments (mean ± SE, n=4). Mean values of each parameter were analyzed by t-test. ** *P*<0.01, *** *P*<0.001, and n.s. not significant

Treatment	Texture (%)			pH
	Sand	Silt	Clay	
Perlite	92.0±0.0	4.0±0.0	4.0±0.0	5.89±0.11
Control	92.0±0.0	4.0±0.0	4.0±0.0	5.31±0.04
Statistical test	n.s.	n.s.	n.s.	**
	C (mol kg^{-1})	N (mmol kg^{-1})	P (mmol kg^{-1})	Ca (mmol kg^{-1})
Perlite	0.62±0.24	12.5±1.8	2.21±0.22	32.6±1.4
Control	0.73±0.26	8.9±3.0	0.29±0.10	2.7±0.3
Statistical test	n.s.	n.s.	***	***
	Mg (mmol kg^{-1})	K (mmol kg^{-1})	Na (mmol kg^{-1})	
Perlite	5.16±0.33	2.79±0.88	0.012±0.012	
Control	1.46±0.16	1.14±0.06	0.083±0.064	
Statistical test	***	**	n.s.	

Table 2. Concentrations of elements (N, P, K, Ca, and Mg; μmol g^{-1} dry mass) in leaves and roots of teak seedlings grown in four treatments (mean ± SE, n=8). Mean values of each parameter were analyzed by t-test. * *P*<0.05, ** *P*<0.01, *** *P*<0.001, and n.s. not significant.

Element		Leaf	Root
N	Perlite	713±40	633±18
	Control	653±11	649±19
	Statistical test	n.s.	n.s.
P	Perlite	484±61	580±18
	Control	318±39	224±08
	Statistical test	*	***
K	Perlite	194±29	187±13
	Control	194±22	222±05
	Statistical test	n.s.	*
Ca	Perlite	226±22	427±60
	Control	196±10	290±18
	Statistical test	n.s.	*
Mg	Perlite	90±03	171±07
	Control	75±03	175±06
	Statistical test	**	n.s.

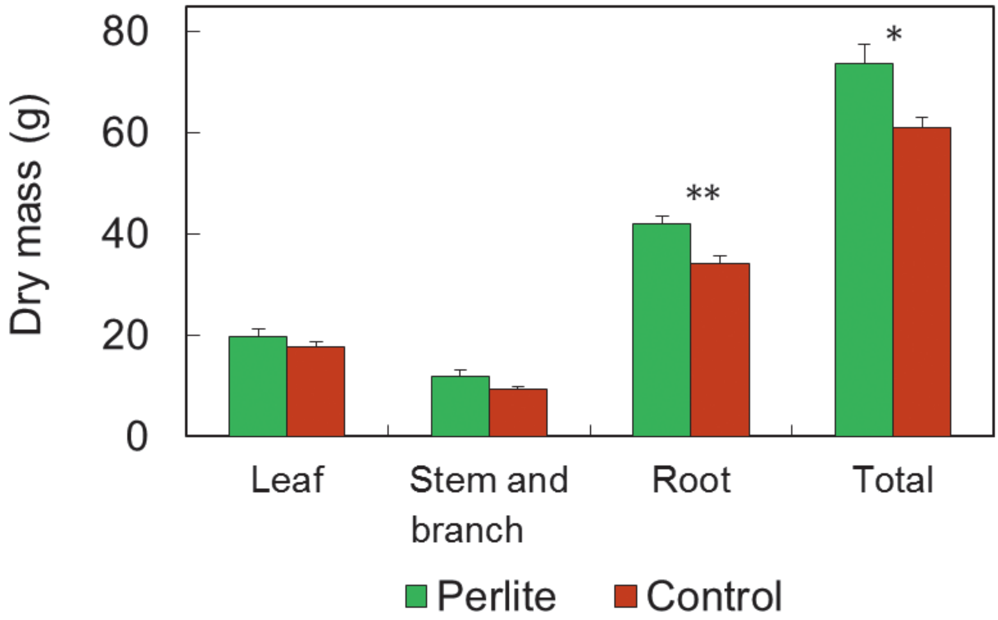

Fig. 8. Dry mass of each organ (leaf, stem and branch, and root) and total dry mass for teak seedlings at the end of the experiment (July 2014) grown in the two treatments (Mean ± SE, n=8). Mean values of each parameter were analyzed by t-test.

* P<0.05, ** P<0.01.

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