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Morphological responses, sensitivity and tolerance indices of four tropical trees species to drought and waterlogging

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Abstract. *Yulianti, Sudrajat DJ. 2016. Morphological responses, sensitivity and tolerance indices of four tropical trees species to drought and waterlogging. Biodiversitas 17: 110-115.* Indonesia's climate model predicts an increase in threat of drought and waterlogging in several areas. However, knowledge on variations between tropical forest tree species, i.e. *Anthocephalus macrophyllus, Anthocephalus cadamba, Fagraea fragrans*, and *Magnolia champaca* to drought and waterlogging stress are still limited, though they are relevant to future development of forest ecosystem. The objective of this research is to investigate the adaptability of four potential tree species to drought and waterlogging stress in a controlled greenhouse. The results showed that the adaptive responses of four tropical tree species were different, according to the results, all species were more tolerant to waterlogging than to drought stress, which can be observed from morphological, seedling survival, stress tolerant and stress sensitivity indices. The waterlogging resistant in four species followed the order of: *A. cadamba* > *F. fragrans* > *A. macrophyllus*, and > *M. champaca*, while for the drought resistant species followed the order: *A. macrophyllus* > *A. cadamba* > *F. fragrans* and > *M. champaca.*

Keywords: Adaptability, seedling, stress, tropical trees

INTRODUCTION

Indonesia, is an archipelago country lies in the equator area, is considered as a susceptible region to climate changes. Rainfall pattern changes, increase of water sea level and temperature, and extreme weather events are some serious impacts of climate changes occurring in Indonesia. According to Policy Synthetic Team of Ministry of Agriculture (2008), climate change will cause the following: (a) Indonesia will undergo temperature increase, the rate of which is lower than the temperature in subtropical areas; (b) South Indonesia area is predicted to undergo rainfall decrease enhancing the drought risks, while in North Indonesia, the rainfall intensity will increase, thus rising the frequency and intensity of floods.

Drought and flood or waterlogging limits the potential range of many species by affecting seedling survival, growth and development potential of plants. They showed significant effects at the initial stages of plant growth (e.g., during the first year of cultivation) (Kozlowski 1997; Dunisch et al. 2003) and endangered plants survival. The effects of water stress have been reported for a large number of angiosperms and gymnosperms, resulting considerable changes in plant physiology, morphology and overall biochemical processes (Cernusak et al. 2007; Chaves et al. 2008; Cordeiro et al. 2009; Ditmarova et al. 2009; Yang and Miao 2010; Li et al. 2011; Xioling et al. 2011). Water stress is a major growth-limiting factor highlighting the need for selecting drought resistant species for successful plantations (Ky-Dembele et al. 2010). To promote the successful current-year tree seedlings settlement, the key to understand is how they are adapted to drought and waterlogging, a critical condition for silviculture activities of several potential tree species.

However, very little is known about species variations in adaptability to drought and waterlogging stresses in tropical forest trees species. Some tropical tree species showed ability to satisfactorily tolerate or postpone drought such as *Swietenia macrophylla* (Cordeiro et al. 2009), *Garcinia kola* and *Garcinia afzelii* (Peprah et al. 2009). In other study, Rao et al. (2008) reported that seedling height and dry biomass of *Albizzia lebbek*, *Dalbergia sissoo, Leucaena leucocephala*, and *Shorea robusta* decreased at very high stress. The drought resistant in different species followed the order of: *L. leucocephala* > *T. grandis* > *D. sissoo* > *S. robusta* and > *A. lebbek*. Adaptability study of *Anthocephalus cadamba* to drought and waterlogging showed that the species were more resistant to waterlogging than to drought stress (Sudrajat et al. 2015).

Therefore, comprehensive knowledge about species responses on drought and waterlogging can become a reference in the development of forest trees species transfer guideline (Wang et al. 1989), selection of adaptive species, and also as a key of adaptation strategy on climate change (Millar et al. 2007). The hypothesis in response to drought and waterlogging stress, there is a large variation among tropical trees species expressed in growth, stress sensitivity and stress tolerance indices.

The objective of this study was to investigate the morphological responses, sensitivity and tolerance indices of *Anthocephalus macrophyllus*, *Anthocephalus cadamba*, *Fagraea fragrans*, and *Magnolia champaca* seedlings to drought and water logging stresses in a controlled greenhouse.

MATERIALS AND METHODS

Materials

The studied species were *A. macrophyllus*, *A. cadamba*, *F. fragrans*, and *M. champaca* (Table 1). The seeds of the species were collected from 10 dominant trees per species. The seeds from individual trees were equally sampled by weight, and bulked by species for the experiment.

Seedling preparation, experimental design and parameter measurement

A. macrophyllus, *A. cadamba*, *F. fragrans*, and *M. champaca* seedlings were tested in a controlled condition in the greenhouse to identify their adaptability on different water stress conditions. For each species, 60 normal seedlings (± 3 cm in height) were randomly taken from sowing boxes and planted in pots (18.5 cm in diameter x 16 cm in height). There were 20 seedling pots planted for each treatment. At the early stage of growing, seedlings were placed in an optimal condition in nursery and after 2 months, they were moved to the greenhouse. During the experiment, the average day and night temperatures in the greenhouse were set at 34° C and 29° C, respectively, and the relative humidity ranged from 60 to 75 %. The treatments of water stress condition were done after 1 month of seedling in the greenhouse.

A completely randomized block design was used with factorial combinations of water stress [well-water supply (control), 3-5 cm-water logging (W_L), watered every 2 days with 25% field capacity (W_{25})] and species (4 species). Five seedlings were randomly assigned accordingly to each of the twelve experimental treatment units and arranged randomly in each of the four blocks (5 seedlings × 4 species × 3 irrigation regimes × 4 blocks). There were a total of 240 seedlings pots or 60 seedlings per species. The soil volumetric water content for control and drought treatments were maintained at 32.8 ± 2.8% and 19.8 ± 1.4% and W_{25}, respectively. 120 days after the initial treatment, the experiment was terminated.

Height (SH) and root collar diameter (RCD) of seedlings were recorded prior to and at the end of the experiment. The growth of seedling height and diameter resulted from reduction of the final measurement with the first measurement. The number of leaves was counted in all plants. Seedling biomass was measured by harvesting roots, stems, and leaves. Roots were elutriated with water to remove soil. Roots, stems, and leaves were dried in a drying oven at 70° C for 48 h and weighed to ±0.0001 g.

Data analysis

The data were analyzed with ANOVA to test the effect on the water stress and populations on the morphological, anatomical and physiological variables. Duncan's multiple range test at a significance level of $p<0.05$ was used to compare the significant differences in the means. The statistical analysis was performed applying SAS 9.1 for windows. To compare the adaptability among species, stress tolerance index (STI) and stress susceptibility index (SSI) were analyzed on the growth parameters (seedling height and root collar diameter). STI was analyzed using formula (Fernandez 1992):

$$STI = (ypi \times ysi) / YP^2$$

while SSI was analyzed using formula (Fischer and Maurer 1978):

$$SSI = 1- (ysi / ypi) / SI, \text{ while } SI = 1- (YS / YP)$$

Where: ysi, ypi, YS, and YP were each species's parameter under stress and non-stress conditions, parameter mean of all species under stress and non-stress conditions, respectively.

RESULTS AND DISCUSSIONS

There were no seedlings died in the control and WL treatments for *F. fragrans*, *A. macrophyllus*, and *A. cadamba*, while in the $W_{25\%}$ treatment, 7 seedlings of *F. fragrans*, 6 seedlings of *A. macrophyllus*, and 8 seedlings of *A. cadamba* were observed to have died at the end of the experiment. The died seedlings on *M. champaca* were more occurred on the all treatments then died seedlings on the other species, i.e. 1seedling in the control, 12 seedlings in the water logging stress, and 14 seedlings in the drought stress (Figure 1).

In our experiment, significant differences among four species (*A. macrophyllus*, *A. cadamba*, *F. fragrans*, and *M. champaca*) were observed in the growth rate (seedling height, root collar diameter and biomass) under drought and waterlogging regimes. The seedling growth on the control (well-water supply) of 4 species was relatively not significant difference (Figure 2) and showed the highest growth. Drought and waterlogging stresses caused significant changes in seedling height and root collar diameter on all species. The lowest growth occurred on drought treatment followed by the growth on the waterlogging treatment. *M. champaca* had lower height and root collar diameter growth both on drought and waterlogging treatments then the other species. On the other hand, *F. fragrans* and *A. macrophyllus* had the highest root collar diameter under the WL treatment (Figure 3). The seedling survival and growth status under drought and waterlogging stress can be regarded as one of the important indices in plant tolerance (Vreugdenhil et al. 2006; Mommer et al. 2006; Li et al. 2011).

Table 1. Geographic origin of the investigated species

Species, family	Location	Latitude	Longitude	Altitude (m asl.)
Fagraea fragrans, Loganiaceae	Ogan Komering Ilir,South Sumatra	04^0 30' S	$104^0$02'E	25
Anthocephalus macrophyllus, Rubiaceae	Bolaang Mongondow, North Sulawesi	00^o39' N	124^o13'E	100
Magnolia champaca, Magnoliaceae	Lahat, South Sumatra	03^o 54' S	103^o 07' E	650
Anthocephalus cadamba, Rubiaceae	Parangloe, Gowa, South Sulawesi	05°14'S	119°35'E	119

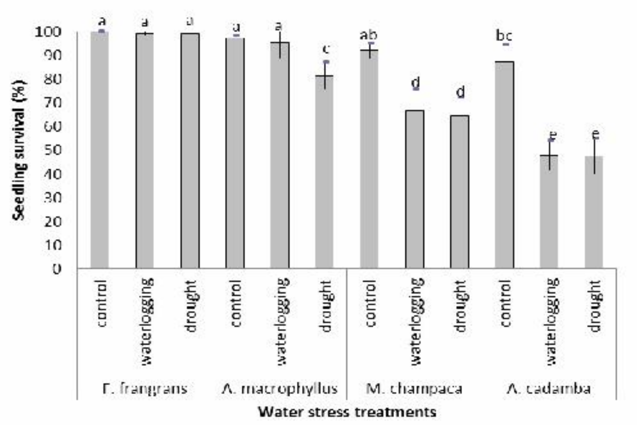

Figure 1. Survival percentage of 4 species under drought and waterlogging stresses at 4 months old

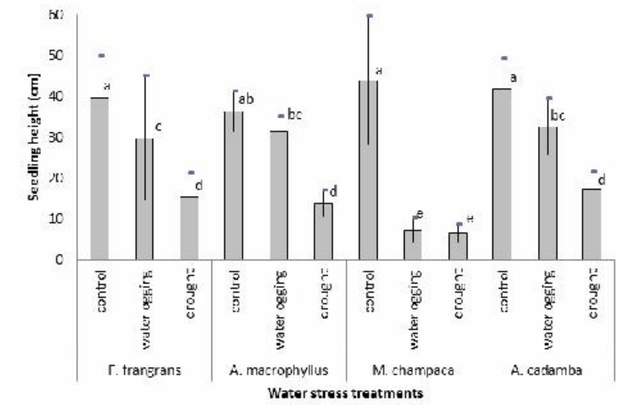

Figure 2. Seedling height of 4 trees species under drought and waterlogging stresses at 4 months old

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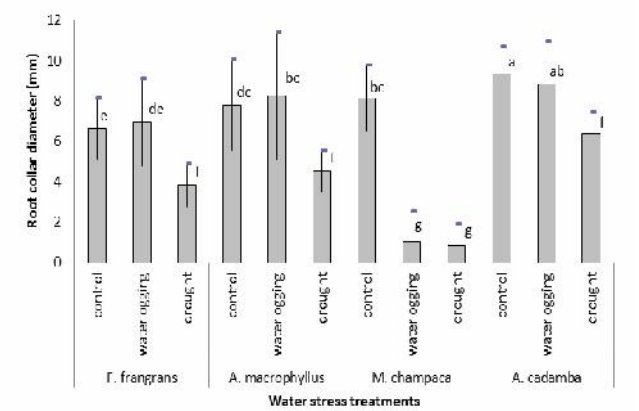

Figure 3. Seedling root collar diameter of 4 trees species under drought and waterlogging stresses at 4 months old

Total biomass, leaf number and leaf area were generally decreased in water stress (Table 2). A reduction biomass by drought stress was higher than waterlogging stress in all species. During water stress, the leaf number and leaf area per plant of white jabon significantly decreased except for leaf area of *F. fragrans* due to the leaf size of the species is very small so the changes on the leaf size is not significantly detected. Leaf number and leaf area were affected adversely in both seedling height and root collar diameter of all species. Reduction in leaf number and leaf area by water stress is an important cause of the reduced growth through reduction in photosynthesis (Rucker et al. 1995). The reduction in leaf area under water stress may be associated with the decline in the cell enlargement (Shao et al. 2008). The cell size reduction in leaf occurred as a result of turgidity being necessary for cell expansion. The cell size reduction is reasonably interpreted as a tolerance mechanism of the leaf to maintain tissue turgidity for the seedlings.

A reduction growth rate by drought stress was higher than by waterlogging stress in all species. The growth parameters reductions of four species were higher in drought stress indicated that the species were more tolerant to waterlogging than drought stress. In waterlogging and drought stresses, *M. champaca* showed the largest growth parameters reductions (Table 3). *F. fragrans* and *A. macrophyllus* had the negative reductions for root collar diameter due to root collar diameter in the waterlogging treatment was higher than in the other treatments. The similar result also occurred in waterlogged seedlings of *Carex lasiocarpa* and *C. limosa* (Lu 2011). According to Kozlowski (1997), waterlogging often affects xylem and phloem production. Waterlogged soils increased stem diameter growth more as a result of increasing bark thickening and stem hypertrophy, which then cause xylem increment. The increase in bark thickness was associated with accelerated proliferation of phloem parenchyma cells and large amounts of intercellular space in the phloem (Yamamoto and Kozlowski 1987).

To compare the adaptability of the stresses among species, stress sensitivity index (SSI) and stress tolerance index (STI) were used to observe the four trees species (Tables 4 and 5). SSI and STI were used to identify the resistant genotype (Yarnia et al. 2011; Anwar et al. 2011). STI can be used to identify genotypes that produces high yield under both stress and non-stress conditions (Fernandez 1992; Anwar et al. 2011). The species with low SSI and high STI can be considered to be more tolerant species among the all tested species (Olaoye et al. 2009). According to Fischer and Maurer (1978) and Badami and Amzeri (2011), the species were categorized as tolerant if SSI < 0.5, medium tolerant if 0.5 < SSI < 1, and sensitive if SSI > 1. While for STI, grouping of tolerant species followed criteria of Doreste et al. (1979) and Susanto and Sundari (2011), i.e. very tolerant species if STI > 0.898, tolerant if 0.74 < STI < 0.898, medium tolerant if 0.41 < STI <0.74, sensitive if 0.25 < STI < 0.41, and very sensitive if STI ≤ 0.25.Based on the SSI and STI on the root collar diameter of the waterlogged seedlings, *F. frangrans*, and *A. cadamba* (SSI ≤0.5, STI > 0.74) could be categorized as tolerant species to waterlogging stress, but for drought stress, no species could be grouped as tolerant species. According to early result, the SSI of *A. cadamba* was lowest on waterlogging stress, but highest on drought stress (Sudrajat 2015). Adaptability of *F. frangrans*

Table 2. Seedling leaf characteristics and biomass of 4 trees species under drought and waterlogging stresses at 4 months old

Treatment (species*watering regime)		**Leaf number**	**Leaf area**	**Biomass total**
Fagraea fragrans	Control	23.5±6.1 a	24.72 ±1.18d	16.62 ± 1.41 a
	Waterlogging	16.3 ± 5.2 b	21.73 ±1.97d	15.06 ± 0.78 a
	Drought	11.5 ± 3.6 c	17.76 ±4.13d	5.06±1.37 b
Anthocephalus macrophyllus	Control	6.4 ± 1.2 e	132.58 ±2.06a	16.95 ± 0.30 a
	Waterlogging	5.5 ± 1.3 ef	97.87 ±1.89b	15.62 ± 0.39 a
	Drought	4.9 ± 1.0 ef	33.19 ±5.22d	4.43 ± 0.86 b
Magnolia champaca	Control	9.4 ± 2.0 d	68.61 ±2.27c	18.42 ± 0.19a
	Waterlogging	5.1 ± 2.1 ef	33.54 ±6.33d	4.84 ± 1.63b
	Drought	4.5 ± 1.5 f	16.27 ±2.74d	3.99 ± 0.44 b
Anthocephalus cadamba	Control	6.4 ± 1.8 e	142.90 ±3.18a	18.17 ± 0.19 a
	Waterlogging	5.5 ± 2.2 ef	103.88 ±4.01b	15.99 ± 0.45 a
	Drought	2.8 ± 1.1 g	42.81 ± 11.35d	3.70 ± 0.70 b
Means		7.89	61.32	11.56
Coefficient of variation (CV)		30.35	7.66	7.51
F test (species*watering regime)		18.85**	72.49**	43.09**

Note: Different letters in the same column indicate significant differences at P ≤ 0.05 between treatment and provenances in each parameter.

Table 3. Percentage decrease of seedling growth parameters under drought and waterlogging compared with control condition

Treatment (species*watering regime)		**Height (%)**	**Root collar diameter (%)**	**Leaf number (%)**	**Leaf area (%)**	**Biomass total (%)**
Fagraea fragrans	Control	0	0	0	0	0
	Waterlogging	25	-5	31	12	9
	Drought	61	42	51	28	70
Anthocephalus macrophyllus	Control	0	0	0	0	0
	Waterlogging	13	-6	14	26	8
	Drought	62	42	23	75	74
Magnolia champaca	Control	0	0	0	0	0
	Waterlogging	83	88	46	51	74
	Drought	85	90	52	76	78
Anthocephalus cadamba	Control	0	0	0	0	0
	Waterlogging	22	5	14	27	12
	Drought	59	31	56	70	80

Table 4. Stress sensitivity index of seedling height and root collar diameter of 4 trees species under drought and waterlogging stresses at 4 months old

Species	**Seedling height**		**Root collar diameter**	
	Waterlogging	**Drought**	**Waterlogging**	**Drought**
Fagraea fragrans	0.59	0.98	0.25	0.92
Anthocephalus macrophyllus	0.67	0.88	0.27	0.73
Magnolia champaca	2.22	1.22	4.09	1.56
Anthocephalus cadamba	0.36	0.89	0.24	0.74

Table 5. Stress tolerance index of seedling height and root collar diameter of 4 trees species under drought and waterlogging stresses at 4 months old

Species	**Seedling height**		**Root collar diameter**	
	Waterlogging	**Drought**	**Waterlogging**	**Drought**
Fagraea fragrans	0.83	0.34	1.30	0.65
Anthocephalus macrophyllus	0.72	0.38	0.73	0.56
Magnolia champaca	0.20	0.18	0.13	0.11
Anthocephalus cadamba	0.70	0.31	1.01	0.40

and *A. cadamba* seedlings to waterlogging is correlated with their natural habitats, generally distributed on the deep, moist, and alluvial sites and vice versa, the general condition of the natural habitat also affected the adaptation of seedlings that is less adapted to drought stress (Soerianegara and Lemmens 1993; Kartawinata 1994). The seedlings of *M. champaca* behaved the opposite way or there was higher SSI on both waterlogging and drought stresses indicating that the species is not adapted both for drought and waterlogged sites, this results is similar with the early results of SSI of *M. champaca* (Yulianti et al. 2015).

In waterlogging stress, SSI values of *A. cadamba* were lowest, followed by *F. fragrans, A. macrophyllus*, and *M. champaca*, while for the STI values, from the highest to the lowest, were *F. fragrans, A. macrophyllus, A. cadamba*, and *M. champaca*. In drought stress, SSI values of seedling height and root collar diameter of *A. macrophyllus* had the lowest, followed by *A. cadamba*, *F. fragrans*, and *M. champaca*. On the other hand, the highest SSI value in drought stress for seedling height was *A. macrophyllus*, and *M. champaca* had the highest STI both for seedling height and root collar diameter. The lower SSI and the higher STI showed better adaptability of the plants to the stresses (Blum et al. 1992). The waterlogging resistant in four species were in the order of: *A. cadamba* > *F. fragrans* > *A. macrophyllus*, and > *M. champaca*, while for the drought resistant species were in the order of: *A. macrophyllus* > *A. cadamba* > *F. fragrans* and > *M. champaca*.

The data from the current experiment indicated that all species tend to be more tolerance to water logging than to drought stress. Waterlogging tolerance is determined by the ability of a plant to grow and survive in soils with water content above field capacity (Rowe and Beardsell 1973). In contrast to water logging, the species in the seedling stage were very sensitive to drought. The more adaptive seedling of four species to waterlogging described the natural habitat of the evergreen tropical tree species generally distributed on the relatively higher humidity and moist sites. The range of response of evergreen species to different drought intensities indicated a lower degree of plasticity than that of deciduous trees (Ditmarova et al. 2010).

In conclusion, seedling height and root collar diameter growth of *A. macrophyllus*, *A. cadamba*, *F. fragrans*, and *M. champaca* were more affected by drought and waterlogging stress conditions. The species were more tolerant to waterlogging than drought stress, which can be observed from morphological, the absence of seedling under the waterlogging treatment that died during the experiment, stress tolerant index, and stress sensitivity index. The waterlogging resistant in four species followed the order of: *A. cadamba* > *F. fragrans* > *A. macrophyllus*, and > *M. champaca*, while for the drought resistant species followed the order of: *A. macrophyllus* > *A. cadamba* > *F. fragrans* and > *M. champaca*. *A. cadamba* and *F. fragrans* can be planted in temporary waterlogging sites, while for dry sites, *A. macrophyllus* is more adaptive. *M. champaca* is preferably not to be planted in waterlogged and dry sites due to its relatively low tolerance to drought and waterlogging stresses.

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REFERENCES

Anwar J, Subhani GM, Hussain M, Ahmad J. Hussain M, Munir M. 2011. Drought tolerance indices and theirs correlation with yield in exotic wheat genotypes. Pakistan J Bot 43 (3): 1527-1530.

Badami K, Amzeri A. 2011. Identification of drought tolerant somaclonal on maize populations resulted from in vitro selection with PEG. Agrovigor 4 (1): 7-13. [Indonesian]

Blum A, Golan G, Mayer J, Sinmena B, Obilana T. 1992. Comparative productivity and drought response of semi-tropical hybrids and open pollinated varieties of sorghum. J Agric Sci Cambridge 118: 29-36.

Cernusak LA, Aranda J, Marshall JD, Winter K. 2006. Large variation in whole-plant water-use efficiency among tropical tree species. New Phytologist 173: 294-305.

Cordeiro YEM, Pinheiro HA, dos Santos-Filho BG, Correa SS, Silva JRR, Dias-Filho MB. 2009. Physiological and morphological responses of young mahogany (*Swietenia macrophylla* King) plants to drought. For Ecol Manag 258: 1449-1455.

Ditmarova L, Kurjak D, Palmroth S, Kmet J, Strelcova K. 2010. Physiological responses of Norway spruce (*Picea abies*) seedlings to drought stress. Tree Physiol 30: 205-213.

Doreste SE, Arias C. Bellotti A. 1979. Field evaluations of cassava cultivars for resistance to tetranychid mites.p. 161-164. *In* T. Brekelbaum, A. Bellotti, J.C. Lozano (*Eds.*) Proceeding of Cassava Protection Workshop. Cali. Colombia 7-12 November 1977.

Dunisch O, Erbreich M, Eilers T. 2003. Water balance and water potentials of a monoculture and an enrichement plantation of *Carapa guianensis* Aubl. in the Central Amazon. For Ecol Manag 172: 355-367.

Fernandez GCJ. 1992. Effective selection criteria for assessing plant stress tolerance. In: Proceedings of the International Symposium on Adaptation of Vegetable and Other Food Crops in Temperature and Water Stress. Taiwan.

Fischer RA, Maurer R. 1978. Drought resistance in spring wheat cultivars: I. Grain yield responses. Austr J Agric Res 29: 897-912.

Kartawinata K. 1994. The use of secondary forest species in rehabilitation of degraded forest lands. J Trop For Sci 7 (1): 76-86.

Konzlowski TT. 1997. Responses of woody plants to flooding and salinity. Tree Physiol Monogr 1: 1-28.

Ky-Dembele C, Bayala J, Savadogo P, Tigabu M, Odén PC, Boussim IJ. 2010. Comparison of growth responses of *Khaya senegalensis* seedlings and stecklings to four irrigation regimes. Silva Fennica 44 (5): 787-798.

Li FL, Bao WK, Wu N. 2011. Morphological, anatomical and physiological responses of *Campylotropis polyantha* (Franch.) Schindl. seedlings to progressive water stress. Scientia Horticulturae 127: 436-443.

Lu W. 2011. Growth and morphological responses to water level variations in two *Carex* species from Sanjiang Plain, China. African J Agric Res 6 (1): 28-34.

Millar CI, Stephenson NL, Stephens SL. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecol Appl 17: 2145-2151.

Mommer M, Lenssen JPM, Huber H, Visser EJW, Kroon HD. 2006. Ecophysiological determinants of plants performance under flooding: a comparative study of seven plant families. J Ecol 94 (6): 1117-1129.

Olaoye G, Menkir A, Ajala SO, Jacob S. 2009. Evaluation of local maize (*Zea mays* L.) varieties from Burkina Faso as source of tolerance to drought. J Appl Biosci 17: 887-898

Peprah T, Kyereh B, Owusu KA, Adu-Bredu S. 2009. Drought tolerance of *Garcinia kola* and *Garcinia afzelii* at the seedlings stage. Ghana J For 25: 13-27.

Policy Synthetic Team. 2008. Impact of climate change on the agriculture, and anticipation strategy and adaptation technology. Development of Agriculture 1 (2): 138-140. [Indonesian]

Rao PB, Kaur A, Tewari A. 2008. Drought resistance in seedlings of five important tree species in Tarai region of Uttarakhand. Trop Ecol 49 (1): 43-52.

Rowe RN, Beardsell DV. 1973. Waterlogging of fruit trees. Hort Abstr 43: 533-548.

Rucker KS, Kevin CK, Holbrook CC, Hook JE. 1995. Identification of peanut genotypes with improved drought avoidance traits. Peanut Sci 22: 14-18.

Shao H-B, Chu L-Y, Jaleel CA, Zhao CX. 2008. Water-deficit stress-induced anatomical changes in higher plants. C R Biol 331: 215-225.

Soerianegara I, Lemmens RHMJ. 1993. Plant resources of South-East Asia 5 (1): Timber trees: major commercial timbers. Pudoc Scientific Publishers, Wageningen, NL.

Sudrajat DJ, Siregar IZ, Khumaida N, Siregar UJ, Mansur I. 2015.Adaptability of white jabon (*Anthocephalus cadamba* Miq.) seedling from 12 populations to drought and waterlogging. Agrivita J Agric Sci 37 (2): 130-143.

Sudrajat DJ. 2015. Population Diversity, Provenance Test, and Adaptability of Jabon (*Neoclamarckia cadamba* (Roxb.) Bosser). [Ph.D. Dissertation]. Bogor Agricultural University. Bogor. [Indonesian]

Susanto GWA, Sundari T. 2011. The Changes of Agronomy Characters of Soybean Germplasm under Shading Condition. Jurnal Agronomi Indonesia 39 (1): 1-6. [Indonesian]

Vreugdenhil SJ, Kramer K, Pelsma T. 2006. Effects of flooding-duration,-frequency and-depth on the presence of saplings of six woody species in north-west Europe. For Ecol Manag 236: 47-55.

Wang JR, Hawkins CDB, Letchford T. 1998. Photosynthesis, water and nitrogen use efficiencies of four paper birch (*Betula papyrifera*) populations grown under different soil moisture and nutrient regimes. For Ecol Manag 112: 233-244.

Xiaoling L, Ning L, Jin Y, Fuzhou Y, Faju Y, Fangqing C. 2011. Morphological and photosynthetic responses of riparian plant *Distylium chinense* seedlings to simulated autumn and winter flooding in three Gorges Reservoir Region of the Yangtze River, China. Acta Ecologica Sinica 31: 31-39.

Yamamoto F, Kozlowski TT. 1987. Effect of ethrel on growth and stem anatomy of *Pinus halepensis* seedlings. IAWA Bull New Ser 8: 11-19.

Yang F, Miao LF. 2010. Adaptive responses to progressive drought stress in two poplar species originating from different altitudes. Silva Fennica 44 (1): 23-37.

Yarnia M, Arabifard N, Khoei FR, Zandi P. 2011. Evaluation of drought tolerance indices among some winter rapeseed cultivars. African J Biotechnol 10 (53): 10914-10922.

Yulianti B, Rustam E, Megawati, Mindawati N. 2015. Growth respon of Bambang Lanang seedling (*Michelia champaca* L.) to stress condition. Jurnal Penelitian Hutan Tanaman 12 (3): 211-221.