How drought tolerant are tropical woody crop species – turgor loss points for the five most common species in the emerging landscapes on the Malaysian Peninsular

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Abstract. Drought events are increasing with climate change and threaten the future of industrial plantations in Southeast Asia. Drought tolerance has been well investigated for oil palm plantations. A comparative study on the tolerance of different woody crop species is still missing. We assessed the leaf turgor loss point of five common woody crop species using osmometry. The aim was to assess possible future risks in terms of the species’ drought tolerance. The research was carried out in Simpang Pertang, Malaysia. We collected botanical material from five species, namely Acacia mangium, Hevea brasiliensis, Tectona grandis, Mangifera indica, and Elaeis guineensis. To assess the adaptation of the local tree species pool, we measured the turgor loss point of the 65 most abundant tree species in the Pasoh forest reserve for comparison. Measured species showed a wide range of drought tolerance, ranging from -2.56 MPa to -1.15 MPa and -2.46 MPa to -0.88 MPa for crop species and forest species, respectively. Under the current precipitation regime, there is less concern about the cultivation success of these species in the study area. With the predicted changes in rainfall intensity and frequency, a reduction in the productivity of woody crop plantations can be expected.

Keywords: Climate change; drought stress; crop security; plant hydraulics.

1. Introduction
Industrial plantations with woody crop species have a long history on the Peninsula of Malaysia. For example, rubber trees were introduced as early as 1877 and in the following decades, rubber was one of the main exports of Malaysia [1]. Malaysia grew to be the largest producer of rubber and it produced half of the world’s rubber by the 1930s [1]. The expansion of palm oil production started with decreasing rubber prices in the early 20th century [2]. Rubber prices dropped rapidly in the 1960s consequently the Malaysian Government implemented an agricultural diversification program. This initiated the cultivation of palm oil intending to liberate the country's economy from its dependence on rubber production [3]. This lead to a substitution of rubber plantations with palm oil and an increase in clearing natural forests for the establishment of new plantations [1]. Only thirty years after this oil palm had gained its importance as the largest industrial crop in Malaysia [3], oil palm plantations cover more than a fourth of the area of Malaysian Peninsular [4]. Today, such large-scale conversion of rainforest to industrial oil palm and rubber plantations dominates the landscape of many lowland regions in South East Asia.

A global assessment of the Food and Agricultural Organization of the United Nations states that palm oil is the fastest expanding crop worldwide [5]. The conversion of rainforests into other land uses has been found to influence the local and regional biogeochemistry and ecohydrology [6]. The most worrying effect of rainforest conversion is the reduction of local and regional rainfall rates [7],
aggravating the negative effects of altering precipitation regimes due to climate change. The extent of alteration of rainfall recycling caused by rainforest conversion strongly depends on the crop species planted or the plantation area in the new land-use form [8,9]. However, most plantations are established as industrial large-scale monocultures containing only one species, which indeed might cause serious changes in the hydrological cycle potential water limitation [10].

Further, species-poor plantations are susceptible to extreme events e.g. cascading die-back events due to water stress followed by pathogen outbreaks [11]. Accordingly, tropical mono-specific plantations are threatened potentially by climatic extreme events. Minimum requirements of water availability and its effects on palm oil productivity have been investigated in detail, however, a comparative study on the tolerance of different woody crop species is still missing. Studies from natural ecosystems [12-14] and for temperate woody species [15-17] show that the species-specific leaf turgor loss point (π_{tlp}, -MPa) is a precise proxy for drought tolerance and describes a species’ anisohydry [18]. π_{tlp} can thus be applied as an index for drought tolerance of plant species and their ability to grow in a future drier climate [19], in particular, if the species-specific π_{tlp} is compared with the π_{tlp}- range of a representative local species pool.

In this study, we assessed the π_{tlp} of the five most important woody plantation species found in tropical lowlands in Southeast Asia, namely oil palm, rubber tree, teak, black wattle, and mango. Those π_{tlp} values were set into relation with the range of the 65 most abundant woody species in the natural forest in the area. With this work, we aim to provide a first physiological climate risk assessment of those woody crop species.

2. Methods

The study was carried out between October and December 2018. We collected the botanical material in the surrounding area of the Pasoh forest reserve, close to the village Simpang Pertang in Malaysia (2°58’08.0’’N, 102°17’49.0’’E). The natural vegetation in this area is an aseasonal tropical moist lowland forest with an annual rainfall rate of about 2,000 mm and a mean annual temperature of about 26°C [20]. However, most of the lowland area has been converted to either palm oil (Elaeis guineensis Jacq., Arecaceae) or rubber (Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg., Euphorbiaceae) plantations. Smaller plantations with teak (Tectona grandis L.f., Lamiaceae), black wattle or mangium (Acacia mangium Willd., Leguminosae) and mango (Mangifera indica L., Anacardiaceae) trees can also be found. The latter species play a relatively minor economical role. Additional to the five crop species, we measured the turgor loss points (π_{tlp}) of the 65 most abundant tree species (accounting for stem number and biomass) in the Smithsonian ForestGeo 50 ha monitoring plot at the Pasoh forest reserve (species list in Table 1).

### Table 1. List of the 65 species sampled in the natural forest at Pasoh.

| Species Name | Species Name | Species Name |
|--------------|--------------|--------------|
| Aanaxgorea javanica | Dyera costulata | Pimelodendron griffithianum |
| Aidia densiflora | Epiprinus malayanus | Pometia pinnata |
| Alangium ebenecum | Garcinia nervosa | Porterandia anisophylla |
| Aporosa aurea | Gironniera parvifolia | Pternandra echinata |
| Aporosa bracteosa | Gluta malayana | Ptychopitys costata |
| Aporosa microstachya | Hopea mengarawan | Rinorea anguifera |
| Archidendron bubalimum | Ixanthes icosandra | Rothmannia macrophylla |
| Archidendron clypearia | Kayea cordata | Sapium bacata |
| Ardisia crasse | Knema furfuracea | Saraca declinata |
| Baccaurea parviflora | Knema laurina | Scaphocalyx spathacea |
| Barringtonia macrostachya | Knema patentinervia | Schoutenia accrescens |
| Bouea macrophylla | Lepisanthes senegalensis | Shorea acuminata |
| Callerya atropurpurea | Lithocarpus curtisi | Shorea leprosula |
| Champerea manillana | Litsea wrayi | Shorea macroptera |
| Cleistanthus malaccensis | Macaranga gigantea | Shorea maxwelliani |
| Croton argyratus | Macaranga hypoleuca | Shorea multiflora |
| Cynometra malaccensis | Macaranga lowii | Syzygium leptostemon |
To estimate $\pi_{tlp}$ we used the osmometric method [21]. In brief, we measured the osmotic potential of leaf samples at full hydration with a VAPRO 5520 vapor pressure osmometer (Wescor, Logan, UT). We collected one sun-exposed branch of three tree individuals per species (5 crop species and 65 forest species). The branches were placed in humid and opaque plastic bags directly after sampling. We brought the branches to the laboratory within 120 minutes after sampling and recut the branches underwater at least two nodes distal to the original cut. The recut branches were placed in buckets with water and covered with plastic bags to rehydrate overnight. On the next day, we chose two fully expanded leaves per branch. Two sample discs were cut from each leaf centrally between the midrib and margin with a 4-mm-diameter cork borer. We wrapped the discs in aluminum foil and deep-froze the sampled in liquid nitrogen (LN2) for at least 2 minutes. After deep-freezing the samples, we punctured the samples with a dissection needle about 10 to 15 times and placed the sample in the standard 10 μL chamber well of the osmometer. The osmometer was set in the auto-repeat mode. A final measurement was recorded when equilibrium was reached. We defined this equilibrium when there was less than a 0.01 MPa deviation between readings (approximately 5 osmometer readings in mmol kg$^{-1}$). The final solute concentration values $c_0$ (mmol kg$^{-1}$) were converted to the turgor loss point ($\pi_{tlp}$, MPa) with the standard calibration equation by [21]

$$\pi_{tlp} = 0.832 \pi_{osm}^{-0.631}$$

(1)

$\pi_{osm}$ is calculated as

$$\pi_{osm} = \frac{R T}{1000} c_0$$

(2)

where $R$ is the ideal gas constant, and $T$, the temperature in degrees Kelvin (here 25°C). Previous studies revealed that species with a more negative $\pi_{tlp}$ occurred more frequently in areas with a drained soil texture gradient and/or less rainfall [13] and are associated with drier biomes [14]. Thus, the more negative the estimate of $\pi_{tlp}$ the higher the drought tolerance of a species.

3. Results

Mean values of $\pi_{tlp}$ ranged from -2.56 MPa to -1.15 MPa and -2.46 MPa to -0.88 MPa for crop trees and 70 measured natural forest species of the Pasoh Reserve, respectively (Figure 1). We found the most negative $\pi_{tlp}$ in rubber trees. With -2.56 ± 0.19 MPa, rubber was more negative than the most negative species in the entire species pool that we collected in the natural forest. Mean $\pi_{tlp}$ of all 70 species averaged -1.57 ± 0.31 MPa. The median of the species pool lies at -1.50 MPa. *Xerospermum noronhianum* (Blume) was one outlier within the 70 species with a very negative $\pi_{tlp}$ of -2.46 ± 0.14 Pa. We recorded an intermediate $\pi_{tlp}$ of -1.97 ± 0.17 MPa for mango and a slightly over average negative $\pi_{tlp}$ -1.61 ± 0.04 MPa for oil palm relatively to the natural forest. On contrary, black wattle and teak were below the average and had a $\pi_{tlp}$ of -1.49 ± 0.28 MPa and -1.15 ± 0.14 MPa, respectively.
Figure 1. Turgor loss points of different woody crop species and boxplot of turgor loss points measured on 65 tree species in a representative tropical lowland forest in Malaysia.

4. Discussion

Our study demonstrates that there is a large variation in $\pi_{tlp}$ across the sampled tree species within the natural forest as well as for the measured woody crop species. This indicates that the investigated species potentially respond very differently to drought stress, from a drought-sensitive to a drought-tolerant response. The oil palm had a higher drought tolerance than the average tree in the natural forest in the Pasoh Reserve. Thus, based on our results and under the assumption that the $\pi_{tlp}$ is a reliable plant functional trait to determine drought resistance of a species, it appears that under the current precipitation regime there is less concern on the cultivation success of the oil palm in most lowland areas in Malaysia. The most negative $\pi_{tlp}$ was found in rubber surpassing even the most drought tolerant native species in the natural forest ($Xerosperum noronhianum$; $\pi_{tlp}$ of -2.46 ± 0.14 MPa). In its natural range in the Amazon Basin in South America, rubber has a naturally higher exposure to rainfall seasonality, especially in the most southern parts of its natural distribution [22]. The species with the lowest drought tolerance was teak, however, teak can shed leaves during dry conditions significantly reducing its transpiration rate [23]. Dry-season deciduousness is another adaptation strategy to deal with seasonal water shortages. Accordingly, the risk of teak plantations under future climatic conditions might be low despite the less negative $\pi_{tlp}$. Mango and black wattle can be classified as low-risk species as their $\pi_{tlp}$ was below the average $\pi_{tlp}$ of the local species pool.

However, with increasing climate variability and changes in rainfall intensity and frequency, a significant reduction in performance and productivity can be expected. For example, a significant shift in species compositions might currently be ongoing in the natural forest. The most drought-tolerant species $Xerosperum noronhianum$ has become, by far, the most abundant tree species in the natural forest outnumbering all other species multiple times (unpublished results from the 50 ha monitoring plot). This indicates an ongoing change and measures to adapt woody crop plantation are urgently needed. Besides the precipitation shifts induced by climate change, a social study in the area has reported that local populations face increasing water shortages since clearage of natural forest for the cultivation of new oil palm plantations, especially in the dry seasons [24]. In addition, it is assumed that expanding oil palm plantations leads to more frequent floods and that intensive monoculture plantation systems severely degrade the soil resulting in impeding the recharge of groundwater reservoirs and increasing surface runoff [25]. In short, oil palm cultivation impacts the local hydrological cycle more severely than other crops [24] and palms might be especially drought sensitive in the future due to their hydraulic properties of palms [26]. Based on our measurements, susceptible to climate change in the Peninsula of Malaysia, resulting in eventually die-back events due to water stress.
5. Conclusion
Most of the cultivated woody crops on the Peninsula of Malaysia have an on average similar or better drought tolerance compared to the local species pool in the natural forest. However, given climate change, there is evidence that in three of the five most cultivated species a significant reduction in performance and productivity of these cultivated large-scale plantations can be expected due to increasing drought stress in a changing future climate.

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