USING ACACIA AS A NURSE CROP FOR
RE-ESTABLISHING NATIVE-TREE SPECIES PLANTATION
ON DEGRADED LANDS IN VIETNAM

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Submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

SCHOOL OF LAND AND FOOD
UNIVERSITY OF TASMANIA

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ABSTRACT

*Acacia mangium*, *A. auriculiformis* and their hybrid, the leguminous fast-growing tree species has been widely adopted as a nurse crop for re-establishing native-tree plantations on degraded lands in Vietnam, but with little success. This may be attributed to not fully understanding the site requirements of target native species and the potential for negative as well as positive between-species interactions. The most planted native species is *Hopea odorata* Roxb., a dipterocarp that is thought to be shade-tolerant. To resolve how best to apply and manage such a system of mixed-species silviculture, this study first investigated the resource requirements of *H. odorata* in its natural habitat and how degraded soils change under consecutive short-rotations of *A*. hybrid plantations. Plantings of *H. odorata* within circular and strip gaps in 3- and 2.5-yr-old *A*. hybrid plantations, respectively, were used to assess the growth and physiological responses of *H. odorata* to competition for light and water. The light gradients created in the circular-gap experiment and the different light condition in the strip-gap experiment were used to assess how changes in growth rate were associated with the efficiency of use of light by the *H. odorata*.

Site requirements for regeneration of *H. odorata* were investigated in its natural habitat in three representative 50 × 50 m inventory plots in a secondary evergreen natural forest in southern Vietnam. The upper canopy was dominated by four dipterocarp species; *H. odorata*, *Shorea roxburghii* G. Don., *Anisoptera costata* Korth., and *Dipterocarpus alatus* Roxb. ex G. Don. The prevailing stand structure supported the vigorous germination, but not development of *H. odorata* seedlings due to low levels of light near the forest floor. Seedling germination was supported when daily transmitted photosynthetically active radiation (PAR) was between 2.2% and 6.6%, but seedling
development was only observed when PAR was 11.4%. The slightly acidic sandy soils with low nutrient concentration were apparently not a constraint on growth of *H. odorata* seedlings given adequate light conditions. The results suggest that the re-establishment of *H. odorata* on degraded sites using nurse crops should be possible provided that high levels of shading are avoided.

The potential to improve soil conditions with *Acacia* hybrid was assessed on degraded gravelly and sandy soils in Central Vietnam, from second- or third-rotation plantations representative of five age classes (0.5- to 5-yr old) and adjacent abandoned lands as controls. Compared to abandoned land, stock of total soil carbon, total nitrogen, and exchangeable calcium, magnesium and sodium were significantly higher in some years of the 5-yr rotation. However, extractable phosphorus and exchangeable potassium were not affected. Electrical conductivity was significantly higher and bulk density was significantly lower in all ages. Soil $\text{pH}_{\text{CaCl}_2}$ was lower at ages 0.5 and 5 yrs, and $\text{pH}_{\text{H}_2\text{O}}$ at age 5 yrs. Within a rotation, most soil properties did not change significantly with plantation age, although they appeared to decrease during the first three years; total carbon then recovered to initial levels, but total nitrogen and exchangeable cations remained lower. Some soil properties were strongly related to gravel content and elevation, but not with growth rate. Thus consecutive plantings of short-rotation *Acacia* hybrid on degraded and abandoned land can lead to changes in some soil properties.

Growth and physiological responses of *H. odorata* to different environmental conditions created in a nurse-crop plantation were examined in a field experiment where *H. odorata* seedlings were planted within three 22 m-diameter gaps opened in a 3-yr-old *Acacia* hybrid plantation in Central Vietnam. At age 2 yrs, stem diameter, total height
and crown diameter of the *H. odorata* increased significantly from gap perimeter (GP) to gap centre (GC). This positive response correlated with significant increases in daily incident photosynthetically active radiation (PAR) from 24% to 61% of total incident PAR. Net photosynthetic rate at 1500 \( \mu \text{mol m}^{-2} \text{s}^{-1} \) \( (A_{1500}) \) and stomatal conductance \( (g_s) \) were significantly lower for trees near the GP than those near the GC. Light-saturated photosynthesis \( (A_{\text{sat}}) \) was significantly lower for trees near the GP than GC at age 1 yr, but not at age 2 yrs. Apparent quantum yield \( (\Phi) \), dark respiration \( (R_{\text{dark}}) \), and photosynthetic biochemical parameters \( (V_{\text{cmax}} \text{ and } J_{\text{max}}) \) were similar between treatments. Chlorophyll content, chlorophyll fluorescence \( (F_v/F_m) \), and leaf N and P concentrations were also unaffected by treatment. Nevertheless, specific leaf area was higher in the GP than other treatments. Despite the substantial difference in PAR between treatments, trees near the GP received levels of irradiation \( >500 \mu \text{mol m}^{-2} \text{s}^{-1} \) for 12% of the day \( v \) 38% at the GC. Significant reductions of leaf water potential \( (\Psi_{\text{leaf}}) \) at the end of the dry season in treatments close to the GP compared to those near the GC suggested competition for water between *H. odorata* and the acacia nurse trees, although pre-dawn \( \Psi_{\text{leaf}} \) remained \( >-0.5 \text{ MPa} \). Thus, despite being a species that regenerates naturally in shade, *H. odorata* quickly acclimates to much higher light environments.

Understanding how *H. odorata* alters its architectural traits and growth rate in response to changing light environments is essential when designing and manipulating mixed-species plantations containing this species. Seedlings of *H. odorata* were planted into the circular gaps referred to above, and in 5 and 7.5 m strip gaps within a 2.5-yr-old *A. hybrid* plantation. Crown structure, absorption of photosynthetically active radiation (APAR) and whole-plant light-use efficiency (LUE; above-ground biomass growth or wood growth per unit APAR) of the seedlings over a gradient of light across the circular gap were examined for two years. Biomass production increased exponentially from the
GP to the GC. This was largely due to an exponential increase in APAR and a minor increase in LUE. The large increase in APAR was associated with an increase in leaf area and a reduction in shading from the nurse trees. Conversely, APAR per unit leaf area decreased towards the gap centre, probably due to steeper branch and leaf angles in order to avoid high radiation. In the strip-gap planting, the PAR was similar to that at the perimeter of the circular gaps; however the light pattern was dominated by sun flecks in the strip gap and direct sunlight in the circular gap. While the LUE of the more shaded *H. odorata* trees in the strip gaps was much higher, this was not enough to make up for the much lower APAR and hence biomass production. This study shows that *H. odorata* is able to grow under a wide range of PAR and that the availability of PAR has a strong influence on its growth. While the strip gaps used in this study appeared to be too narrow, the circular gap indicated that nurse plantings are an effective silvicultural design for establishing *H. odorata* provided that competition for other resources is managed.

The study concluded that *Acacia* hybrid is a potential species for recovery of some key soil chemical and physical properties. It is a potential nurse crop for re-establishment of native-tree species on degraded lands. Although *H. odorata* is shade-adapted species, it has great plasticity to acclimate to a range of light environments. However for mixed-species systems using these species, interspecific competition for light and soil water between A. hybrid and *H. odorata* needs to be addressed during the design and then management of the plantations.
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<table>
<thead>
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<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACIAR</td>
<td>Australian Centre for International Agricultural Research</td>
</tr>
<tr>
<td>AGB</td>
<td>above ground biomass</td>
</tr>
<tr>
<td>$A_{\text{max}}$</td>
<td>maximum photosynthetic rate</td>
</tr>
<tr>
<td>APAR</td>
<td>absorption of photosynthetically active radiation</td>
</tr>
<tr>
<td>$A_{\text{sat}}$</td>
<td>light-saturated photosynthesis</td>
</tr>
<tr>
<td>$BA_b$</td>
<td>branch basal area</td>
</tr>
<tr>
<td>BD</td>
<td>bulk density</td>
</tr>
<tr>
<td>C:N</td>
<td>carbon:nitrogen ratio</td>
</tr>
<tr>
<td>$C_a$</td>
<td>ambient CO$_2$ partial pressure</td>
</tr>
<tr>
<td>chl</td>
<td>chlorophyll</td>
</tr>
<tr>
<td>$C_i$</td>
<td>intercellular CO$_2$ partial pressure</td>
</tr>
<tr>
<td>$D_{0.3}$</td>
<td>diameter at 0.3 m above ground</td>
</tr>
<tr>
<td>DBH; $D_{1.3}$</td>
<td>diameter at breast height</td>
</tr>
<tr>
<td>$D_c$</td>
<td>crown diameter</td>
</tr>
<tr>
<td>EC</td>
<td>electrical conductivity</td>
</tr>
<tr>
<td>Ex-Ca</td>
<td>exchangeable calcium</td>
</tr>
<tr>
<td>Ex-K</td>
<td>exchangeable potassium</td>
</tr>
<tr>
<td>Ex-Mg</td>
<td>exchangeable magnesium</td>
</tr>
<tr>
<td>Ex-Na</td>
<td>exchangeable sodium</td>
</tr>
<tr>
<td>Ext-P</td>
<td>extractable phosphorus</td>
</tr>
<tr>
<td>FIPPI</td>
<td>Forest Inventory and Planning Institute</td>
</tr>
<tr>
<td>$F_v/F_m$</td>
<td>maximum quantum yield of photosystem II</td>
</tr>
<tr>
<td>GC</td>
<td>gap centre</td>
</tr>
<tr>
<td>GP</td>
<td>gap perimeter</td>
</tr>
<tr>
<td>$g_s$</td>
<td>stomatal conductance</td>
</tr>
<tr>
<td>$H_t$</td>
<td>top height</td>
</tr>
<tr>
<td>IUCN</td>
<td>International Union for Conservation of Nature</td>
</tr>
<tr>
<td>IVI</td>
<td>important value index</td>
</tr>
<tr>
<td>$J_{\text{max}}$</td>
<td>the potential rate of electron transport</td>
</tr>
<tr>
<td>LA</td>
<td>leaf area</td>
</tr>
<tr>
<td>LAD</td>
<td>leaf area density</td>
</tr>
<tr>
<td>LAI</td>
<td>leaf area index</td>
</tr>
<tr>
<td>$L_b$</td>
<td>branch length</td>
</tr>
</tbody>
</table>
\( L_{bg} \) length of branch with green leaves
\( L_c \) crown length
\( \text{LUE} \) light-use efficiency
\( \text{LZ} \) lower crown zone
\( \text{MAI} \) mean annual increment
\( \text{MARD} \) Ministry of Agriculture and Rural Development of Vietnam
\( \text{MZ} \) middle crown zone
\( N_{\text{leaf}} \) leaf nitrogen concentration
\( P \) phosphorous
\( \text{PAR} \) photosynthetically active radiation
\( P_{\text{leaf}} \) leaf phosphorous concentration
\( R_{\text{dark}} \) dark respiration
\( \text{SD} \) standard deviation
\( \text{SLA} \) specific leaf area
\( \text{SOM} \) soil organic matter
\( \text{TC} \) total organic carbon
\( \text{TN} \) total nitrogen
\( \text{UZ} \) upper crown zone
\( V_{cmax} \) maximum rate of RuBP carboxylation
\( \text{VPD}_L \) vapour pressure deficit based on leaf temperature
\( W_b \) branch weight
\( W_l \) leaf weight
\( W_s \) stem weight
\( W_{\text{UUE}} \) intrinsic water-use efficiency
\( \theta_b \) branch angle from stem
\( \theta_l \) leaf angle from horizontal line
\( \Phi \) apparent quantum yield
\( \Psi_{\text{leaf}} \) leaf water potential
\( \#_b \) number of live branches