

SANDALWOOD AS A COMPONENT OF AGROFORESTRY: EXPLORATION OF PARASITISM AND COMPETITION WITH THE WaNuLCAS MODEL

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ABSTRACT

Sandalwood is an important component of agroforestry systems in the drier Eastern parts of Indonesia, although its value to farmers is still limited by existing policies and regulation of marketing. As a relatively slow growing root parasite, sandalwood will interact with other components in a complex pattern of competition and host-parasite relationships, depending on root distribution and rooting depth of potential hosts. We describe a number of modifications to the generic tree-soil-crop simulation model WaNuLCAS, that allow exploration of the transition between parasitism and competition. The key variable in this transition is the effectiveness of formation of the parasitic link for all situations where roots of the host and parasite occur in the same volume of soil. At low values of this effectiveness competition dominates, at higher values sandalwood will weaken the host, until it effectively kills it, leading to an optimum response of sandalwood to the effectiveness parameter. Unresolved questions in the formulation of the model are the lifespan of parasitized roots and the question whether or not sandalwood will allocate energy resources for maintenance respiration of host roots after the formation of haustoria. The 'desk study' reported here was intended to focus subsequent field studies on these unresolved issues.

Keywords: Sandalwood (*Santalum album* L.), agroforestry component, host parasite, parasitism, competition, WaNuLCAS model.

INTRODUCTION

Conditions for agroforestry development

Sandalwood has to rapidly make the transition from an over-regulated 'forest product' (Rohadi et al., 2000) to a commodity grown in plantation forestry or agroforestry context if future supply is to keep up with the demand that is expected to persist. Other forest products, either timber or non-timber, have gone through such a transition before and a number of steps and thresholds have been recognized. Wiersum (1997) identified three thresholds: 'controlled utilization' (separating the open-access from the controlled harvesting regime), 'purposeful regeneration' (separating the dependence on natural regeneration from the interventions that generally require control over subsequent utilization) and 'domestication' (into horticultural or plantation style production system). Sandalwood utilization is 'controlled' but the incentive structure may not be conducive yet to achieve 'purposeful regeneration'

As evident in other contributions to this seminar, the transition involves aspects of local

institutions controlling access to the remaining forest resources, market access, rules and regulations, cultural traditions as well as technical aspects. Technical aspects include the identification and supply of quality germplasm, nurture in the tree establishment phase and interactions with other components of an agroforestry system, assuming the latter provides the most interesting option for smallholders who want to get involved in growing the tree.

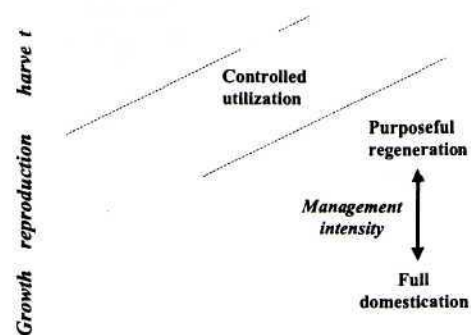


Figure 1. Stages in 'domestication' of forest resources (modified from Wiersum, 1997)

In this contribution we will explore how a generic simulation model of tree-soil-crop interactions can be adapted to the specific properties of sandalwood, and explore a range of possible agroforestry systems. Our contribution is a preliminary attempt, not based on any specific knowledge of the tree or the system but aimed at identifying open questions that warrant further research.

Parasite-host relationships in agroforestry

Sandalwood (*Santalum album*), along with other members of the Santalaceae is a (non-obligatory?) root parasite, that uses the root system of companion plants to complement its limited own root system and acquire water and nutrients. It is native to open monsoon forest and is a slow grower, despite being evergreen. It can apparently parasitize a wide range of host plants, but little is understood of the reasons why some hosts turn out to be better than others. Effective host plants include: *Capsicum spec*, *Acacia villosa*, *Desmanthus virgatus*, *Crotalaria juncea*, *Alternanthera spec*. (Fox et al., 1995a,b). Sandalwood is not shade tolerant, and a vigorously growing host can easily outshade the parasite. Agroforestry systems of potential interest include food crops in early stages and leguminous host trees that yield potentially viable products (fodder) while pruned and regulated in vigour to allow the sandalwood to gradually reach harvestable size. Some income stream in the early years is probably essential to maintain farmers interest in tending the plot, while waiting for the payback through sandalwood in 30-50 year.

Simple schemes for analyzing the balance of impact of positive and negative interactions between tree, soil and crop components have contributed to our understanding of agroforestry systems (Ong and Huxley 1997, Sanchez 1996, Van Noordwijk et al, 1997; Cannell et al, 1998). For simultaneous tree-crop systems, such as hedgerow intercropping where most of the direct

value for the farmer is to be derived from the annual food crops, the focus is on the tree effects on crop yields. The simplest scheme then is $I = F + C$, stating that the overall impact I on the crop is the balance of a positive effect F on soil fertility (largely via the organic matter feedback) and a negative competitive interaction, C . For a positive effect on the crop a simple requirement is that $|F| > |C|$ (there is some confusion in whether C is counted as a negative number, as in $I = F + C$, or as positive value in an equation written as $I = F - C$). Can we develop a similar approach for root hemiparasites such as sandalwood?

For a facultive (non-obligatory) parasite-host relationship between two plants, we may have to consider three interaction terms: parasitic resource capture (P), competition (C) and soil fertility effects (F). For the yield of the parasite in a mixed system we can expect:

$$Y_{\text{parasite_in_mixture}} = Y_{\text{parasite_in_monoculture}} (I + C + P + F)$$

The parasitic relation should thus be considered from three terms:

- the degree to which parasitism weakens the host and thus reduces the negative impacts of competition C for water, nutrients and/or light; this effect will be approximately proportional to the growth and vigour of the host,
- the benefits of root parasitism in the capture of water and nutrients it allows to take place at low energy cost for the parasite; these potential benefits will increase with the vigour of the root system of the host,
- the effects of the host on soil fertility, that may be inversely proportional to the vigour and growth of the host, and may need time to develop.

By combining these three effects we expect a non-linear relationship between the vigour (growth rate) of the host and its impacts on the parasite (Fig. 2), if the relative effectiveness of the parasitic relationship is constant, and a similar relation (Fig.

3) if we compare relations hosts of the same vigour but different susceptibility to exploitation by the parasite root system.

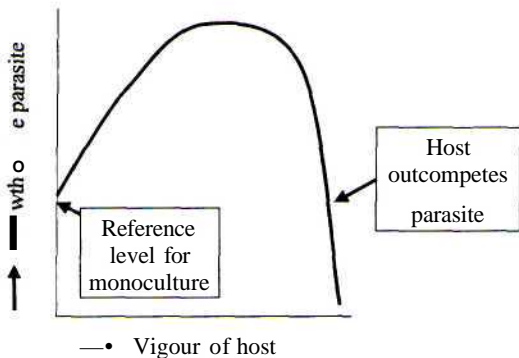


Figure 2. Schematic representation of relation between vigour of host and growth of the parasite

to specific substances (hormones, growth regulators) derived from the host. This may be the immediate (proximate) effects of a mechanism that is ultimately driven by the resource access it provides.

To apply this conceptual scheme to the question of finding suitable hosts for sandalwood in an agroforestry context, we will try to separate the competitive effects of hosts of different vigour from the benefits of parasitism. *A priori* we expect that the best choice of host should (strongly) depend on the growth conditions of the site, and that general statements on species X or species Y is a suitable host are restricted to the site conditions (resource supply) for which they were derived. We may also expect that the curves in figure 2 and 3 shift over time and that what may be an 'optimum' host in early growth is too vigorous for later growth stages.

Explorations with the WaNuLCAS model

The WaNuLCAS model (van Noordwijk and Lusiana 1999, 2000) was designed to describe water, nutrient and light capture in agroforestry systems, with a high degree of flexibility for defining the temporal and spatial aspects of the way different trees, crops and weeds interact and are managed.

The steps required for the development of WaNuLCAS applications for sandalwood agroforestry are:

- adapt input files to the climate and soil conditions typical of the sandalwood domain in eastern Indonesia (NTT province),
- estimate main tree growth parameters for sandalwood,
- modify the model to account for root parasitism,
- sensitivity analysis for root parasitism parameters,
- explore agroforestry systems with different spacings and companion crops. At the moment we have not done this. This would be for future research

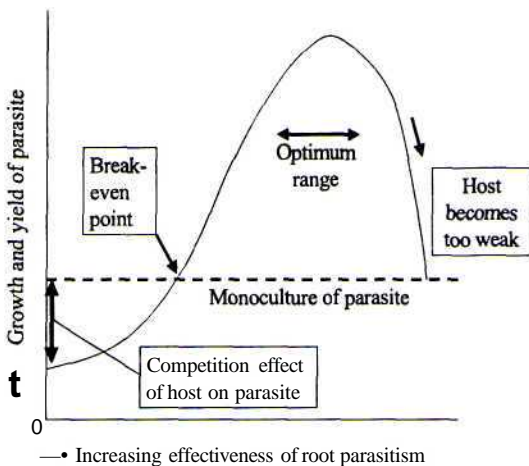


Figure 3. Expected response of sandalwood if the effectiveness of root parasitism is increased (by comparison of different hosts that only differ in the degree to which they allow a parasitic relation to be established)

In this scheme the benefits for the parasite are all attributed to resource capture relations: extra water and/or nutrients taken up and less light intercepted by the host. In the literature on parasitism (as in allelopathy) mention is made of other benefits for the parasite, based on its response

Climate and soil conditions typical of the sandalwood domain in NTT

Most of Eastern Indonesia has a unimodal rainfall with a distinct rainy season (2-4 months with rainfall exceeding potential evapotranspiration) and 4 - 8 dry months (Monk et al., 1997). Climates classified as D3, D4, E3 or E4 in the Oldeman classification scheme (E with <3 wet months, D with 3-4 wet months, *3 with 4-6 and *4 with >6 dry months) dominate Lombok, Sumbawa, Flores, Sumba and W. Timor.

In WaNuLCAS we use an option to generate random rainfall patterns based on a set monthly average, using weather records for P. Sumba with an annual total of 1200 mm.

Soils in NTT show a wide range of depths, texture and fertility. We choose a medium textured soil (50% sand, 25% silt, 25% clay) and a depth of 0.6 m. As the available data show a very wide range in P status, we opted for simulation with a low P supply.

main tree growth parameters for sandalwood

For sandalwood we model it as a tree with similar characteristics to *Peltophorum dasymchis*, a slow growing tree with rather weak but deep root system, a fairly open but narrower canopy compared to *Gliricidia*.

Based on available tree parameters, we explored how a tree such as *Gliricidia sepium* would behave as a host: a reasonably fast grower with good N₂ fixation properties and a fairly open canopy, that expands rapidly, with a rather shallow root system. These parameter choices will need further attention in future work.

Modify the model to account for root parasitism

In the WaNuLCAS model version 2.0 water and nutrient uptake is described by up to three trees along with a crop or weed (that can differ from zone to zone), on the basis of the respective root length densities (corrected for mycorrhizal hyphae). The routine first considers the potential combined

uptake by the roots of all types of plants from each layer and zone, and then allocates this uptake over the various plant types on the basis of effective root length and demand. A simple representation of root parasitism can be obtained by shifting a certain fraction [0,1] of the host root in each zone to the parasite, leaving all other relations intact. As long as the fraction parasitized is less than 1 and water and nutrient supplies are abundant, both the host and the parasite can grow undisturbed, but if the resources are in short supply the parasite becomes an effective competitor.

As a first approach we assume that the fraction of the host roots parasitized and added to the host root system is:

$$\text{ParasitFrac} = \text{Min}(1, \text{Effectiveness} * \text{RootLengthDensHost} / \text{RootLengthDensParasite})$$

The cross product of root length densities represents the need for contact between host and parasite roots to be established by the presence of both within close range, while the effectiveness parameter can attain any value > 0.

For the time being we assume that parasitic relationships are established in the topsoil, on the basis of root length densities in layer 1. If there is root parasitism, a constant fraction of the host roots in all layers is allocated to the parasite, as roots in deeper layers can be 'tapped' by the parasite in the topsoil.

Sensitivity analysis for root parasitism parameters

Results

Figure 4 shows the result of simulations to explore the sensitivity of root parasitism parameters. We simulate sandalwood and *Gliricidia* grown together as hedgerow in an alley cropping system with maize growing between the alley. We mainly focused on the result of both the biomass of sandalwood and *Gliricidia*.

In figure 4(a) the biomass of sandalwood in the agroforestry setting is expressed relative to the biomass when grown in a monoculture (compare Figs 2 and 3). In the simulation we assume that

sandalwood is able to grow without host tree. Similarly, figure 4(b) shows biomass of *Gliricidia* as host tree relative to *Gliricidia* when grown as monoculture.

As the effectiveness of host tree increases we see a general increase of predicted sandalwood biomass. The opposite results occurred for *Gliricidia*. When the effectiveness of host is 0, both sandalwood and *Gliricidia* are growing less than in their respective monocultures, but the competition effect is stronger for sandalwood (-60%) than for *Gliricidia* (-10%).

The break-even point for competition and parasitism is reached for a parasit effectiveness of about 0.2 and beyond those values growth of cendana is promoted by the presence of a host. At a host effectiveness above 1 the simulated results

show a large decrease of sandalwood biomass, especially for biomass after 4 years. This decline is as expected because by that time the host tree has severely suffered from parasitism and is no longer able to grow and support the parasite (sandalwood) through its N_2 fixation. We expected the biomass will continue to decrease at a higher value of host effectiveness, but the results in Figure 4(a) show an unexpected oscillation. The continued positive impacts of parasitism in the near absence of a host is probably due to a rather artificial assumption in the model. In the current runs we do not consider a feedback effect of host biomass on host root development, allowing the cendana to take advantage of the host tree roots. Because of this we believe that the results shown for high value of host effectiveness are overestimates.

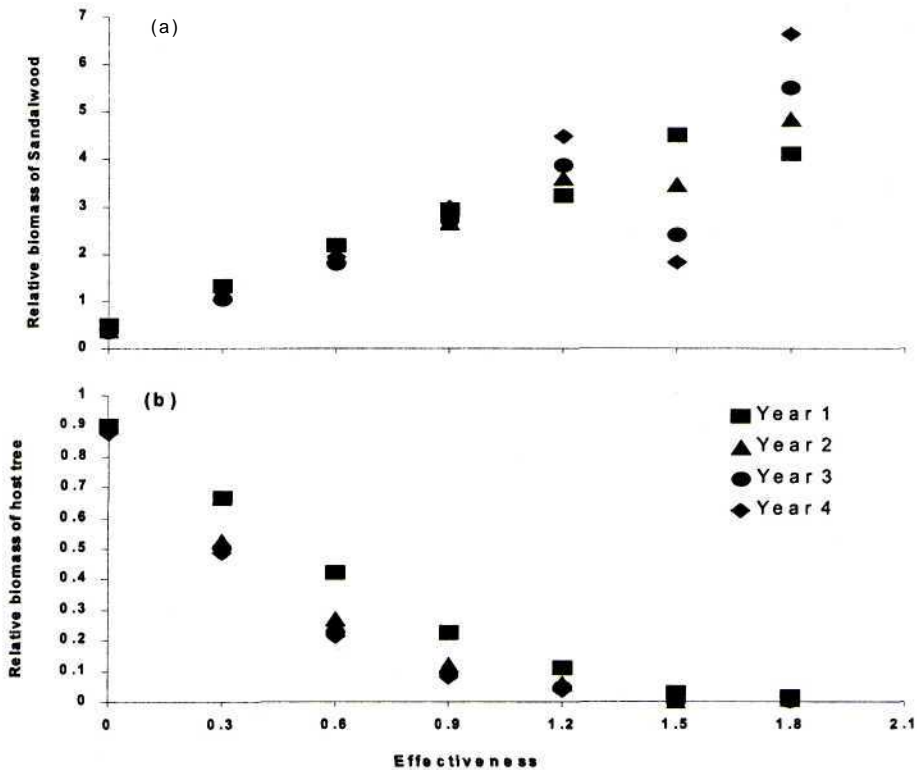


Figure 4. Relative biomass of sandalwood and *Gliricidia* after 1, 2, 3 and 4 years

Discussion

The results of initial simulations presented here may raise more questions than they answer. In developing the model we realize that the information in the literature on how the host-parasite relation functions is rather superficial. The description of parasitism we developed here may serve as a 'null hypothesis' for actual experiments - root parasitism requires the host and the parasite roots to meet and establish contact. Expressing the number of parasite points relative to the root length density of both species would be a first step in quantifying the parasitism. Other factors contributing to our 'effectiveness' parameters are the share of the root system that is actually exploited per infection point and the question for how long such parasitized roots can depend on the energy supply of the host and stay alive and functional. For the parasite there is a continued need to establish new parasitic relations and it needs to invest in roots to do so: for very low root investment it will not find enough hosts, at high root investment it might as well depend on its own roots, so a parasitism benefits probably highest for intermediate root allocation of the parasite. We plan to quantify these factors in existing field experiments with a range of hosts in the near future.

Technical aspects are only part of the constraints on successful agroforestry development, as indicated in our introduction. Resolving existing 'parasitic' relationships among the human actors may be a prerequisite for successful agroforestry with this parasitic tree.

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