Developing establishment guidelines for *Shorea palosapis* in smallholder plantings in the Philippines

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SUMMARY

A series of trials examining fertilizer-shading interactions on the island of Leyte (Philippines, 11°N) revealed that the endemic dipterocarp mayapis (*Shorea palosapis*) benefits from shade trees, either directly above or to the east, during the early stages of plantation establishment. Although it can attain 2 cm/year diameter increment in plantations, mayapis exhibits poor growth and survival under wide spacing, when waterlogged and in exposed bare soil. Indications that early growth can be hampered by high soil temperatures warrant further research and development of practical planting techniques for smallholders.

Keywords: establishment, endemic tree species, fertilizer-shade interaction, nurse crop

Développement de lignes de conduite pour l'établissement du Shorea palosapis dans des petites plantations des Philippines

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Une série d'essais examinant les interactions engrais/ombre sur l'île de Leyte (Philippines, 11 degrés N) a révélé que le dipterocarp mayapis (Shorea palosapis) endémique profite des arbres offrant un ombrage, directement au dessus ou vers l'est, pendant les premiers stades de son établissement en plantation. Bien qu'il puisse atteindre des croissances de diamètre de 2 cm/an dans les plantations, le mayapis connait maigre croissance et survie quant il est trop espacé, noyé ou exposé sur la terre nue. Des indications que la croissance initiale peut être empêchée par des fortes températures du sol encouragent une recherche plus poussée et un développement de techniques pratiques de plantation pour les petits exploitants.

Elaboración de directrices para el establecimiento de *Shorea palosapis* en plantaciones de pequeños propietarios de Filipinas

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Una serie de ensayos que examinaron las interacciones entre sombreado y fertilizante en la isla de Leyte (Filipinas, 11°N), revelaron que durante las etapas iniciales del establecimiento de la plantación, la dipterocarpácea endémica mayapis (*Shorea palosapis*) se beneficia de la presencia de árboles de sombra, ya sea directamente por encima o bien localizada al este. Aunque incremento diamétrico en plantaciones puede alcanzar los 2 cm/año, mayapis muestra un crecimiento y una supervivencia pobres bajo espaciamientos amplios, así como en los suelos anegados o los desnudos y expuestos. Ciertos indicios de que el crecimiento inicial puede verse obstaculizado por altas temperaturas del suelo merecen investigación adicional y el desarrollo de técnicas de plantación prácticas para pequeños propietarios.

INTRODUCTION

During the past decade, the Philippine government's policies on forest management have shifted from a focus on large-scale, timber-oriented industrial forestry to multiple-product, people-oriented small-scale tree farming (Mangaoang 2002). Small-scale forestry has been promoted as an effective approach to solve the widespread loss of forest, promising poverty alleviation while increasing environmental protection. It is envisaged that smallholder tree crops can benefit the rural economy (Nichols and Vanclay 2012) and ensure the supply of plantation timber (Dy and Bautista 1999, Guiang 2001). However, previous research undertaken in Leyte Island indicates that only about 30% of the potential timber yield is being realized by smallholder tree farmers (Herbohn *et al*. 2009a). Lack of appropriate silviculture, inadequate site-species matching and inferior germplasm contribute to low financial returns from smallholder tree plantations (Herbohn *et al*. 2009b). This study forms part of a larger project that addresses these issues (Herbohn and Harrison 2005).

Existing tree farms on Leyte Island comprise almost entirely two exotic species – gmelina (*Gmelina arborea*) and mahogany (*Swietenia macrophylla*) (Herbohn *et al*. 2009a). These species were widely planted during the National Forestation Program (NFP) of the Department of Environment and Natural Resources (DENR) during the 1990s (Harrison *et al*. 2004). Although these exotics dominate most tree farms and reforestation projects, some areas have been planted with longer rotation species including dipterocarps (Cedamon *et al*. 2011), and there is interest in domesticating indigenous tree species (Mangaoang and Pasa 2003). Local and national laws have been enacted to promote planting of native trees, the most recent being the National Greening Program which aims to establish 1.5 billion native trees during the next five years (DENR 2011). There have been several local and national initiatives to promote planting of native trees, including trials of the "Rainforestation Farming System" (known locally as Rainforestation) established on Leyte Island in the mid-1990s (Milan *et al.* 2004). Under this system, fast growing native species were planted first with successional species and then with dipterocarps and fruit trees in the subsequent year.

Mayapis (*Shorea palosapis* (Blanco) Merr.), a native forest hardwood endemic to the Philippines, is a prime candidate for domestication. It has long been recognised as a prime timber species (Nablo 1940, Reyes 1959), it is one of the species most preferred by farmers (Santos *et al.* 2003), has one of the highest growth rates amongst dipterocarps in cultivation (Milan *et al*. 2004), and is on the IUCN Red List (Ashton 1998). Despite past exploitation, mayapis remains one of the most widespread dipterocarps on Leyte, occurring naturally on a wide range of sites from 100–800 m elevation (Langenberger 2006). Previous work on reforestation has recognised its potential, categorising it as a "superb, all purpose" tree (Schulte 1996). However, further work is needed, as planting stock is problematic and site requirements remain ill-defined. Mayapis has recalcitrant seeds typical of dipterocarps, viable for 3–7 days after collection, so most plantings rely on wildlings. Paler and Alcober (1991) and Zabala (1993) reported some success with rooted cuttings, but these techniques have not yet been operationalized. In his review of dipterocarp plantations, Weinland (1998) recognised the challenges of effective establishment, and called for "controlled (artificial) experiments . . . for base line information on the light requirements of species to be complemented by field trials where shade from natural vegetation is manipulated". Our trials (Gregorio *et al*. 2009) address this question, and seek to inform future reforestation efforts with this species, specifically with regard to establishment procedures.

Some guides advocate that mayapis "can be planted directly in open areas" (Visayas State University c.1995) and is "pioneer-like, least susceptible to drought and performing best in open areas" (Marohn 2008), whilst others recommend it as a shade-loving tree that should be planted during the second year of a rainforestation effort (Margraf and Milan 1996). Otsamo (1998) recommended *Paraserianthes falcataria* as a nurse tree to assist establishment of "fast-growing plantations on *Imperata* grasslands using dipterocarps with wide ecological tolerance". It has long been observed that shade can improve the nutrient balance in tree seedlings (Bevege and Richards 1970), and this concept is applied commercially with agroforestry coffee typically grown under shade with minimal fertilizer input, whilst industrial coffee tends to be grown in full sun with fertilizer and irrigation (DaMatta *et al*. 2007). In this study, we explore the utility of both artificial shade and nurse trees in facilitating plantation establishment.

Bruzon (1978) reported that potted mayapis grew better with fertilizer, and recommended 1–2g NPK per seedling, but others have shown that fertilizer may have no effect, or may even be detrimental to *Shorea* seedlings if it interferes with ectomycorrhizae (e.g., Turner *et al*. 1993). Our study includes fertilizer applications to provide preliminary guidance for plantation establishment.

METHODS

A series of trials was established at Leyte Leyte (11°N 124°E, Figure 1) to explore several aspects of the silviculture of mayapis (*Shorea palosapis*) and its interactions with three other species of interest to smallholders (narra, *Pterocarpus indicus;* falcata, *Paraserianthes falcataria;* mahogany, *Swietenia macrophylla*). These species were chosen to evaluate well-documented synergies between nitrogen-fixing and other species (Forrester *et al*. 2006) in both native and exotic species. Two trials employed clinal designs (Vanclay *et al*. 1995, Vanclay 2006a) to investigate specific responses to a wide range of spacing and species composition, and these offer some insights into early growth of mayapis. A third trial specifically examined shade and fertilizer responses of mayapis, in an attempt to resolve contradictions observed in the literature. The experiments were established in 1.2 ha of former pasture land in the municipality of Leyte in Leyte Island, Philippines. Figure 2 shows the location of the study site and

FIGURE 1 *Trial location in Leyte Leyte, Philippines*

FIGURE 2 *Google Earth image (4 July 2011), showing variable spacing trial (top), mixture trial (centre, mayapis in south-west corner), and shading+fertilizer trial (bottom). Oval indicates watercourse causing seasonal waterlogging*

distribution of the three field trials within the experiment area.

Collection of seeds and production of seedlings for the trials

Suitable mayapis mother trees were identified using the database of premium native trees (Gregorio *et al*. 2010) and seeds were collected from four mother trees in the forest reservation of Visayas State University (VSU) in Leyte Island. Seeds were sown directly in polybags filled with a potting medium comprising 60% forest soil, 20% mudpress and 20% rice-hulls. Fungicide was applied weekly through overhead sprays until seeds germinated, and subsequent watering, weeding and pest control applied as needed. Since the potting medium was relatively fertile, no fertiliser was added to the pots. Seedlings were hardened ten weeks after germination by exposure to full sunlight and reduced watering. Also, seedlings were placed on elevated beds to promote air-pruning of roots. The hardening process lasted for one month after which 500 seedlings with relatively uniform height and base diameter were selected for the trial.

Two of the trials included mahogany, falcata and narra and these seedlings were propagated together with the mayapis. Mahogany seeds were collected from five phenotypically superior mother trees from the VSU forest reservation. Narra and falcata seeds were purchased from Bukidnon Forest Industries, a company producing genetically superior seeds of timber species. Seeds of narra and falcata were sown in germination boxes with pasteurised medium composed of 60% soil and 40% sand. Young seedlings were potted to individual polybags after a pair of leaves formed. Because seeds of mahogany are relatively large, these were sown directly to individual pots. The pots were placed on elevated beds and hardened by exposing to sunlight and reducing water application. A total of 250 seedlings with relatively uniform height and diameter were selected from each species for the field trials.

Experimental design and treatments

The shading trial employed a randomized complete block design with two replicates and 15 treatment combinations (5 shade levels and 3 fertilizer rates). Shade treatments included an untreated control, nurse trees and artificial screens (light, medium and dense). Screens measuring 60 × 60 cm were assembled from 4 cm bamboo slats to provide dense, medium and light dappled shade with densities of 90%, 60% and 30%

respectively. Kakawate (*Gliricidia sepium* (Jacq.) Steud.) was used as shade tree as is common practice in agroforestry plantings locally. Fertilizer treatments included control (no fertilizer), 'light' (65 g) and 'heavy' (130 g of 14-14-14 fertiliser per seedling). Fifteen plots were established in each replicate with each plot comprising 12 seedlings at a uniform spacing of 3 × 3 m.

Four species were planted in the mixed species trial – mayapis (native and non-nitrogen fixing); mahogany (exotic and non-nitrogen fixing); narra (native and nitrogen fixing) and falcata (exotic and nitrogen fixing). The planting layout was designed to facilitate investigation of inter- and intra-specific competition (Vanclay 2006a), with four plots each planted with 100 seedlings spaced at 3 × 3 m, with the species mix varying systematically across the plot. The same four species were planted in the variable spacing trial, which employed a rectangular layout with spacing varying continuously from 0.6 m at the centre to 7.5 m at the perimeter of the trial, offering a compact way to evaluate a wide range of spacings (Vanclay 2006a).

The experiment was established on private land previously used as livestock pasture, arranged through a Memorandum of Agreement with the owner. The adjacent areas were irrigated rice fields and smallholder agricultural farms planted to annual crops. Brushing was undertaken to remove established vegetation including pioneer trees, shrubs and tall grasses. Stems of trees and brushes were removed while grasses were allowed to decompose on the site. Experiments were laid out using a compass and tape measure, and planting locations were marked with stakes. Seedlings were planted into holes approximately 0.3 m wide and 0.3 m deep. A fence was constructed around the planting to protect from stray animals. Quarterly plantation maintenance included removal of weeds within one meter radius from the base of the seedlings.

Treatments

Cuttings of the shade tree *G. sepium* were planted two months before the planting of mayapis seedlings, by which time the cuttings were well established and offered considerable shade to mayapis seedlings. Shade screens were installed immediately after planting, directly above the seedlings and fastened to three bamboo poles at the height of approximately 0.3 m above the shoot tip. Screens were adjusted regularly as seedlings grew to maintain 0.3 m clearance between the screen and the seedling. Because growth rates differed, this adjustment of screens were not synchronous for all seedlings. Both the shade screens and the shade trees were removed 18 months after planting.

Fertiliser treatments were applied 45 days after planting, when seedlings should have formed new roots capable of absorbing the nutrients applied. Doses were prepared by weighing and dispensing into sealed, labelled plastic bags which were emptied and distributed in a trench 5 cm deep, surrounding and approximately 12 cm from the base of the seedling. In the mixed species and variable spacing trials, all seedlings received 130 g of 14-14-14 fertiliser 45 days after planting.

Tree parameters including total height, base diameter, diameter at breast height (dbh), and maximum photosynthesis were measured. Seedling health was also monitored and recorded. Measurement of dbh commenced 2 years after planting. Photosynthesis measurements commenced when seedlings were 6 months old and were repeated regularly using a LI-COR LI-6400 portable photosynthesis system (Herbohn *et al*. 2009b). Height and diameter measurements were taken at 2-month and 3-month intervals for the first 6–24 months, after which measurement frequency was reduced to 6 monthly. Calipers were used to measure basal diameter, while dbh was measured using a diameter tape. Seedling height was measured initially with a metre rule, and with a hypsometer once seedlings exceeded 1 m tall.

RESULTS AND DISCUSSION

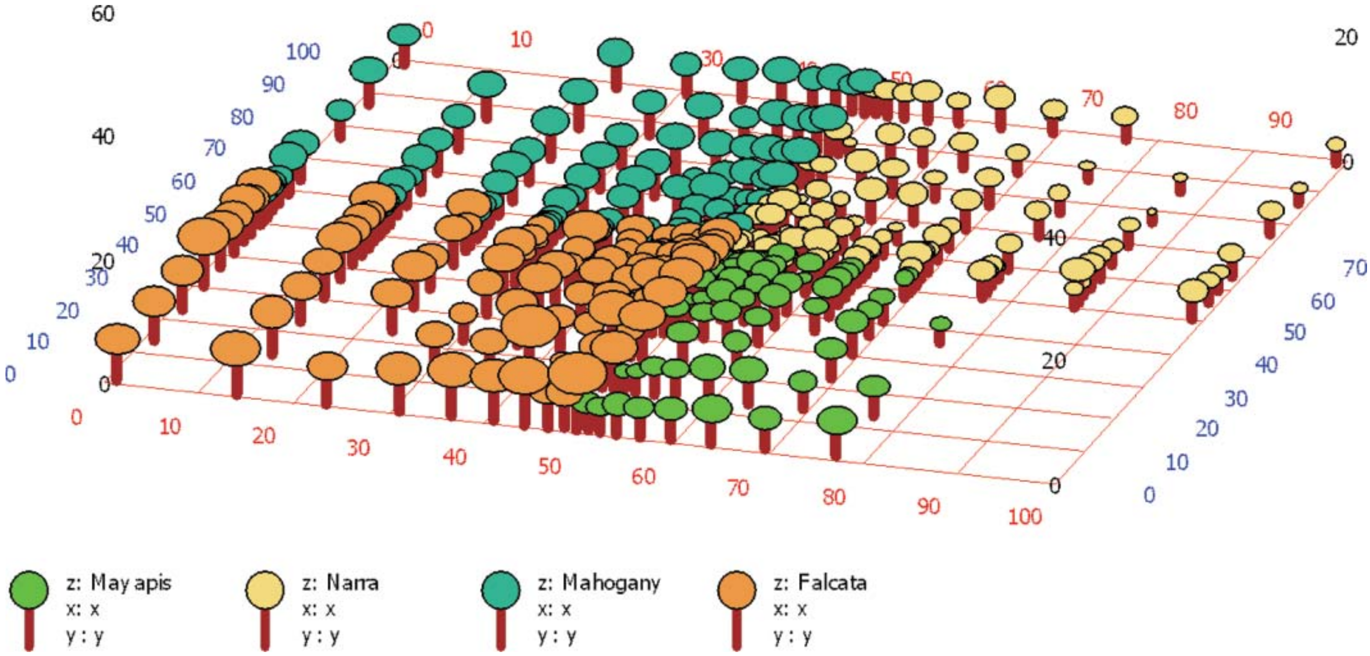
Mayapis suffered high mortality in all three trials, averaging about 40% mortality, partly because of harsh conditions during the first year after planting. While this mortality detracts somewhat from the utility of the trials, the surviving trees nonetheless convey much useful information about the behaviour of this species in plantations. The pattern of mortality in the spacing trial (Figure 3) is a reminder that mortality is often spatially clustered (Ashton and Hall 1992) and suggests that mayapis may perform better at closer spacings.

Survival of mayapis trees was slightly better in the mixed species trial (Figure 4), but mayapis performed better (both survival and growth) in the monoculture part of the trial, and worse in the mixed species composition at the centre of the trial (correlation r=–0.54). This trial offers insufficient evidence to assert that mayapis thrives best in a high density monoculture, but does reveal indicative trends that warrant further research.

While the spacing (Figure 3) and mixture trials (Figure 4) suggest some growth characteristics of mayapis, the main thrust was the shading and fertilizer trial (Figure 5) that sought to inform establishment practices. Unfortunately, four-year survival of this planting was poor (52%), with most of the mayapis in the north-east corner of the trial dying (Figure 6), apparently due to harsh conditions in the year following planting and seasonal waterlogging in subsequent years. Initial site surveys in 2007 suggested a relatively uniform and suitable site, but it subsequently appeared that the north-east corner of this trial is liable to seasonal waterlogging, which may contribute to the high mortality rate experienced in parts of this trial (Figure 2).

Although the loss of many trees is disappointing, and detracts from the design (a randomised complete block with two replications), the trial nonetheless conveys much information, and warrants analysis. However, caution is needed in the analysis, because several factors are confounded. A simple summary of the data offers a good overview (Table 1): either fertilizer or shade improves growth, but the effects are not additive so there is little benefit from both shade and fertilizer. Nurse trees appear effective, but the benefit derived by the

FIGURE 3 *Spacing trial showing death of Mayapis at wide spacings (bottom right)*



shade tree from the fertilizer may lead to increased competition for the crop tree (i.e., in Table 1, application of fertilizer halved the mean size of mayapis under nurse trees from 8 to 4 cm) – such fertilizer-weed interactions have been recorded elsewhere (e.g., Roth and Newton1996). In Table 1, some treatments (e.g., 30%, 60% or 90% overhead shade; light or heavy fertilizer) have been amalgamated to provide representative samples, but treatment differences remain non-significant at the usual statistical thresholds (P>0.05).

Treatment differences in Table 1 are not statistically significant because of large within-treatment variation, caused in part by seasonal waterlogging in the north-east corner, poor health of some mayapis, and site variation. For instance, there is a strong correlation between tree size (dbh) and distance

FIGURE 4 *Many of the blanks near the centre of the mixed species trial are due to the death of mayapis trees, which appears to exhibit better survival and growth is better as a monoculture (top left)*

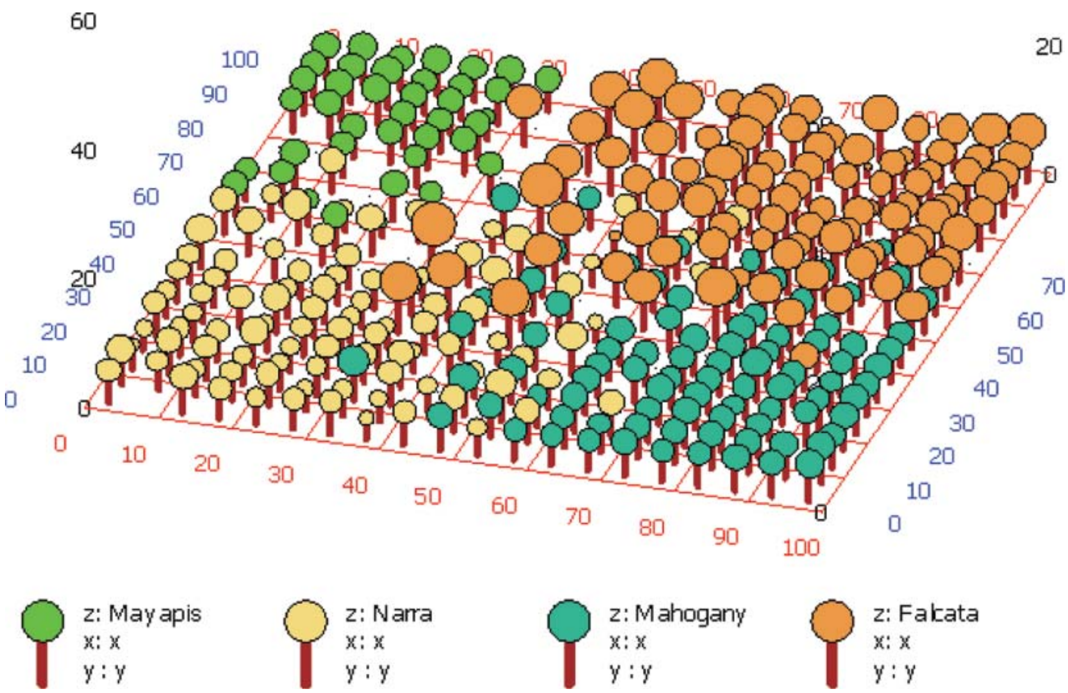
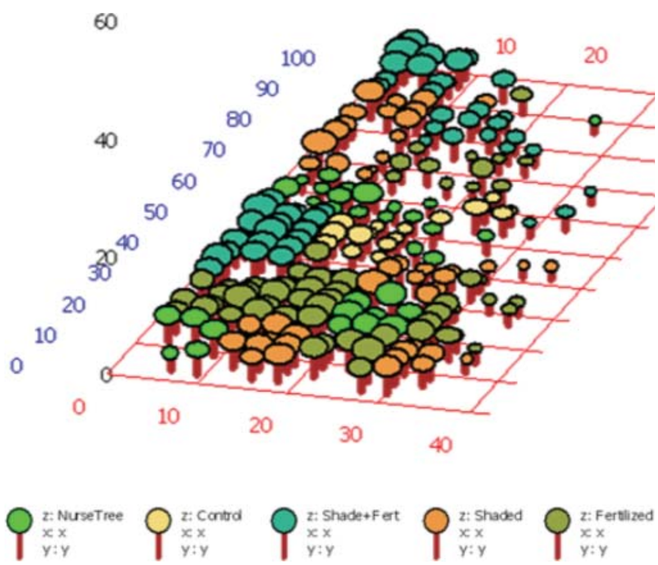


FIGURE 5 *Shading trial, photographed in November 2008 (left), and October 2009 (right)*

from the waterlogged north-east corner (r=0.57), with visual assessment of tree health (dead=0, vigorous=5; r=0.55), and with the basal area of mayapis in the eight nearest planting positions (r=0.82). There are different ways to deal with such issues. For instance, distance from north-east corner could be included in a regression as a covariate, or all planting positions thought to suffer waterlogging could be excluded from the analysis. Similarly, tree health could be used as a criterion to omit some trees from the analysis (e.g., health 1 or 2 are likely to die, so omit), could be included explicitly as a covariate, or could be included implicitly through the assumption that health is an outcome of treatment. Fortunately, in this case, the implications for mayapis planting remain the same for all these alternatives. However, the correlation with basal area is different and need not imply that mayapis prefers crowded stands: instead it reflects the fact that trees are likely to be big if their neighbours are big because tree size within each 12-tree treatment subplot should be similar, and because any site variation means that trees close together should be more similar than trees far apart.

FIGURE 6 *Shading and fertilizer trial, showing poor survival of mayapis in north-east corner (at top right of diagram)*



The analysis that makes best use of all available data is to include distance from waterlogging (i.e., from north-east corner) and health as co-variates, and to fit a linear regression model. This model was fitted to individual tree measurements, using ARC (Cook and Weisberg 1999). The resulting model that includes all treatments is:

$$\mathrm{Sqrt(DBH)} = \beta_0 + \beta_1\mathrm{Distance} + \beta_2\mathrm{Health} + \beta_3/\mathrm{Fert.Shade} + \beta_4\mathrm{Nurse} + \beta_5\mathrm{Nurse/Fert} \quad (1)$$

where *Distance* is the number of planting positions from the north-east corner, *Health* is a visual assessment of tree vigour (0=dead, 5=vigorous), *Fert* is fertilizer treatment (1=none, 2=light, 3=heavy), *Shade* reflects the density of the cage (0=none, 1=30%, 2=60%, 3=90%) and *Nurse* indicates the presence of a shade tree (0=no, 1=yes). The square-root transformation of dbh is desirable to satisfy conventional statistical assumptions (normally-distributed residuals). All parameter are significant (Table 2) and trend in ways consistent with established silvicultural understanding.

TABLE 1 *Mean diameter (cm dbh) versus aggregated treatment at age 4 years (April 2012; all 206 surviving trees)*

Fertilizer	Shade			Mean
	None	Overhead	Nurse tree	
Unfertilized	4.5	6.5	8.2	6.3
Fertilized	6.8	6.9	4.0	6.4
Mean	6.0	6.8	5.6	6.4

TABLE 2 *Parameter estimates for Equation 1*

Variable	Estimate	Std. Error	Student's t	p-value
Constant	–0.634	0.232	–2.73	0.007
Distance	0.038	0.004	8.97	<.001
Health	0.457	0.047	9.66	<.001
1/Fert.Shade	–0.294	0.121	–2.44	0.016
Nurse	–0.582	0.188	–3.09	0.002
Nurse/Fert	0.955	0.281	3.40	0.001

Table 3 offers a more accessible insight than the parameters listed in Table 2, and presents the diameters expected for a healthy mayapis in the centre of the trial (at median distance from the waterlogged corner). Equation 1 is consistent with the results shown in Table 1, implying that either shading or fertilizer improves growth, but that there is little benefit in both fertilizer and shade. Nurse trees offer an efficient way to provide shade and stimulate growth, but fertilizer may stimulate the nurse tree to the detriment of the crop tree (e.g., in the rightmost column of Table 3, more fertilizer means smaller trees).

Several variants of this analysis were investigated, including the omission of treatment subplots affected by waterlogging, the removal of health and/or distance as a covariate, and the use of treatment means rather than individual trees, but all lead to conclusions similar to Table 3, but with different error estimates (and thus different implications for statistical significance). We also considered the use of spatially-explicit competition indices (Vanclay 2006b) as explanatory variables, but they conveyed no significant improvement over Equation (1). Since the present analysis is concerned less with testing for significance and more for calibrating well-established trends, Equation (1) seems appropriate.

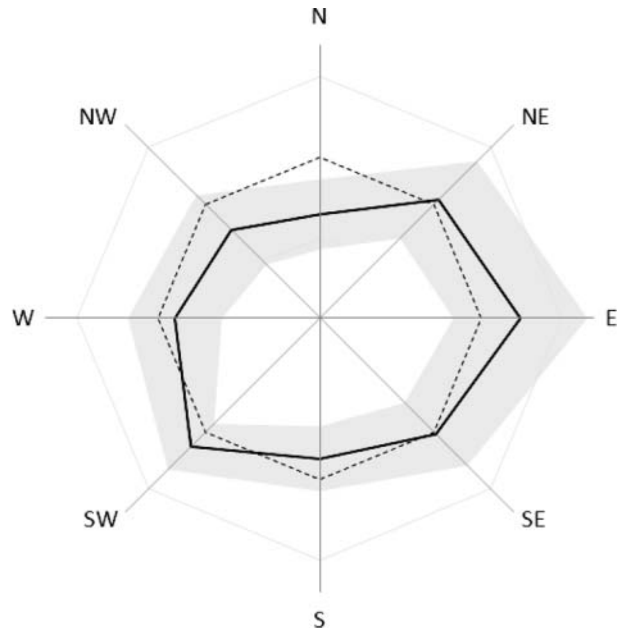
Equation 1 is not quite the full story. The 2009 photograph (Figure 5) is oriented towards the southeast, and it is evident that mayapis to the left of the foreground person are taller than those to the right, despite receiving the same treatment, perhaps because they receive morning shade. An analysis of inter-treatment shading by shade trees reveals a small but non-significant effect (Figure 7).

Mayapis (in unshaded treatments) with shade trees to their west or north are smaller than average, so it seems that they suffer competition without deriving benefit. But mayapis with shade trees to the east are slightly larger than the average, so apparently derive benefit from morning shade. Although this trend is not statistically significant (in Figure 7 or in Equation 1), it is logical and indicates that mayapis may derive benefit from alternative planting schemes, such as alternate rows (especially with rows oriented north-south). Such a scheme with alternate rows may help overcome resistance to practical uptake of mixed species plantings (Nichols *et al*. 2006).

TABLE 3 *Expected mayapis dbh (cm) implied by equation (1)*

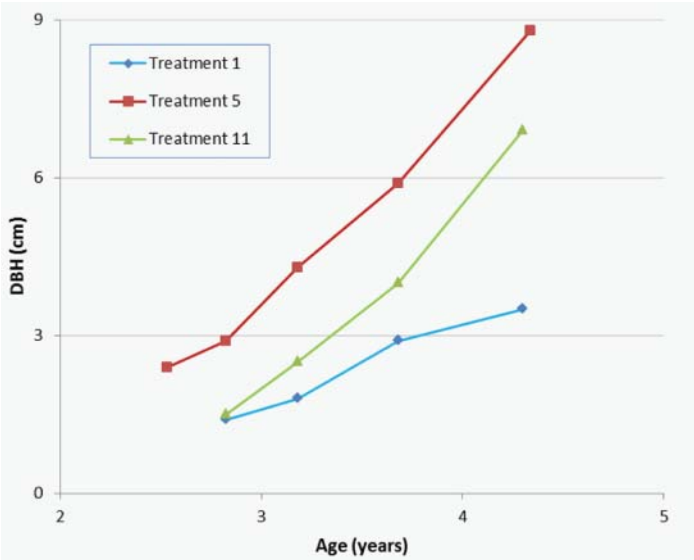
Fertilizer	Shading				Nurse tree
	None	30%	60%	90%	
None	6.3	7.0	7.3	7.4	8.3
Light	7.0	7.4	7.6	7.6	6.5
Heavy	7.3	7.6	7.6	7.7	5.9

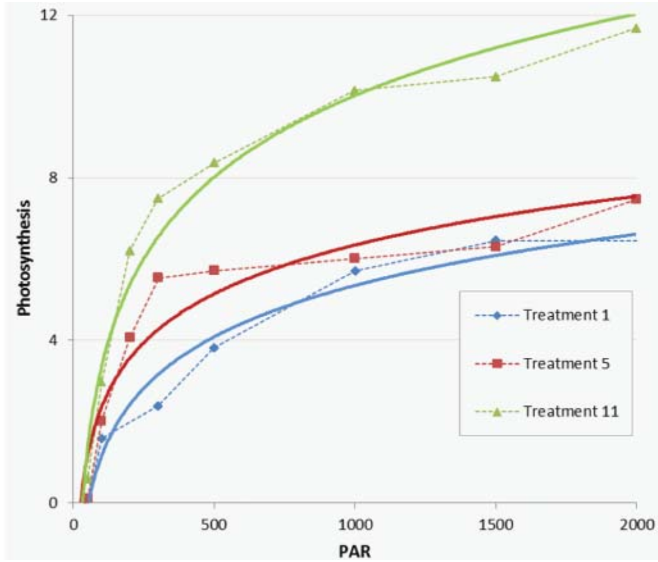
FIGURE 7 *Relative size of mayapis receiving shade from adjacent shade trees. Black line shows relative size of mayapis trees; grey shading indicates 95% confidence interval; dotted line is the reference (average) tree diameter. Shade from the north is detrimental: both the black trend line and grey confidence interval remain less than the overall average*



In an attempt to better understand the response of mayapis to the various treatments, we investigated the light curves of three of the treatments, the control, shade tree and fertilizer (Figure 8), because they are strong contrasts. Each of these treatments have 10–12 trees that reached breast height and have 3 or more measurements at dbh by 4 years of age. Figure 8 illustrates the growth pattern of the median tree, and the corresponding light response curve. It is evident that the greatest instantaneous photosynthesis is exhibited by fertilized trees, but that overall the best performance is achieved by mayapis with shade trees. Our interpretation makes an analogy to the race between the hare and the tortoise: even though fertilised trees exhibit higher instantaneous photosynthesis, they cannot sustain this performance throughout the heat of the day, and overall achieve lower growth than shade trees that sustain lower photosynthesis throughout a greater proportion of the day. Observations suggest that photosynthesis in mayapis leaves shuts down at around 34°C, an air temperature commonly reached in the exposed areas of the site. Shade cover invariably leads to cooler air temperatures and thus photosynthesis in shade treatments would have continued for a longer period during hotter periods. The shape of the light response curves whereby there is a rapid increase in

FIGURE 8 *Growth curves (left) and light response curves (right) of the median tree in three treatments (1=no shade, no fertilizer; 5=shade tree, no fertilizer; 11=no shade, with fertilizer)*





photosynthesis from 0 to 400 µmol m-2 s-1PAR means that reasonably high levels of photosynthesis still occur even in partial shade.

Mycorrhizae have been shown to confer tolerance to drought and high soil temperature (Lee 1996) and thus to improve early growth (Turjaman *et al*. 2005). Bruzon (2002) recorded that mulching increased height growth of seedlings by 70%, perhaps by moderating soil temperatures.

Understanding the biophysical factors that affect the establishment and early success of mayapis is only one step in the development of successful silviculture for a new plantation species. A further critical requirement is ready availability of seedlings. Currently mayapis seedlings are seldom available in tree nurseries, as is the case with most native species in the Philippines (Mangaoang and Pasa 2003, Gregorio *et al*. 2008). This is partly due to a lack of germplasm (i.e., mayapis only fruits irregularly and there are few natural forest areas from which wildings can be collected). While germplasm remains difficult to obtain, government nurseries are probably best placed to supply planting material because of their greater ability to access germplasm and propagate less commonly produced species compared to smallholder and community nurseries (Gregorio *et al*. 2008), especially given that farmers have little knowledge of tree nursery systems (Baynes *et al.* 2011a).

Given the shift away from industrial forestry systems in the Philippines, the domestication of mayapis will involve planting as part of smallholder and community forestry systems. The silviculture for mayapis will however differ from that of commonly grown exotic species such as gmelina and mahogany. As such, for mayapis to be successfully adopted in these systems, culturally appropriate extension programs will need to be developed (Baynes *et al*. 2011a; Baynes *et al.* 2011b).

CONCLUSIONS

Mayapis benefits from shade trees, either directly above or to the east, that provide midday or morning shade. Mayapis exhibits poor growth and survival under wide spacing, when waterlogged and in bare soil exposed to full sunlight. Light response curves suggest that fertilizer helps to increase the peak photosysnthesis, whilst shade trees modify the microenvironment and allow mayapis to photosynthesise actively for longer each day.

Trial plantings exhibited an average survival of only about 50%, not sufficient for operational plantings by smallholders. Further research is needed to explore the interaction of soil temperature and mycorrhiza on seedling survival and growth. Further study is also needed to explore the feasibility of operational mixed-species plantings with mayapis, possibly as alternate rows of mayapis and shade trees.

ACKNOWLEDGEMENTS

This research has been conducted as part of ACIAR project ASEM/2006/091 Enhancing Tree Seedling Supply via Economic and Policy Changes in the Philippines Nursery Sector.

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