Experiments to inform Mixed-Species tree planting in Agroforestry

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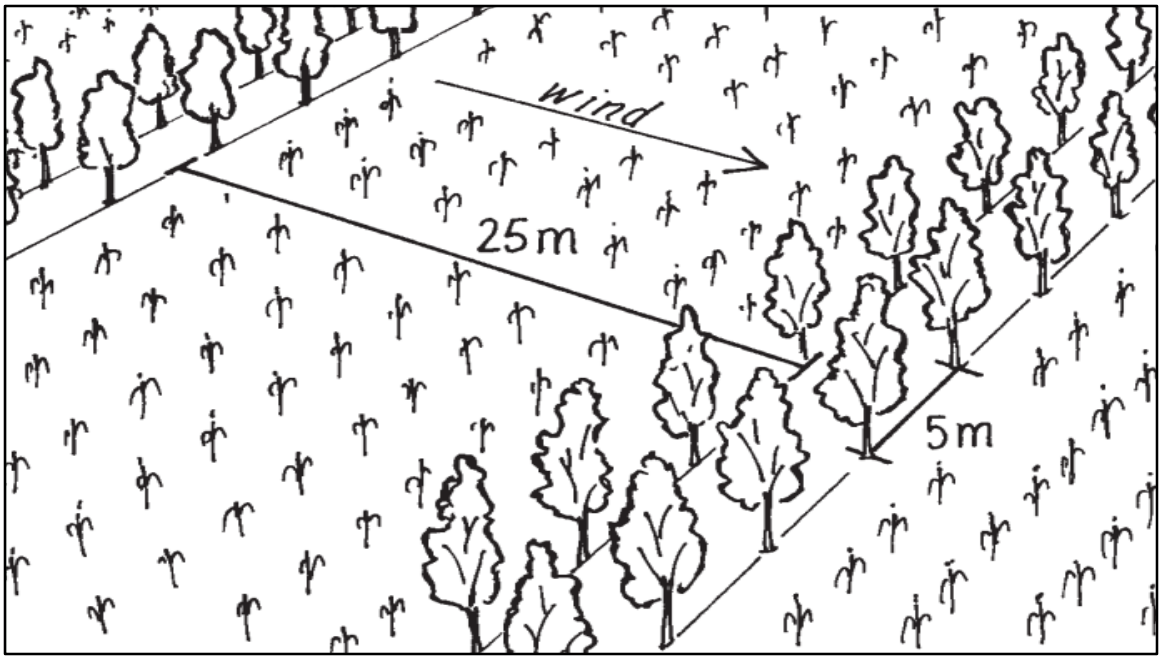
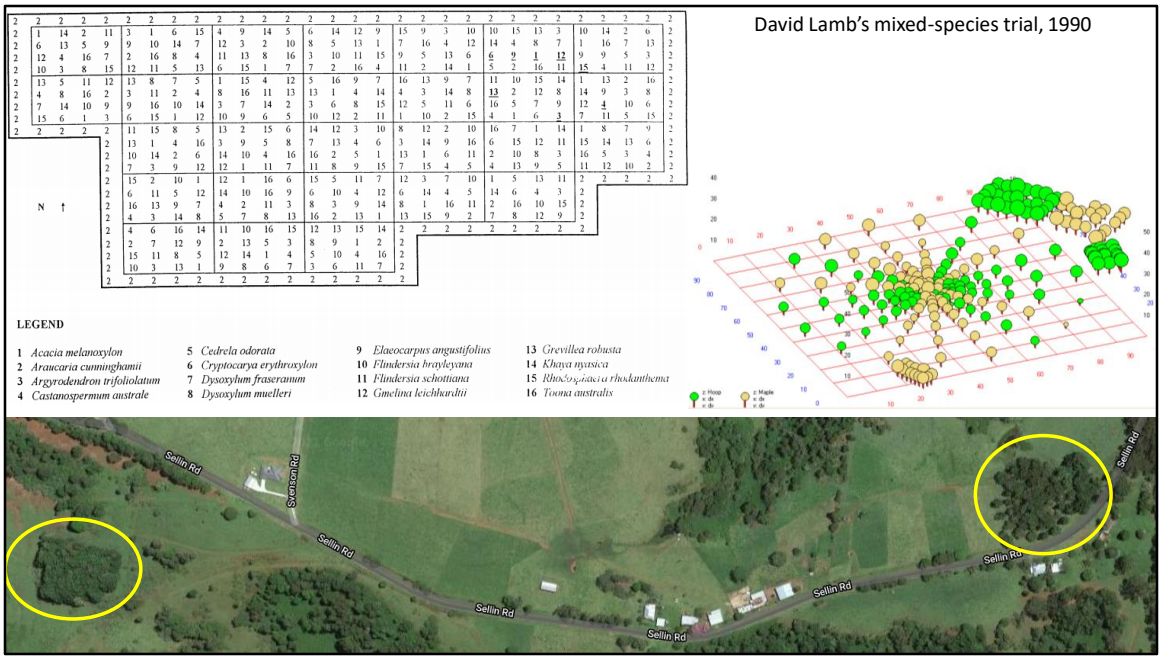
Good afternoon. I'm from Southern Cross University, named for this prominent group of stars, easily visible in the southern hemisphere. The first nations people in my part of Australia call these stars "Gnibi", the black swan flying; that black swan that is their totem and their source of inspiration and direction – and I hope I can offer some more inspiration and innovation in agroforestry research.

Footnote: there is a nice summary of the role of the black swan in science here: https://link.springer.com/article/10.1007/s00381-020-05009-3



Long ago, early in my career, part of my work involved extension work with government approved material and messaging – and I was disappointed that there was too much dogma with insufficient regard for capabilities of the site or aspirations of the farmer. But then I met David Lamb who sought my help with had a rather interesting agroforestry trial…



This is David Lamb's trial at Mt Mee, Queensland (27°S, comparable to Florida), in which he trialled 16 species in mixed plantings (left), and investigated spacing with two species in a Nelder wheel (right). The species trial involved 25 contiguous plots, each with the same 16 species in a randomized layout. When I attempted an analysis, I was disappointed by this randomization, because by chance, some pairs of species were frequently adjacent, while other pairs were hardly ever adjacent, hampering analyses. Plus there is a kilometre, and some topographic differences, between the two parts of the trial, making some inferences problematic. But this experience got me thinking about better ways to explore species interactions in compact robust designs…

Lamb, D. & G. Borschman, Agroforestry with High Value Trees. http://www.agrifutures.com.au/wp-content/uploads/publications/98-142.pdf

Nelder, J.A., 1962. New kinds of systematic designs for spacing experiments. *Biometrics* **18**(3), 283-307.

Vanclay, J.K., D. Lamb, P. Erskine and D.M. Cameron, 2013. Spatially-explicit competition in a mixed planting of *Araucaria cunninghamii* and *Flindersia brayleyana. Annals of Forest Science* **70**:611–619

Jeff Goelz - 1995 - Experimental designs for mixed-species plantations -

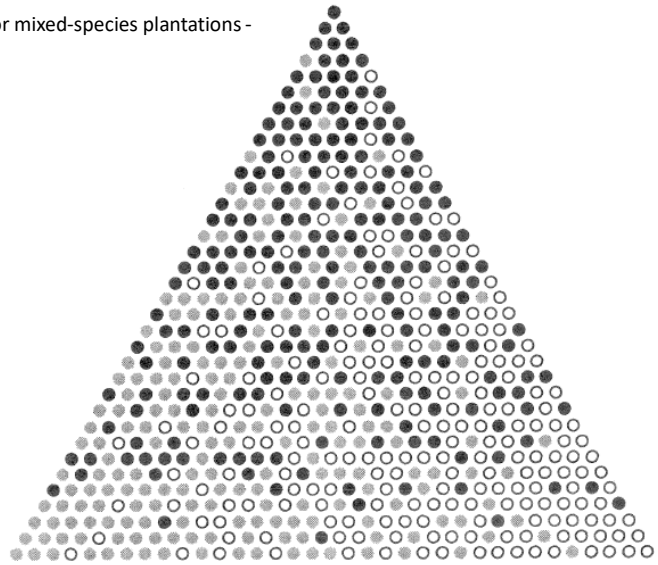
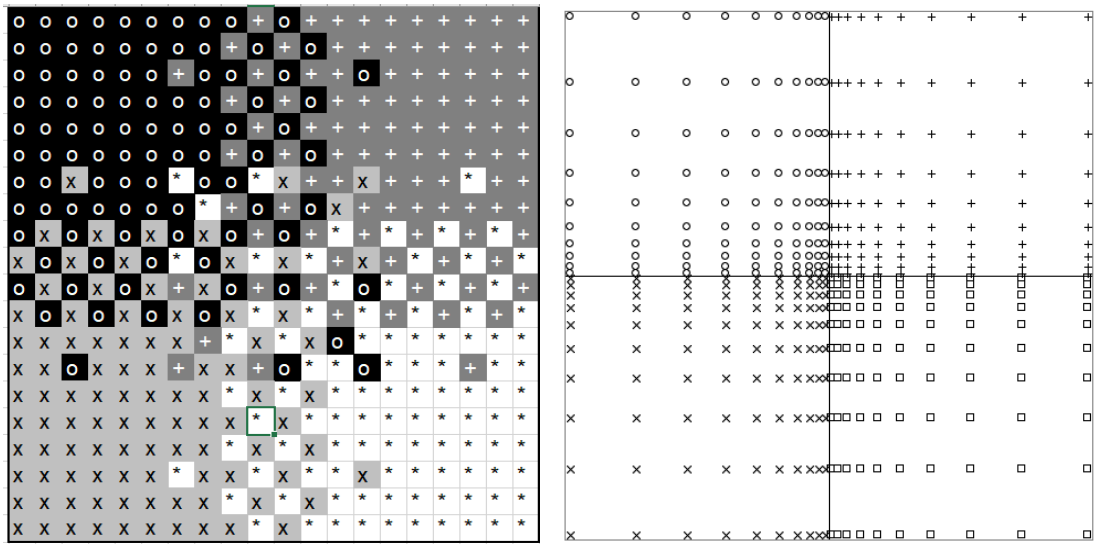


Figure 2--The Stoneville design for three species. Shading distinguishes species. Species is assigned to each planting spot using a constrained random procedure.

In looking for alternatives, I came across this design by Jeff Goelz, in which 3 species are planted in a pattern that offers detailed insights into 3-way species interactions. But this design uses a single constant spacing, and I suspect that spacing has a big effect on the way that competition is manifested, so I came up with my own design to include a range of spacings.

Goelz, J.C.G. 1995b. Experimental designs for mixed-species plantations. In: USDA Forest Service, Southern Research Station, General Technical Report SRS-1. p 559–563.

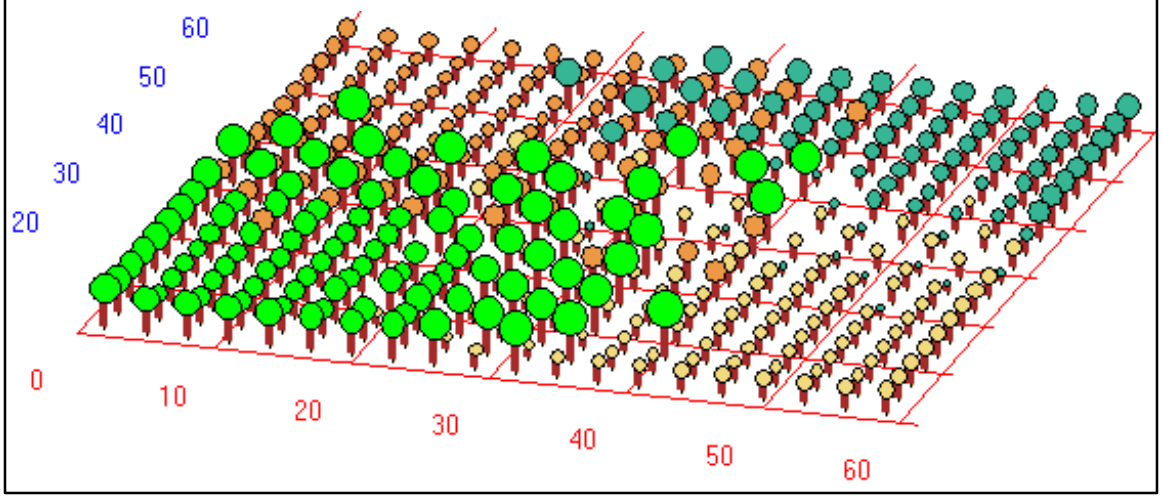
Vanclay, J.K. 2006. Experiment designs to evaluate inter- and intra-specific interactions in mixed plantings of forest trees. *Forest Ecology and Management* 233, 366–374.



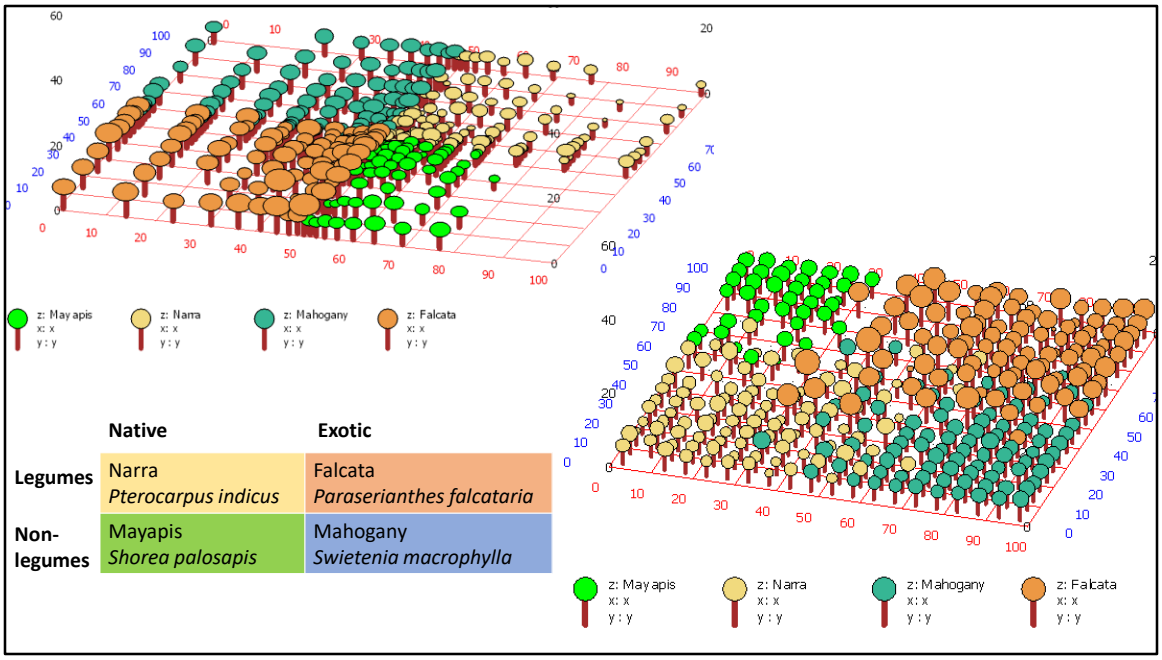
This is the design that I devised, for 4 tree species. There are two plots, one to vary species composition (left), and one to vary spacing (right), both set out in a conventional rectangular layout to assist fieldwork. One part (left) examines species composition, which ranges from monoculture (100%, in the corners) to a 4-way mixture (each with 25%, in the centre). The other part (right) examines a range of spacing, ranging from 0.6x0.6 to 7.5x7.5 metres. There are plenty of critics of this design, but I find it interesting, and in the next few slides I'll explain why…

Vanclay, J.K. 2006. Experiment designs to evaluate inter- and intra-specific interactions in mixed plantings of forest trees. *Forest Ecology and Management* 233, 366–374.

Prediction, published in 2006, based on prior knowledge about 4 species

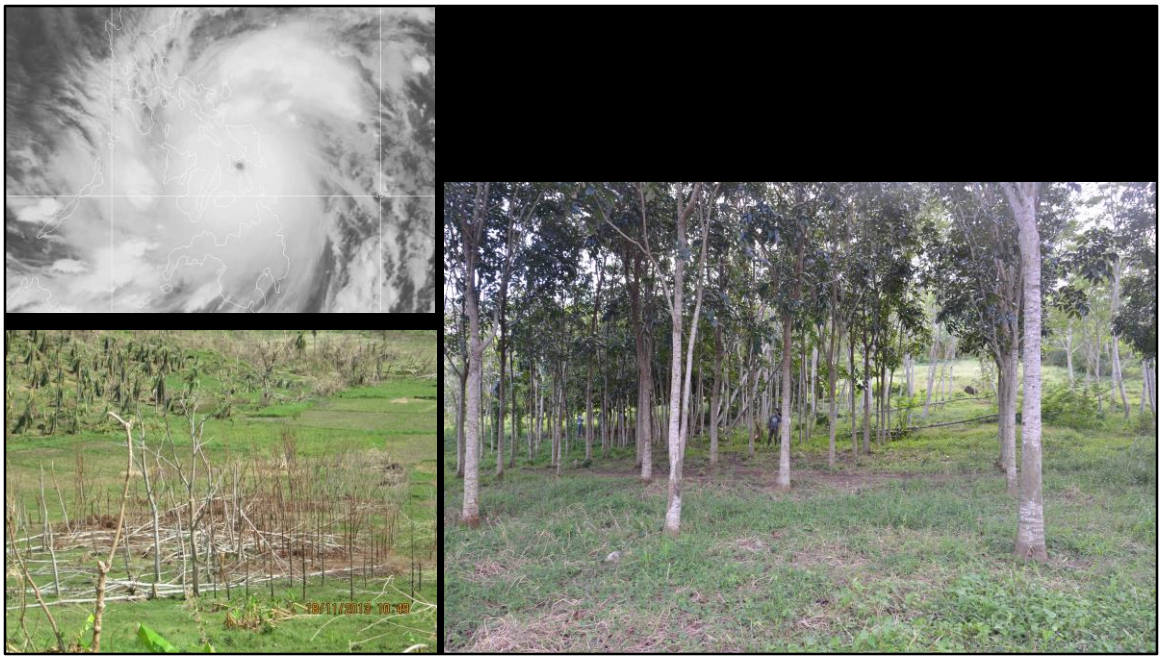


In my 2006 publication, I made a simulation to predict how such a species mixture might develop, based on existing data from potential species. This prediction helped give me confidence that my proposed trial would be informative (and as you will see in a minute, it was a reasonable prediction, even though some of the species changed in the resulting planting).



This design was used to evaluate four tree species for potential agroforestry plantings in the eastern Philippines (11°N, cf. Costa Rica). Local interests dictated that the trial should use two native and two exotic species, and that one of each should be leguminous. So the four species chosen were Falcata (*Paraserianthes falcataria*), Mahogany (*Swietenia macrophylla*), Narra (*Pterocarpus indicus*) and Mayapis (*Shorea palosapis*). This is a graphical summary of the tree measurements taken in 2013, when 6 years old. It is evident (and we knew this when it was designed) that Narra is comparatively slow growing, but it is native, N-fixing, and has high value timber, so there were good reasons to include it. It was deliberate to put the two N-fixers (Narra, Falcata) at opposite corners of each plot, because we were especially interested in the legume/non-legume interaction. It can be seen clearly that some species are affected by spacing more than others, and that the Falcata grows better in mixtures than in pure stands (right). The Mayapis (top, green) suffered high mortality at wide spacings – this became evident early in the trial, and this was first attributed to weed competition – but weed control made things worse, and further investigation cast suspicion on high soil temperatures, which were solved by mulching and the deaths ceased. These images are a useful summary, but the best insights are gained by visiting the plots – such visits have stimulated many insightful discussions with our fellow Philippine agroforesters.

I can’t offer you a field visit, but these photos (2013) may give you some insights. Top left shows the plot with constant spacing and variable composition, and differences in crown habit and understorey vegetation are evident – and it is noteworthy that villagers relocated a path to rice paddies, previously well to the east of the plots, now going through the plot to take advantage of the shade. Bottom right shows the variable spacing plot, illustrating the high density at the plot centre.



Unfortunately, one of the strongest typhoons ever recorded, Typhoon Yolanda/Haiyan passed directly over this trial in 2013, and completely defoliated all the trees, and smashed many trees in the plot (bottom left) – as it left a trail of destruction across the island. However, most of the trees recovered well, and the trial provided useful insights into the windfirmness of each species at different spacings (bottom right, 2018).

Fitted model: relative growth = species – competition

$\text{Log}(DI/D) = \alpha i + \sum \beta ij\ (Cij)$

Indicators of competition

Victim	All competitors
Mayapis	-2
Narra	-3
Mahogany	-4
Falcata	-4
All species	-3

Aggressive interactions highlighted in yellow; Benign in green

As expected, competition reduces growth of individual trees

… but species differ in the way they are impacted, some tolerant to competition

… and others more susceptible

To look for evidence of differences in competition, I fitted a model that estimated relative growth (diameter increment/dbh) as a linear function of competition, using a size-distance index of competition. Quite deliberately, it is a simple model to focus attention n competition, but it provides a good fit, and satisfies the usual statistical requirements. If we assume that all species behave the same, and fit this model, we get relative increment RI=6-3C, showing that as expected, competition reduces growth. We can also fit different equations for each species, thus assuming that all species cause the same competition but respond differently - this table shows the βs, revealing that Mayapis is tolerant, and Falcata is susceptible to competition.

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Fitted model: relative growth = species – competition

$\text{Log}(DI/D) = \alpha i + \sum \beta ij\ (Cij)$

Intraspecific (within species) competition always greater than interspecific competition

Indicators of competition

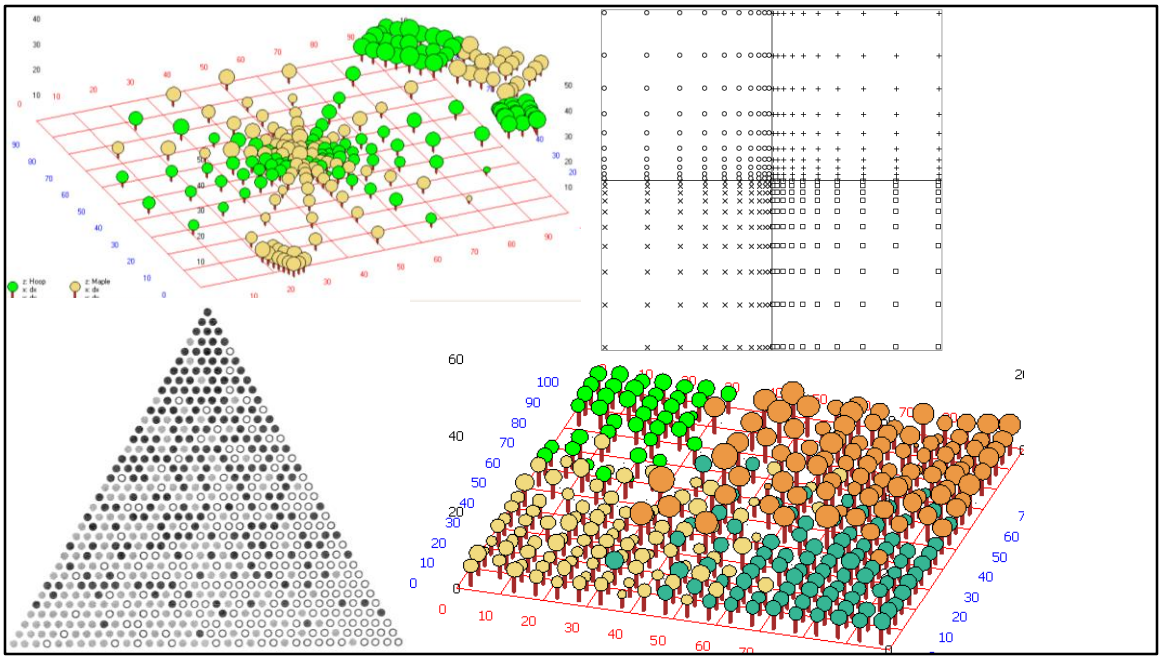
Victim	Cause of competition ('bully')				All competitors
	Mayapis	Narra	Mahogany	Falcata	
Mayapis	-6	2	-5	0	-2
Narra	4	-6	-1	-5	-3
Mahogany	1	-1	-6	-4	-4
Falcata	8	-5	-2	-9	-4
All species	3	-3	-4	-5	-3

Aggressive interactions highlighted in yellow; Benign in green; and potential polyculture candidates highlighted in blue.

Mayapis is tolerant of competitors (top row); and may stimulate growth of neighbours (left column).

When we fit this model with all 16 βs (4 competitor species x 4 victim species), we get a deeper insight. The diagonal shows the intra-specific (within-species) competition, and reveals that it is always bigger than interspecific (between species) competition, especially for Falcata. Mahogany is an interesting plantation species, as it's intraspecific competition was small (-5.6), it doesn't cause much competition to the other species (-1, -2), and its growth is not greatly affected by others (-1, -4). The numbers for Mahogany-Mayapis interactions are grey, because there are few data to support this estimate. Mayapis is also an interesting species, as it seems tolerant of interspecific competition (+2), and may stimulate others (+4, +8). This is not unexpected, as Mayapis is known to be shade tolerant, but it is premature to suggest that Mayapis stimulates growth of others, as the apparent response (+4, +8) may arise because Mayapis is a weaker competitor than grass, or because it's heavy shade has a favourable effect on soil temperature and humidity.

This experiment didn't resolve all our questions, but it did provide plenty of discussion, and this simple analysis offered useful insights – even though the planting was only 6 years old when damaged by the typhoon. Hopefully it gives you some inspiration too!



There are many interesting designs that could help offer inspiration for your work. I'm not going to lobby for any one design – I'm just asking you to think about the information you need and how you might gain inspiration and new insights. Some of these designs I've mentioned are efficient, and need only a small area and a modest number of plants. So see if you can include a small experimental area in your next project, and think about what new information would be inspirational for your work. And if your local biometrician thinks it's a silly idea, don't give up, but seek more advice – and remember that sometimes the visual impression can be more important than the statistical analysis!

Thank You!

References & further reading

Goelz, J.C.G. 1995b. Experimental designs for mixed-species plantations. In: USDA Forest Service, Southern Research Station, General Technical Report SRS-1. p 559–563.

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