Survival and growth of *Swietenia macrophylla* seedlings from seeds sown into slash and burn fields in Quintana Roo, Mexico

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Photo 1.
One mahogany seedling in the middle of the photo.
Note corn leaf and abundance of surrounding vegetation.
Photo P. Negreros-Castillo.

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RÉSUMÉ

Survie et croissance des semis de *Swietenia macrophylla* à partir de graines semées dans des champs de brûlis à Quintana Roo, Mexique

Un problème clé dans la gestion de la production de bois d'œuvre est d'assurer la régénération d'espèces ayant une valeur commerciale, telles que *Swietenia macrophylla* King (acajou), ce qui nécessite une connaissance approfondie des espèces concernées. Cet article rend compte des résultats du semis direct de l'acajou dans trois champs cultivés sur brûlis au cours de la dernière année de culture, à Betania, dans la région de Quintana Roo au Mexique. Dans chaque champ, 121 sites de semis ont été identifiés dans une parcelle de 0,25 ha, et cinq graines ont été semées dans chacun d'entre eux. La hauteur, le diamètre et les indications de dommages causés par *Hypsipyla grandella* de toutes les graines germées ont été enregistrés à 2, 11, 23, 38, 45 et 58 mois après le semis. Les niveaux d'ombrage et la couleur du sol ont été notés. À 11 mois, la mortalité chez les semis qui étaient vivants à 2 mois variait d'un champ à l'autre, mais ne variait pas selon le niveau d'ombrage ou la couleur du sol. Un champ a été abandonné après 11 mois car le protocole de recherche n'avait pas été respecté. En comparant les semis vivants à 58 mois avec les semis vivants à 2 mois mais morts à 58 mois, le pourcentage de survie variait selon les champs et selon les niveaux d'ombrage, mais ne variait pas selon la couleur du sol. Le diamètre moyen des semis vivants à 58 mois a été influencé par les conditions du champ, mais n'a pas varié selon la couleur du sol ou les niveaux d'ombrage. Leur hauteur moyenne variait d'un champ à l'autre, probablement en fonction de la couleur du sol, et n'était pas influencée par les niveaux d'ombrage. Deux mois après le semis, 20 % des sites de semis avaient au moins un semis. Cinq ans plus tard, 63 % de ces semis étaient morts, laissant 7,4 % des sites de semis occupés par un semis. La hauteur des semis à 58 mois variait de 0,3 à 8 m, avec une moyenne de 2,7 m. Fait remarquable, aucun des 212 semis observés ne montrait des signes de dommages causés par *H. grandella*, et le coût de la technique est minime. Les champs de milpa dans leur dernière année de culture semblent être des sites prometteurs pour la régénération de l'acajou à partir de graines dans un contexte de forêt tropicale mixte.

Mots-clés : *Hypsipyla grandella*, *Swietenia macrophylla*, acajou, régénération, sylviculture, forêt tropicale, Mexique.

ABSTRACT

Survival and growth of *Swietenia macrophylla* seedlings from seeds sown into slash and burn fields in Quintana Roo, Mexico

A key issue in managing for timber production is ensuring the regeneration of commercially valuable species, such as *Swietenia macrophylla* King (mahogany), which requires in-depth knowledge of the relevant species. This paper reports on the results of direct seeding of mahogany in three slash-and-burn fields during the last year of cultivation, in Betania, Quintana Roo, Mexico. In each field, 121 sowing sites were identified in a 0.25 ha plot, and five seeds were sown in each. Height, diameter and indications of damage by *Hypsipyla grandella* of all sprouted seeds were recorded at 2, 11, 23, 38, 45, and 58 months after sowing. Shade and soil colour were noted. At 11 months, mortality among seedlings that were alive at 2 months varied among fields but did not vary with shade levels or soil colours. One field was abandoned after 11 months as the research protocol had not been observed. When comparing seedlings alive at 58 months with seedlings alive at 2 months but dead at 58 months, the percentage of survival varied among fields and according to levels of shade, but did not vary with soil colours. The average diameter of seedlings alive at 58 months was influenced by field conditions but did not vary with soil colour or levels of shade. Their average height varied among fields, probably varied with soil colour, and was not influenced by levels of shade. Two months after sowing, 20% of the sowing sites had at least one seedling. Five years later, 63% of those seedlings had died, leaving 7.4% of the sowing sites occupied by a seedling. Seedling height at 58 months varied from 0.3 to 8 m, averaging 2.7 m. Remarkably, none of the 212 seedlings observed showed indications of damage by *H. grandella*, and the cost of the technique is minimal. *Milpa* fields in their last cropping year seem to be promising sites for regenerating mahogany from seed in a mixed species tropical forest context.

Keywords: *Hypsipyla grandella*, *Swietenia macrophylla*, mahogany, regeneration, sylviculture, tropical forest, Mexico.

RESUMEN

Supervivencia y crecimiento de plantíos de semilla de *Swietenia macrophylla* sembrados en campos de tala y quema de Quintana Roo, Mexico

Un problema clave en la gestión de aprovechamiento madedero es asegurar la regeneración de las especies con valor comercial, lo que requiere un considerable conocimiento de las especies que se gestionan, como la *Swietenia macrophylla* King (caoba). Este artículo proporciona los resultados de la plantación directa de caoba en tres campos de tala y quema durante su último año de cosecha en Betania, Quintana Roo, México. En cada campo, 121 lugares de siembra se situaron en una parcela de 0,25 ha, y se sembraron cinco semillas en cada uno. 2, 11, 23, 38, 45 y 58 meses después de la siembra se registraron la altura, el diámetro y las indicaciones de daños por la *Hypsipyla grandella* de todas las semillas que brotaron. Se anotaron las zonas de sombra y el color del suelo. A los 11 meses, la mortalidad entre los pimpollos que estaban vivos a los 2 meses variaba entre campos, pero no variaba con los niveles de sombra o los colores del suelo. Un campo fue abandonado después de 11 meses porque no se siguieron los protocolos de investigación. Comparando los pimpollos vivos a 58 meses con pimpollos vivos a los 2 meses, pero muertos a los 58 meses, el porcentaje de supervivencia varió entre campos y según los niveles de sombra, pero no varió con los colores del suelo. Las condiciones del campo influyeron en el diámetro promedio para pimpollos vivos a los 58 meses, aunque el diámetro no varió con los colores del suelo ni con los niveles de sombra. La altura media variaba entre campos, probablemente variaba con los colores del suelo, y no estaba influida por los niveles de sombra. Dos meses después de sembrar, el 20 % de los lugares de siembra tenían al menos un pimpollo. Cinco años después, el 63 % de estos pimpollos habían muerto, dejando el 7,4 % de los lugares de siembra ocupados por un pimpollo. La altura de los pimpollos a los 58 meses variaba entre 0,3 y 8 m, con un promedio de 2,7 m. Destaca que ninguno de los 212 pimpollos observados mostraba indicaciones de daños por *H. grandella*, y que el coste de la técnica es mínimo. Los campos *Milpa* en su último año de cultivo parecen ser un lugar prometedor para regenerar caoba desde la semilla en condiciones de bosque tropical con mezcla de especies.

Palabras clave: *Hypsipyla grandella*, *Swietenia macrophylla*, caoba, regeneración, silvicultura, bosque tropical, México.

Introduction

The continuous management of forests for timber production depends upon ensuring regeneration and adequately fast growth of commercially valuable species for subsequent harvest (Smith *et al.*, 1997). This requires a good understanding and knowledge of the forest and commercial timber species being managed. With few exceptions, tropical forests are characterized by complex mixtures of hundreds of species, of which a small number are commercially valuable (Foggie, 1960; Peña-Claros *et al.*, 2008). In addition, some species, often commercially important ones, are relatively common in the canopy but are scare or rare in the understory (Pancel, 1993; Peña-Claros *et al.*, 2008; Toledo-Aceves, 2009; Negreros-Castillo and Martínez-Salazar 2011). This is the case for bigleaf mahogany, *Swietenia macrophylla* King, in natural forests of the Yucatan Peninsula in Mexico (Pennington and Sarukhán, 2005).

Bigleaf mahogany (mahogany) is the most important tree species commercially in tropical America, and for centuries, its timber has been one of the most valuable in the world. In the tropics, when the focus of forest management is on harvesting valuable species without regenerating them, conversion of forests to other ecosystems can be accelerated (Fredericksen and Putz, 2003). Mahogany is so important that it could be considered a “financial” keystone species because its absence increases the likelihood of conversion of a forest to another, more profitable land use (Negreros-Castillo *et al.*, 2016). The presence of mahogany encourages landowners to protect their forests and use them for timber production rather than convert them to other uses, such as pasture, the most common land use conversion in the tropics (Buschbacher, 1986; Strassburg, 2014; Brenner, 2011; pers. obs. in Quintana Roo, Mexico).

Some of the earliest reported techniques to regenerate mahogany are “tree improvement, bush improvement, and repeated seedling improvement on mahogany regeneration and growth” (Stevenson terminology) (Stevenson, 1927) in the tropical forests of Belize and were generally found to be unsuccessful, except for “repeated seedling improvement” applied to sites with abundant mahogany seedlings. Although abundant mahogany regeneration was noted in some abandoned slash and burn fields, it was never pursued as a silvicultural technique (Stevenson, 1927). Lamb (1966) and Mayhew and Newton (1998) stated that mahogany is an intolerant species which is consistent with Stevenson’s observations and seems to indicate that creation of conditions with high-light levels and low competition should be a logical way to promote mahogany regeneration.

For many years, however, intensive silvicultural treatments (for example, large clearings that promote high light levels) were socially unacceptable and discouraged. As a result, creation of high light conditions was erroneously sought through low impact silvicultural treatments (LIST). In 1986, a study to evaluate the impact of basal area reduction on mahogany regeneration in Quintana Roo found that initial natural mahogany regeneration was very abundant (Negreros-Castillo and Mize, 1993), but 10 years after the removal few mahogany seedlings were alive (pers. obs., unpublished data). In another experiment, mahogany and Spanish cedar, *Cedrela odorata* L., seeds were sown under gaps created by extraction of trees used to produce railroad ties. Gaps closed in about two years, and the seedlings died (Negreros-Castillo and Mize, 2008). A similar study in Belice found that gap sizes had shrunk 90% within 4 years (Snook *et al.*, 2005)

Since 1985, the Mexican government has required enrichment planting as a LIST and a way to replenish harvested trees, including mahogany, since seedling are planted in the forest as left after harvesting. An evaluation of an enrichment planting program done by a forestry organization in Quintana Roo showed that seedlings planted on landings (large openings normally created using heavy machinery which removed all vegetation) performed better than those planted under a forest canopy and in trails created during harvesting (Negreros-Castillo and Mize, 2003); however, landings represent less than 1% of the harvesting area and in general logging for only a few species create insufficient disturbance to regenerate mahogany (Whitman *et al.*, 1997). One can conclude that LIST do not favor regeneration of mahogany and probably many other important intolerant commercial species and that large clearings need to be created to achieve abundant regeneration of mahogany (Whitman *et al.*, 1997; Mayhew and Newton, 1998; Peña-Claros *et al.*, 2008; Negreros-Castillo *et al.*, 2014) which will help to deter the conversion of forests to other land uses.

Photo 2.
Mahogany seedling (80 cm tall) with surrounding vegetation. Tall vegetation in background is outside the slash and burn field. The two men are participating farmers.
Photo P. Negreros-Castillo.

Photo 3.
Mahogany seedling (3 m tall). Note seedling is in narrow opening used for accessing seedlings and surrounding vegetation is of a similar height.
Photo P. Negreros-Castillo.

In 1996, Stevenson's observations about slash and burn agriculture (SBA) and mahogany regeneration were tested in the first experiment that created relatively large openings (0.5 ha) to compare regeneration after four treatments, one of which was SBA (Negreros-Castillo *et al*., 2003; Snook and Negreros-Castillo, 2004). Although SBA proved to be the best treatment to regenerate mahogany from seeds and seedlings, number of seedlings from seeds was low, arguably because seeds sown at the beginning of the experiment did not germinate and seeds were sown again the next year (1997) when plots had one year's growth of secondary vegetation (Negreros-Castillo *et al*., 2003). Thus, direct seeding during the year of abandonment of a SBA field still had not been tested. This paper reports results of direct seeding of mahogany during the year of abandonment of the field.

SBA has been used in the Maya region of the Yucatan peninsula for more than 3,000 years, and it is the most widely distributed disturbance in mahogany forests (Ford and Nigh, 2010). In SBA, farmers clear 1 to 2 ha of forest, cultivate crops for about 3 years, and then abandon them for 7 to 12 years. Fallow is basically a process of natural secondary succession and forest reestablishment. Mahogany populations in the Yucatan Peninsula exhibit strong spatial correlations in their size distributions because of the patchy nature of suitable regeneration conditions in time and space created by abandoned SBA fields. For thousands of years forests of the Yucatan peninsula have been under a constant process of cycling from forest to agriculture field then back to forest (Ford and Nigh, 2010; Peters, 2000).

For many years, planting bagged seedlings has been the primary regeneration technique for mahogany (Mayhew and Newton, 1998; Mexal *et al*., 2005), but direct seeding has a significant advantage operationally because two mahogany seedlings ready for planting weigh about 1 kg, and 1,300-3,500 mahogany seeds weigh about 1 kg (King, 1886; Parraguirre-Lezama, 1992). As SBA sites are often a considerable distance from any road, sowing seeds is far easier, and under similar growing conditions, planted seedlings and mahogany seedlings from seeds are about the same height in only two years (Navarro-Cerrillo *et al*., 2011).

Materials and Methods

Study area

The study was conducted in the state of Quintana Roo, Mexico, located on the eastern side of the Yucatan Peninsula. Classified as seasonal tropical forests, forests of central and southern Quintana Roo are the most important type of tropical forest in Central America. *Brosimum alicastrum* (ramón blanco) and *Manilkara zapota* (chicozapote) are the most abundant tall trees (Pennington and Sarukhán 2005; Negreros-Castillo *et al*., 2014). For centuries, vegetation in the Yucatan peninsula has been significantly impacted by hurricanes, fires, and SBA activities (Edwards, 1986; Ford and Nigh, 2010). Climate is classified as Aw, which is defined as warm and submoist with abundant rains in summer and dry winters by the Köppen classification system, modified by García (1973). With a 5 to 6-month dry season, annual rainfall totals about 1,200 mm, usually falling between June and October (INEGI, 2013). Soils are derived from limestone, and Rendolls is the most common type (Bautista and Zinck, 2010). With a rolling profile that creates diverse micro soil-site conditions, topography is relatively flat (INEGI, 2013).

The study was established in 2012 in the forestry community of Betania, located near the center of Quintana Roo (figure 1). Betania owns 10,800 ha of tropical forest, and in 1985 it assigned 5,800 ha of forest to diverse types of management including SBA, and the remaining 5,000 ha were put under commercial timber management. The study was established in a portion of the forest that is used for SBA. The study site was also used for a study on mahogany seed predation (Negreros-Castillo *et al.,* 2016).

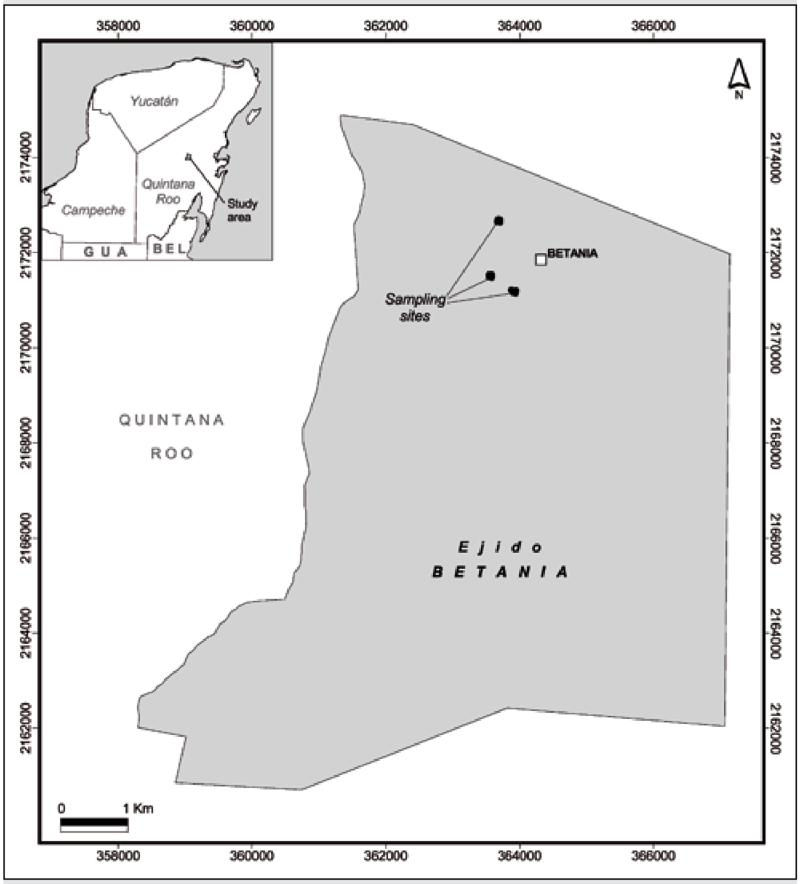

Figure 1.
Location of the community (ejido) of Betania, Quintana Roo, Mexico.

Experimental design

Three farmers in Betania, each with a SBA field that was in its last year of use for crop production and that would not be farmed for at least the next 10 years, agreed to participate in the study. The three SBA fields, which served as experimental blocks called SBA1, SBA2, and SBA3, were at least 500 m apart and surrounded by secondary vegetation that was about 18 m tall, and, according to the farmers, was 16-18 years old. In the middle of each field, a 50 x 50 m (0.25 ha) plot was established.

In each 0.25 ha plot 11 rows 5 m-apart were established, and in each row 11 points that were 5 m-apart were located. At each point five mahogany seeds were buried in a diamond shape for a total of 121 sowing points (in eleven rows) with a total of 605 seeds. Mahogany seeds, which had been soaked in water for 24 hrs, were sown on July 16-18, about 20 to 30 days after corn had been sown and had grown to about 20 to 50 cm tall, depending upon the milpa. Seeds were from capsules removed from crowns of good quality mahogany trees on a commercially managed forest 10 km from Betania in March 2012. Seeds were stored in paper bags in a refrigerator (above 0°C). A strip about 0.5 m wide was kept cleared along each of the 11 rows for easier access to each sowing site for repeated measurements. Farmers were told to remove competition around corn plants as they typically do but were told not to remove competition from around mahogany seedlings unless it was competing with the corn.

After seedlings emerged, height and any indication of damage caused by *Hypsipyla grandella* were recorded at 2, 11, 23, 38, 45, and 58 months after seed were sown. Basal diameter was recorded also until seedlings reached a height of 1.30 m, at which time diameter was measured at a height of 1.3 m. At 2 months, the level of shade each seedling received was evaluated using three categories: 100% - planting sowing site was completely surrounded by vegetation; 50% - half of an imaginary 50 cm diameter circle around the sowing site had vegetation and half had none, and 0% - there was no vegetation at all around the mahogany seedling in an imaginary 50 cm circle. Soil color, using the Munsell color chart, was recorded when seeds were planted. Only two soil colors were found: 7.5 R 2.5/1 (Reddish Black, referred to as RB) and 7.5 R 2.5/2 (Very Dusky Red, referred to as VDR). Color is a good indicator of soil properties in the Yucatan Peninsula (Bautista and Zinck, 2010).

Analysis

Average survival, diameter, and height of all live seedlings were calculated for each measurement on each milpa, and those values were analyzed with analysis of variance (ANOVA) using milpa as blocks and soil color and shade level as treatments. Survival data were transformed using the arcsine to make the variances more homogeneous (Snedecor and Cochran, 1989), but the resulting P values were changed only slightly, so the untransformed mortality data were analyzed. A few ANOVAs were done with individual milpa data using individual measurements and treating soil color and shade level as treatments. Analyses were done with SAS (1990).

Results

Of 605 seeds sown in each milpa 18%, 21%, and 21% emerged for milpas SBA1, SBA2, and SBA3, respectively. The number of live seedlings and their characteristics by age, averaged over the three milpas, are listed in table I. For seedlings located 2 months after sowing, mortality 11 months after sowing varied among milpas ($P = 0.032$) but not among levels of shade ($P = 0.46$) or between soil colors ($P = 0.98$), and there was no shade level by soil color interaction ($P = 0.87$) (table II). Comparing average height and diameter at two months of seedlings that had died by 11 months to the average height and diameter at two months of survivors at 11 months indicated diameter varied among milpas ($P = 0.008$) and that height might have varied among milpas ($P = 0.086$) but soil color, level of competition, and their interaction had no influence ($P \geq 0.16$).

To study seedling mortality between months 2 and 11 more deeply, ANOVA was done separately for each milpa (table III). For milpa SBA1, shade level was close to significantly different ($P = 0.069$) while soil color and the interaction of the two had no affect ($P \geq 0.10$). For milpa SBA2, shade level influenced mortality ($P = 0.040$) but not soil color or the interaction of the two ($P \geq 0.51$), and milpa SBA3 had similar results with $P < 0.001$ for shade level and $P \geq 0.43$ for soil color and the interaction of the two.

Comparing seedlings alive at 58 months to those that were alive at two months but had died by 58 months, percentage survival varied among milpas (P = 0.001), gave an indication of a difference among shade levels (P = 0.098), and did not vary among soil colors (P = 0.29). There was no soil color by shade level interaction (P = 0.33). In milpa SBA1 93% of seedlings found at 2 months had died by 58 months, compared to 56% and 73% for milpas SBA2 and SBA3, respectively (table II).

The number of live seedlings after 58 months was 8, 60, and 41 for SBA1, SBA2, and SBA3, respectively. The number of seedlings in SBA1 was so low compared to the other two milpas, likely due to the farmer of SBA1 not following the research protocol (discussed later), that data from SBA1 were not included in the rest of the analyses, except as noted.

Of seedlings alive at 58 months in SBA2 and SBA3, average diameter was influenced by milpa (P = 0.006) but not by soil color (P = 0.17) or shade level (P = 0.14), and

Table I.
Number of live seedlings, average number of seedlings per sowing site (st. dev) and average, minimum and maximum diameter and height by age for the three milpas combined.

Age (months)	Number live seedling	Seedlings per sowing site	Diameter (mm) Average	Min	Max	Height (cm) Average	Min	Max
2	361	1.6 (0.9)	0.4	0.1	1.8	11	2	24
11	212	1.4 (0.7)	1.7	0.1	6.6	22	9	160
23	139	1.4 (0.7)	6.8	1.0	19	89	10	290
38	121	1.4 (0.7)	10	1.0	39	130	17	420
45	120	1.4 (0.8)	15	2.0	51	160	18	500
58	109	1.4 (0.8)	20	4.0	54	270	34	800

Table II.
Number of live seedlings 2, 11, and 58 months after sowing and percentage mortality from 2 to 11 months and 2 to 58 months by milpa of 605 seed sown at 121 sites

Milpa	Number of seedlings at 2 months	Number of seedlings at 11 months	% dead (2 to 11 mos.)	Number of seedlings at 58 months	% dead (2 to 58 mos.)
SBA1	106	40	62	8 (32/ha)	92
SBA2	130	98	24	60 (240/ha)	59
SBA3	125	74	41	41 (164/ha)	67

Table III.
Percentage mortality for mahogany seedlings between 2 and 11 months after sowing by milpa and shading level within each milpa.

Shade Level	SBA1 Number of seedlings	SBA1 % dead	SBA2 Number of seedlings	SBA2 % dead	SBA3 Number of seedlings	SBA3 % dead
0	46	56 a*	58	36 a	77	53 a
50	32	59 a	48	17 ab	41	24 ab
100	28	75 a	21	14 b	7	0 b

* Mean separation with Duncan's multiple range test (p=0.05) done for each milpa.

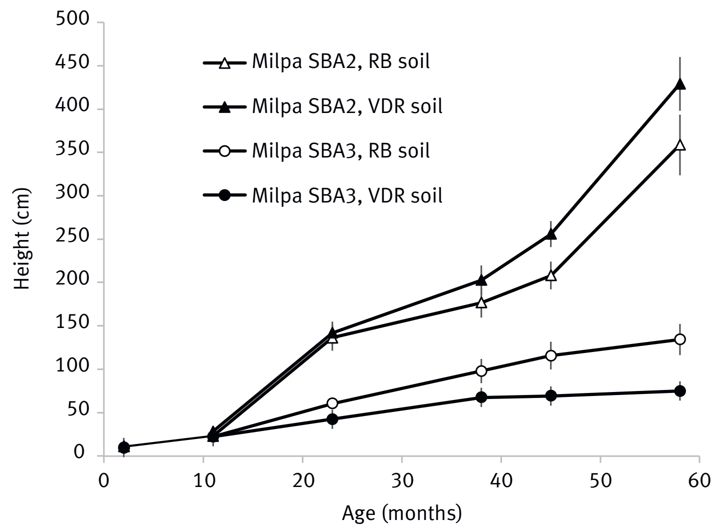

Figure 2.
Average height of seedlings by age and soil classification for milpas SBA2 and SBA3. Soil type RB is 7.5 R 2.5/1 and type VDR is 7.5 R 2.5/2 in the Munsell system. Vertical lines are for +/- 1 SE for each average.

there was no soil color by shade level interaction (P = 0.64). Average height at 58 months did not vary between milpas (P = 0.16), between soil colors (P = 0.67), or among shade levels (P = 0.64), and there was no soil color by shade level interaction (P = 0.79).

Based only on trees alive at 58 months, average height of seedlings by age for the two soil colors for milpas SBA2 and SBA3 is shown in figure 2. Height growth by soil type was quite different for the two milpas. Regression analyses of height on age (not shown) indicated that mahogany on RB soils grew faster than on VDR soils for milpa SBA3 (P ‹ 0.001), but for milpa SBA2 mahogany height growth was not different for the two soils (P = 0.20) with the seedlings on RB averaging less growth, though not significantly less, than on VDR (figure 2). Average diameter followed similar trends. On milpa SBA2 47% of seedlings had soil color RB and 53% VDR, and on milpa SBA3 68% of seedlings had soil color RB and 32% VDR.

Based on the three milpas, overall average percentage of sowing sites with one or more seedlings established at 2 months was 20%. Five years later, using only SBA2 and SBA3, 63% of seedlings found at 2 months had died which would leave 7.4% of the original sowing sites occupied by a seedling.

The effect of *H. grandella* was not observed on any seedlings in the three milpas in any measurements up to 58 months (table I).

Discussion

In a previous study of mahogany seeds sown into slash and burn fields one year after abandonment in Quintana Roo, seedlings averaged 65 cm in height at 49 months (Negreros-Castillo *et al.*, 2003) while in this study seedling height averaged 170 cm at 45 months. Shorter height for the other study could be due to differences in site quality and/or weather, but the impact of seed being sown a year and a half later relative to the time the field was abandoned should be substantial (Brown *et al.*, 2003). This would likely result in considerably more competition and less growth for those seedlings than seedlings in this study, in which seeds were sown 20 days after corn was sown during the last cropping year. In natural conditions, mahogany seedlings (‹ 25 cm height) reach an average height of 25 cm in 8 years (Navarro-Martínez, 2015).

The effect of shade level on height growth likely varies with the difference between the height of a mahogany seedling compared to the height of vegetation around it. As mahogany is shade intolerant, those seedlings with heavy shade will likely grow slowly and eventually die. In a natural forest near the study area, survival of a cohort of mahogany seedlings was 4% after 8 years. To increase the likelihood of survival and the number of mahogany per hectare and to increase height growth rate of seedlings, we will study the impact of releasing seedlings from competition and increasing the number of seeds sown to cope with the unpredictable secondary vegetation.

An important result was related to the farmer of SBA1 whose data were eliminated from analyses after month 2. The three farmers were instructed to not clear plants around mahogany seedlings unless they would impact corn growth, but one decided to clear around mahogany because that always had been done when trees were being cultivated. What his action seems to have demonstrated is that young seedlings need some shading, likely to reduce evapotranspiration and/or just provide some shade from the sun. The mortality of seedlings on SBA1 was 62% between the measurement at 2 and 11 months compared to 24% and 41% for the other two farmers (P = 0.037). For the analysis across milpas, shade level did not affect mortality during that period (P = 0.30), but mortality was highest for 0% shade, 47%, versus 28% and 31% for 50% and 100%, respectively. Additionally, the analyses done separately for the milpas SBA2 and SBA3 showed significantly less mortality for 50% and 100% shade than for 0% shade.

The most exciting result was to find that 0 of 109 seedlings alive at the end of the study and 0 of the 99 that died since month 11 of the study showed signs of *Hypsipyla grandella* because attacks by various species in the *Hypsipyla* genus are a major problem for almost all mahogany plantations (Mayhew and Newton, 1998). Attack by *H. robusta* has been shown to be reduced by shading (Mahroof *et al.*, 2002; Opuni-Frimpong *et al.*, 2008). While height of

Photo 4.
Farmers and researchers who attended the first workshop on sowing mahogany seed into slash and burn fields that are about to be abandoned.
Photo C. W. Mize.

surrounding vegetation was not measured, observations by the second author were that mahogany were often about the same height as surrounding vegetation, which would imply that many seedlings' leaves were shaded while the top of the seedlings was not. Thus, shading might be a reason for reduced attacks. Another reason could be that the abundance of surrounding vegetation made it more difficult for *H. grandella* to find mahogany. Typically, mahogany plantations receive intensive weed control that eliminates all trees and large shrubs, creating a park-like condition with mahogany seedlings clearly visible. The sowing areas in this study had thousands of trees and shrubs per hectare, making mahogany less conspicuous.

A new silvicultural system (Peninsular Silvicultural Method) has been developed for the "mahogany forests" of Quintana Roo that proposes Slash and Burn Agriculture as one of the regeneration techniques for mahogany. Some of the bases for developing the systems are in Negreros-Castillo *et al.* (2014). The system seeks to improve the value of the forest by improving the composition and quality of the trees while maintaining species diversity (Unpublish information). As shown in this study, sowing mahogany seed and likely seed from other desirable species into the slash and burn field during the last year of cropping is a promising technique to substantially improve the composition towards high-value timber species.

Aside from being an effective technique to regenerate mahogany, sowing its seed into a recently abandoned slash and burn field has a significant advantage as part of a management system in that it substantially reduces establishment costs. Keeping start-up costs low is very important to prevent costs from exceeding financial benefits (Keefe *et al.*, 2012). Generally, the largest cost in managing a forest and the one that must be carried the longest is precisely establishment cost. Sowing seed into a field that has already been cleared for another use is far cheaper than any establishment technique except for doing nothing, which will result in a tract with no mahogany. If damage from *H. grandella* is reduced close to as much as observed in this study, that would substantially increase the profitability of growing mahogany. These results should be applicable in many countries where mahogany is grown and would likely work with *Cedrela odorata* L. (Spanish cedar), another very valuable tree species that is difficult to regenerate.

Sowing mahogany seed into slash and burn fields has an advantage for adaptation in that farmers in areas, such as Quintana Roo, have used slash and burn for thousands of years, although never to regenerate mahogany. As a financial keystone species, successfully regenerating mahogany may help to make forest management economically attractive for owners and thereby deter forest conversion to other land uses.

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