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**Mahogany (*Swietenia*) Trials in Haiti:  
1989–1996**

**by**

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## RESUME

Ce document résume les résultats de 5 ans de recherches sur l'acajou (*Swietenia*) en Haïti. Ces essais font partie d'un programme plus large d'amélioration génétique forestière qui a été implanté sous l'égide du Projet d'Agroforesterie II (1988-1991) financé par l'USAID et qui s'est poursuivi sous le Projet PLUS (de 1992 à nos jours). Les progénitures de *S. mahogani* et *S. macrophylla*, sélectionnées pour l'excellente forme de l'arbre, ont été établies dans 2 vergers et 4 arboreta en 1990-1991. Trois lots de semences de l'hybride *S. macrophylla* x *S. mahogani* ont été importés de Porto-Rico et de Ste Croix pour comparer leur survie et leur croissance à celles des progénitures sélectionnées des espèces parentales. Les provenances de *S. macrophylla* et *S. humilis* ont été importées de Costa Rica et comparées pour la survie et la croissance sur 2 sites dans le sud-ouest du pays.

### Survie

Après 5 ans d'établissement des essais, le taux de survie pour le site, tant pour le *S. macrophylla* que pour le *S. humilis*, a été plus élevé à Bérault (59%) qu'à Labordette (38%). Des différences statistiques ont été détectées entre les espèces à 1 et 3 ans à Labordette et à 1 an à Bérault. Aux deux sites, le *S. humilis* a montré un taux de survie plus élevé que le *S. macrophylla*. Cette supériorité a toujours persisté après 5 ans, bien qu'aucune différence statistique à 0,05 de probabilité n'ait été observée.

L'hybride du *S. macrophylla* x *S. mahogani* a accusé un taux de survie plus élevé, comparé aux espèces parentales tant à Roche Blanche que dans les vergers producteur de graines de Marmont, mais s'est classé le dernier des 3 à l'arboretum de Marmont. En comparant les deux espèces parentales, le *S. mahogani* a mieux survécu que le *S. macrophylla* dans quatre des cinq essais (Fauché, arboretum de Marmont, Paillant et Roche Blanche). Au stade de 3 ans, l'hybride a accusé une survie moyenne de 57%, variant de 51% à 67%. La moyenne correspondante pour *S. mahogani* a été de 62%, passant de 38% à 82%. *S. macrophylla* a donné une moyenne de 42%, allant de 24% à 58%. Les sites testés sont situés dans l'aire de distribution naturelle de *S. mahogani* en Haïti.

Les différences de survie entre les familles ou lots de semences ont beaucoup varié dépendant du site. La survie des familles de *S. mahogani* a varié de 0% à 91% pendant 3 ans; celle de *S. macrophylla* de 0% à 100%; celle de l'hybride de 27% à 100%. Des différences de survie n'ont pas pu être analysées au niveau de la famille ou de lot de semences parce que les vergers et arboreta n'ont pas été conçus pour tester de telles différences.

### Croissance en Hauteur

Il n'y a eu aucune différence significative dans la croissance en hauteur entre le *S. humilis* et le *S. macrophylla* après 5 ans à Bérault et à Labordette. La seule différence s'est manifestée à Labordette après la première année de croissance avec le *S. macrophylla* 2469 qui a

montré une légère supériorité sur le *S. humilis* 2470. Le site humide de basse altitude (Bérault) a accusé une croissance moyenne en hauteur de 7,1 m après 5 ans, comparé à 4,4 m au site montagneux (Labordette). Les différences de profondeur de sol et d'humidité expliquent largement les taux de croissance plus rapides observés à Bérault.

L'hybride a accusé des taux de croissance annuelle de 1,0 m/an et 1,2 m/an à Roche Blanche et Marmont, respectivement, pendant les trois premières années. Il n'a pas montré de différence statistique avec les familles des espèces parentales au verger de Roche Blanche. Il s'est montré inférieur pour la croissance en hauteur comparé aux familles tant du *S. macrophylla* (486) que du *S. mahogani* (465) à l'arboretum de Marmont après 1 an, mais pas à 3 et 5 ans. Au verger à graines de Marmont, la seule famille qui ait montré une croissance en hauteur supérieure à celle de l'hybride, a été le *S. macrophylla* (487) à 1 an. Pour les années suivantes, il n'y a pas eu de différence significative entre les familles des espèces parentales et l'hybride.

Des différences significatives de croissance en hauteur entre le *S. macrophylla* et le *S. mahogani*, ont été observées à Fauché, le site le plus humide, pour toute la période de 5 ans des essais. *S. macrophylla* a accusé une hauteur moyenne de 10,6 m, contre 5,7 m du *S. mahogani*. Aucune différence dans la croissance en hauteur entre les deux familles de *S. mahogani* n'a été détectée. Les autres essais, établis sur les sites plus secs, n'ont révélé aucune différence entre les 2 espèces. Cependant, des différences ont été détectées entre certaines familles de chaque espèce à Marmont et à Paillant. *S. macrophylla* 486 a manifesté la meilleure croissance en hauteur de famille issue d'un seul arbre à Marmont, significativement meilleure que 5 autres familles de *S. macrophylla* (482, 483, 487, 489 et 497) et une famille de *S. mahogani* (466) après 3 ans de croissance. La croissance moyenne en hauteur de la progéniture de *S. macrophylla* a varié entre 2,1 m et 6,0 m - une différence de 186% - comparée à une variation moins grande de 3,7 m à 4,2 m - une différence de 14% - pour le *S. mahogani* à l'arboretum de Marmont après 5 ans. Le *S. macrophylla* 497 a montré une meilleure croissance que le *S. macrophylla* 494 à Paillant après 3 ans - différence significative à 0,05 de probabilité.

### Croissance en Diamètre

Des différences ont été décelées entre les provenances de *S. humilis* et de *S. macrophylla* à Bérault, mais pas entre les 2 espèces. *S. humilis* 2470 a accusé le dhp moyen le plus élevé (11,6 cm) après 5 ans, ce qui est statistiquement différent du *S. macrophylla* 2469 (9,0 cm), mais pas des 2 autres provenances. Cette différence a été aussi observée pour le diamètre basal (15,5 cm versus 13,0 cm). Exactement la tendance contraire a été observée à Labordette. *S. macrophylla* 2469 a accusé une croissance de tige significativement supérieure à celle de *S. humilis* 2470 après 5 ans, tant pour le dhp que pour le diamètre basal. Après 5 ans, l'essai de Bérault a donné une moyenne de croissance en dhp environ deux fois supérieure à celle des arbres à Labordette (10,5 cm versus 5,6 cm).

Le taux de croissance moyenne en dhp de l'hybride après 3 ans a été de 1,0 cm, 1,1 cm et 1,3 cm au verger de Roche Blanche, à celui de Marmont et à l'arboretum de Marmont,

respectivement. La croissance en diamètre de tige a été stagnante pendant les 4ème et 5ème années à cause de sécheresses sévères et de la compétition des mauvaises herbes dans l'essai pendant la période 1994-95. Les différences en dhp et diamètre basal n'ont pas été significatives entre l'hybride et les espèces de *S. mahogani* et *S. macrophylla*.

Les essais qui ont montré la meilleure croissance (à Fauché et à l'arboretum de Marmont) ont été les seuls essais qui ont accusé des différences statistiques entre les familles de *S. mahogani* et de *S. macrophylla*. Le dhp moyen de *S. macrophylla* à Fauché a été de 11,4 cm après 5 ans, équivalent à un taux de croissance moyenne annuelle de 2,3 cm. Ce résultat a été significativement meilleur que le dhp moyen de *S. mahogani* (7,0 cm). A l'arboretum de Marmont, le *S. macrophylla* 486 a été classé le premier parmi les familles d'acajou après 5 ans, avec un dhp moyen de 7,1 cm. Des différences significatives ont été décelées entre cette famille et le reste des génotypes de *Swietenia* à 0,05 de probabilité. Le *S. macrophylla* 489 a été classé comme la meilleure famille d'acajou du verger pendant la même période avec un dhp moyen de 6,8 cm. Il n'y a pas eu de différences significatives entre les familles du verger après 5 ans à 0,05 de probabilité.

### **Volume marchand**

Le site de Bérault produit 3 fois plus de volume de bois scié de qualité que celui de Labordette. La moyenne du site par arbre, y compris les deux espèces *S. humilis* et *S. macrophylla*, a été approximativement de  $5,77 \times 10^{-2} \text{ m}^3$  à Bérault et  $1,73 \times 10^{-2} \text{ m}^3$  à Labordette. A Bérault, il n'y a pas eu de différence significative entre le *S. humilis* ( $5,7 \times 10^{-2} \text{ m}^3$  par arbre) et le *S. macrophylla* ( $5,6 \times 10^{-2} \text{ m}^3$  par arbre). La provenance la plus productive a été le *S. macrophylla* 1982 ( $6,8 \times 10^{-2} \text{ m}^3$  par arbre) et la moins performante a été le *S. macrophylla* 2469 ( $4,3 \times 10^{-2} \text{ m}^3$  par arbre). Il n'y a pas eu de différences significatives entre les provenances à aucun des sites. Les provenances qui ont atteint la meilleure croissance en hauteur et en diamètre ont été aussi celles qui ont donné le volume de bois marchand le plus élevé.

*S. macrophylla* produit 3 fois plus de volume de bois scié de qualité que le *S. mahogani* à Fauché, sur une base par arbre. Cependant, cette différence diminue au double du volume, sur une base par hectare, à cause du plus bas taux de survie du *S. macrophylla*. Les différences de rendements en volume entre les 2 familles du *S. mahogani* n'ont pas été significatives à 0,05 de probabilité.

### **Recommandations**

Bien que le financement par l'USAID de la section d'amélioration génétique forestière ait pris fin, il reste encore beaucoup à faire pour protéger le riche héritage de l'acajou, et pour restaurer la population de cette source de bois précieux en mettant à la disposition des fermiers et des propriétaires terriens, des semences de génotypes sélectionnés. Les activités suivantes sont recommandées pour éviter de perdre les bénéfices de ce qui a été accompli jusqu'ici:

1) Procéder à l'éclaircie sélective des deux vergers à Roche Blanche et Marmont, en éliminant les individus inférieurs et en maintenant une quantité équilibrée d'individus bien formés de chaque génotype. Le croisement entre progénitures des arbres sélectionnés et la production de descendants vigoureux est la première étape dans la production de semences améliorées. La production de semences n'est pas prévue avant l'âge de 12-13 ans (Lamb, 1996) ou avant 2002.

2) Distribuer des lots de semences provenant des vergers en tenant compte des zones écologiques et à travers des pépinières centralisées qui permettent de suivre la trace du germoplasme de sources identifiées. Des semences de *S. mahogani* et des hybrides de *S. macrophylla* x *S. mahogani* devraient être collectées pour les régions forestières humides d'Haiti; celles du *S. macrophylla* et des hybrides pour les zones forestières humides et pluvieuses. Des efforts devraient être faits pour étudier les époques de floraison des arbres des vergers et observer la variabilité de leurs progénitures en pépinière. L'acajou est largement pollinisé par les insectes et par la pollinisation croisée naturelle, mais peut donner une grande quantité de semences par auto-pollinisation (Yang, 1965; Styles et Khosla, 1976). Les vergers devraient être sélectionnés sur la base de la performance des progénitures sur le terrain.

3) Procéder à des éclaircies sélectives des arboreta et des essais de provenances de *S. humilis* et de *S. macrophylla* pour encourager le développement des individus les mieux formés. Ces arbres devraient être sélectionnés sur la base de caractéristiques désirables telles que: 1) forme de tige et volume, 2) résistance aux pestes et aux maladies, 3) couronnes symétriques et rapport couronne idéale:dhp, et 4) survie générale et vigueur. Les provenances de *S. humilis* sont les seuls représentants de l'espèce en Haiti et devraient être observées soigneusement par rapport au *S. macrophylla*. Les provenances de *S. macrophylla* peuvent constituer un important apport à la diversité génétique de l'espèce en Haiti, étant donné que ce qui a été promu en Haiti vient de la base génétique étroite des peuplements établis à Franklin et Bayeux.

4) Si de nouveaux vergers sont établis, sélectionner une large base d'arbres phénotypiquement supérieurs, y compris la seconde génération d'individus dans les arboreta et les vergers, et les propager végétativement via des procédures esquissées dans Howard et al. (1988) et Leakey et al. (1990). La propagation végétative de génotypes sélectionnés réduit les risques d'introduire des complexes de gènes moins désirables résultant du croisement des arbres-mères.

5) Des essais de progénitures, planifiés pour tester de façon optimum les différences génétiques entre les familles, devraient être installés et suivis pour une période de rotation (au moins 20 ans) avec une sélection large de génotypes venant des vergers pour prouver leur supériorité sur les génotypes non sélectionnés. Cette étape est critique pour satisfaire les exigences de semences certifiées. Les critères de qualification du stock génétique pour la certification devraient être clairement définis, aussi bien que les conditions environnementales sous lesquelles un génotype particulier est supposé donner une performance au-dessus de la moyenne. Ces essais peuvent être éliminés plus tard et convertis en vergers producteurs de

graines pour des lignées améliorées d'acajou en Haïti. Ils devraient être établis avec le support du Service des Ressources Forestières, pour répondre aux exigences de sécurité à long terme et de supervision.

6) Contrôler toute régénération naturelle ou plantules venant des vergers pour confirmer le modèle et le degré d'hétérosis (i.e. hybridation) et ses effets sur la survie, les taux de croissance et la forme. La plupart des acajous plantés en Haïti sont des lignées pures de *S. mahogani*. Cependant, la demande pour l'hybride peut augmenter à cause de la supériorité de sa forme et les taux de croissance plus rapides sur les sites testés. Les banques de gènes de lignées pures de *S. mahogani*, sélectionnées à travers Haïti et l'île d'Hispaniola, devraient être établies pour continuer les efforts de conserver le mélange génétique restant d'une espèce économiquement importante, qui a toujours été considérée comme une espèce de bois précieux en Haïti.

7) Informer le Service des Ressources Forestières du MARNDR de l'importance et de l'urgence de développer une stratégie à long terme, intégrant la conservation génétique et l'amélioration du *S. mahogani* comme une espèce indigène de valeur économique. Coordonner le transfert des informations venant d'une série d'organisations internationales impliquées dans la conservation génétique et l'amélioration de l'acajou en Amérique Centrale et dans les Caraïbes. Citons particulièrement les efforts entrepris par CATIE et IITF dans la collaboration avec des universités et des organisations internationales (Glogiewicz, 1986; Newton et al., 1993). Le gouvernement devrait encourager le secteur privé à investir dans la production de produits fabriqués avec du bois d'acajou certifié et de semences avec pour objectif de développer des grandes lignes de gestion qui combinent la conservation et la production.

## SUMMARY

This document summarizes the 5-year results of mahogany (*Swietenia*) trials in Haiti. These trials are part of a larger tree improvement program that was implemented under the USAID-funded Agroforestry II (1988–1991) project and continued during the PLUS (1992–present) project. The progeny of *S. mahagoni* and *S. macrophylla*, selected for their excellent tree form, were established in 2 orchards and 4 arboreta in 1990–1991. Three seed lots of the *S. macrophylla* x *S. mahagoni* hybrid were imported from Puerto Rico and St. Croix to compare their survival and growth with selected progeny of the parent species. *S. macrophylla* and *S. humilis* provenances were imported from Costa Rica and compared for survival and growth at 2 sites in the southwestern part of the country.

### Survival

Site survival after 5 years, including both *S. macrophylla* and *S. humilis*, was higher at Bérault (59%) than at Labordette (38%). Statistical differences were detected between species at the 1- and 3-year stage at Labordette and at the 1-year stage at Bérault. At both sites, *S. humilis* showed a higher survival rate than *S. macrophylla*. This superiority was still evident after 5 years, though not statistically significant at the 0.05 probability level.

The *S. macrophylla* x *S. mahagoni* hybrid exhibited higher survival than either parent species at the Roche Blanche and Marmont seed orchards, but ranked the lowest of the 3 at the Marmont arboretum. Comparing the two parent species, *S. mahagoni* survived better than *S. macrophylla* at four of five trials (Fauché, Marmont arboretum, Paillant, and Roche Blanche). At the 3-year stage, survival of the hybrid averaged 57%, ranging from 51% – 67%. Corresponding means for *S. mahagoni* was 62%, ranging from 38% – 82%. *S. macrophylla* averaged 42%, ranging from 24% – 58%. The sites tested were located within the natural range of *S. mahagoni* in Haiti.

Differences in survival among families or seed lot varied greatly depending on site. Survival of the *S. mahagoni* families ranged from 0% – 91% after 3 years; survival of the *S. macrophylla* families ranged from 0% – 100%; survival of the hybrid seed lots ranged from 27% – 100%. Differences in survival could not be analyzed at the family or seed lot level because the orchards and arboreta were not designed to test such differences.

### Height Growth

No differences were shown in height growth between *S. humilis* and *S. macrophylla* after 5 years at Bérault and Labordette. The only difference occurred at Labordette after the first year of growth with *S. macrophylla* 2469 showing a slight superiority over *S. humilis* 2470. The lowland moist site (Bérault) exhibited a mean height growth of 7.1 m after 5 years compared to 4.4 m at the mountainous site (Labordette). Differences in soil depth and moisture balances largely account for the faster growth rates observed at Bérault.

The hybrid achieved mean annual growth rates of 1.0 m/yr and 1.2 m/yr at Roche Blanche and Marmont, respectively, during the first 3 years. The hybrid showed no statistical difference from the families of either parent species at the Roche Blanche orchard. The hybrid was inferior in height growth to selected families of both *S. macrophylla* (486) and *S. mahagoni* (465) at the Marmont arboretum after 1 year, but not at 3 and 5 years. At the Marmont seed orchard, the only family that showed superior height growth to the hybrid was *S. macrophylla* 487 at 1 year. Subsequent years showed no statistical differences among the families of the parent species and the hybrid.

Significant differences in height growth between *S. macrophylla* and *S. mahagoni* was exhibited at Fauché, the wettest site, throughout the trial period of 5 years. *S. macrophylla* averaged 10.6 m compared to a mean height of 5.7 m of *S. mahagoni*. No difference in mean height growth between the two *S. mahagoni* families was detected. The other trials, established on much drier sites, showed no difference between the 2 species. However, differences were detected between certain families of each species at Marmont and Paillant. *S. macrophylla* 486 exhibited the best height growth of any single-tree family at Marmont, significantly better than 5 other *S. macrophylla* families (482, 483, 487, 489 and 497) and one *S. mahagoni* family (466) after 3 years of growth. Mean height growth of the *S. macrophylla* progeny ranged between 2.1 m and 6.0 m – a difference of 186% – compared to a smaller range of 3.7 m to 4.2 m – a difference of 14% – for *S. mahagoni* at the Marmont arboretum after 5 years. *S. macrophylla* 497 showed better growth than *S. macrophylla* 494 at Paillant after 3 years – significant at the 0.05 probability level.

### Diameter Growth

Differences were shown among *S. humilis* and *S. macrophylla* provenances at Bérault, but not between the 2 species. *S. humilis* 2470 exhibited the highest mean dbh (11.6 cm) after 5 years, which was statistically different from *S. macrophylla* 2469 (9.0 cm), but not the other 2 provenances. This difference was also shown for basal diameter (15.5 cm versus 13.0 cm). The exact opposite trend occurred at Labordette. *S. macrophylla* 2469 exhibited significantly greater stem growth than *S. humilis* 2470 after 5 years for both dbh and basal diameter. After 5 years, the Bérault trial averaged nearly twice the dbh growth as the trees at Labordette (10.5 cm versus 5.6 cm).

The mean annual dbh rate of the hybrid after 3 years was 1.0 cm, 1.1 cm and 1.3 cm at Roche Blanche, Marmont orchard and Marmont arboretum, respectively. Stem diameter growth was stagnant during the 4th and 5th years because of severe droughts and grass competition of the trial that occurred during 1994–95. Differences in dbh and basal diameter were not shown to be significant among the hybrid, *S. mahagoni* and *S. macrophylla* species.

The trials that exhibited the best growth (Fauché and the Marmont arboretum) were also the only trials that showed statistical differences among the *S. mahagoni* and *S. macrophylla* families. The mean dbh of *S. macrophylla* at Fauché was 11.4 cm after 5 years, equivalent to a mean annual growth rate of 2.3 cm. This was significantly better than the mean dbh of *S. mahagoni* (7.0 cm).



At the Marmont arboretum, *S. macrophylla* 486 was the top-ranked mahogany family after 5 years with a mean dbh of 7.1 cm. Significant differences were exhibited between this family and the rest of the *Swietenia* genotypes at the 0.05 probability level. *S. macrophylla* 489 was the top-ranked mahogany family in the orchard during the same time period with a mean dbh of 6.8 cm. No differences were shown among the families in the orchard after 5 years at the 0.05 probability level.

### Merchantable Volume

The Bérault site produced 3 times the volume of lumber quality wood as Labordette. The site average per tree, including both *S. humilis* and *S. macrophylla* species, was approximately  $5.77 \times 10^{-2} \text{ m}^3$  at Bérault and  $1.73 \times 10^{-2} \text{ m}^3$  at Labordette. At Bérault, there was an insignificant difference between *S. humilis* ( $5.7 \times 10^{-2} \text{ m}^3$  per tree) and *S. macrophylla* ( $5.6 \times 10^{-2} \text{ m}^3$  per tree). The highest yielding provenance was *S. macrophylla* 1982 ( $6.8 \times 10^{-2} \text{ m}^3$  per tree) and the poorest production was exhibited by *S. macrophylla* 2469 ( $4.3 \times 10^{-2} \text{ m}^3$  per tree). Differences among provenances were not shown to be significant at either site. The provenances that achieved the best height and diameter growth were also the ones that exhibited the highest merchantable volume.

*S. macrophylla* produced 3 times the volume of lumber quality wood as *S. mahagoni* at Fauché, on a per tree basis. However this difference decreased to double the volume, on a per hectare basis, because of the lower survival of *S. macrophylla*. Differences in volume yield between the 2 families of *S. mahagoni* were not significant at the 0.05 probability level.

### Recommendations

Although USAID support for this tree improvement phase of the PLUS project has ended, much needs to be done to protect Haiti's rich heritage of mahogany, and to restore the population of this valuable lumber source by making seed of selected genotypes available to farmers and land owners. The following activities are recommended to avoid jeopardizing the progress that has been accomplished to date.

- 1) Selectively thin the two seed orchards at Roche Blanche and Marmont by eliminating the inferior individuals and maintaining a balanced number of well-formed individuals of each genotype. The outcrossing of progeny from plus trees and the production of vigorous offspring is the first step in the production of improved seed. Seed production is not forecasted until 12–13 years of age (Lamb, 1966) or 2002.

- 2) Distribute seed lots from the orchards according to life zone considerations and through centralized nurseries that can track source-identified germplasm. Seed should be collected from the *S. mahagoni* and *S. macrophylla* x *S. mahagoni* hybrids for dry and moist forest regions of Haiti; that of *S. macrophylla* and the hybrids for moist to wet forest zones. Efforts should be made to study the flowering patterns of the orchard trees and observe the variability of their progeny in the nursery. Mahogany is largely pollinated by insects and normally outbreeds, but can set a high quantities of seed by self-pollination (Yang, 1965; Styles and Khosla, 1976). The orchards should

be rogued based on the field performance of their progeny.

3) Selectively thin the arboreta and the *S. humilis*/*S. macrophylla* provenance trials to encourage development of the best-formed individuals. These trees should be selected based on desirable characteristics such as 1) stem form and volume, 2) pest and disease resistance, 3) symmetrical crowns and ideal crown:dbh ratio, and 4) overall survival and vigor. The *S. humilis* provenances are the only representatives of the species in Haiti and should be observed carefully vis-à-vis the *S. macrophylla*. The *S. macrophylla* provenances may be an important addition to the genetic diversity of the species in Haiti since most of what has spread in Haiti originates from the narrow genetic base of the stands at Franklin and Bayeux.

4) If additional orchards are established, select a wide base of plus trees, including second generation individuals located in the arboreta and orchards, and vegetatively propagate them via procedures outlined in Howard et al. (1988) and Leakey et al. (1990). Vegetative propagation of a selected genotype reduces the risk of introducing less desirable gene complexes that result from outbreeding of the mother trees.

5) Progeny trials, designed to optimally test for genetic differences among families, should be installed and monitored for a rotation age (at least 20 years) with a wide selection of genotypes from the orchards to prove their superiority over unselected genotypes. This step is critical to fulfill the requirements of certified seed. Characteristics qualifying genetic stock for the level certified must be carefully spelled out, as are the environmental conditions under which a particular genotype is expected to give above-average performance. These trials can later be rogued and converted to seed orchards for improved lines of mahogany in Haiti. They should be established with the support of the Service des Ressources Forestières, satisfying long term security and supervision requirements.

6) Monitor any natural regeneration or seedlings originating from the orchards to confirm the pattern and degree of heterosis (i.e., hybridization) and its effects on survival, growth rates and form. Most mahogany currently cultivated by Haitian farmers are pure *S. mahagoni*. However, demand for the hybrid may increase because of its superior form and faster growth rates on selected sites. Gene banks of pure *S. mahagoni*, selected throughout Haiti and the island of Hispaniola, should be established to continue efforts to conserve the remaining gene pool of a species that has economic importance, but that has been seriously high-graded throughout the history of Haiti.

7) Inform the Service des Ressources Forestière (MARNDR) of the importance and urgency to develop a long-term strategy, integrating genetic conservation and improvement of *S. mahagoni* as a native species of economic value. Coordinate the transfer of information from the wide range of international organizations involved with genetic conservation and improvement of mahogany in Central America and the Caribbean, particularly efforts undertaken by CATIE and IITF in collaboration with universities and international organizations (Glogiewicz, 1986; Newton et al., 1993). The government should encourage private sector investment in the certified production of mahogany wood products and seed with a view of developing management guidelines that combine conservation with production.

## TABLE OF CONTENTS

<b>Resumé</b> .....	<b>i</b>
<b>Summary</b> .....	<b>vi</b>
<b>Acknowledgments</b> .....	<b>xiv</b>
<b>Acronyms</b> .....	<b>xv</b>
<b>Introduction</b> .....	<b>1</b>
<b>Review of Mahogany Research in Haiti</b> .....	<b>2</b>
<b>Objectives</b> .....	<b>3</b>
<b>Methods and Materials</b> .....	<b>3</b>
<b>Site Description</b> .....	<b>3</b>
<b>Seedling Propagation</b> .....	<b>5</b>
<b>Experimental Design and Trial Establishment</b> .....	<b>6</b>
<b>Measured Variables and Observations</b> .....	<b>7</b>
<b>Statistical Analyses</b> .....	<b>8</b>
<b>Results and Discussion</b> .....	<b>8</b>
<b><i>S. humilis</i> and <i>S. macrophylla</i></b> .....	<b>8</b>
<b>Survival</b> .....	<b>8</b>
<b>Height Growth</b> .....	<b>9</b>
<b>Stem Diameter Growth</b> .....	<b>11</b>
<b>Merchantable Volume</b> .....	<b>12</b>
<b><i>S. macrophylla</i> x <i>S. mahagoni</i> Hybrid</b> .....	<b>12</b>
<b>Survival</b> .....	<b>13</b>

<b>Height Growth</b> .....	13
<b>Stem Diameter Growth</b> .....	14
<b><i>S. mahagoni</i> and <i>S. macrophylla</i></b> .....	14
<b>Survival</b> .....	14
<b>Height Growth</b> .....	15
<b>Stem Diameter Growth</b> .....	20
<b>Merchantable Volume</b> .....	21
<b>Conclusions</b> .....	22
<b>Recommendations</b> .....	23
<b>References</b> .....	25
<b>Annex 1a. Characteristics of <i>S. mahagoni</i> plus tree candidates selected in Haiti</b> .....	28
<b>Annex 1b. Characteristics of <i>S. macrophylla</i> plus tree candidates selected in Haiti</b> .....	29
<b>Annex 2. Survival means of <i>S. mahagoni</i>, <i>S. macrophylla</i> and <i>S. macrophylla</i> x <i>S. mahagoni</i> hybrid families and seed lots at various ages and sites in Haiti</b> .....	30
<b>Annex 3. Total height means of <i>S. mahagoni</i>, <i>S. macrophylla</i> and <i>S. macrophylla</i> x <i>S. mahagoni</i> hybrid families and seed lots at various ages and sites in Haiti</b> .....	31
<b>Annex 4. Stem diameter (DBH and <math>D_{0.1}</math>) means of <i>S. mahagoni</i>, <i>S. macrophylla</i> and <i>S. macrophylla</i> x <i>S. mahagoni</i> hybrid families and seed lots at various ages and sites in Haiti</b> .....	32

## LIST OF TABLES

Table 1. Site description of the <i>Swietenia</i> trials in Haiti. ....	4
Table 2. Source information of the <i>S. mahagoni</i> , <i>S. macrophylla</i> and <i>S. humilis</i> germplasm used in this study. ....	5
Table 3. Experimental design of the <i>Swietenia</i> trials in this study. ....	6
Table 4. Survival of <i>S. humilis</i> and <i>S. macrophylla</i> at 2 sites in Haiti. ....	9
Table 5. Height growth of <i>S. humilis</i> and <i>S. macrophylla</i> at 2 sites in Haiti. ....	9
Table 6. Stem diameter growth and wood volume yield per tree of <i>S. humilis</i> and <i>S. macrophylla</i> at 2 sites in Haiti. ....	11
Table 7. Merchantable volume comparisons between <i>S. mahagoni</i> and <i>S. macrophylla</i> after 5 years at the Fauché trial. ....	22

## LIST OF FIGURES

Figure 1. Location of the <i>Swietenia</i> trials in Haiti. ....	4
Figure 2. Height growth of <i>S. humilis</i> and <i>S. macrophylla</i> after 1, 3, and 5 years at Bérault. ....	10
Figure 3. Height growth of <i>S. macrophylla</i> 2469 and <i>S. humilis</i> 2470 after 1, 3, and 5 years at Labordette. ....	10
Figure 4. Height growth of the <i>S. macrophylla</i> x <i>S. mahagoni</i> hybrid, <i>S. mahagoni</i> and <i>S. macrophylla</i> at Roche Blanche and Marmont after 3 years. ....	14
Figure 5. Survival rates of <i>S. mahagoni</i> at various trials in this study. ....	16
Figure 6. Survival rates of <i>S. macrophylla</i> at various trials in this study. ....	16
Figure 7. Variation in height of <i>Swietenia</i> families at the Marmont arboretum after 5 years. ....	17
Figure 8. Variation in height of <i>Swietenia</i> families at the Marmont orchard after 5 years. ....	19
Figure 9. Variation in height of <i>Swietenia</i> families at the Roche Blanche orchard after 5 years. ....	19

**Figure 10. Mean height comparisons of *S. mahagoni* and *S. macrophylla* at various trials in this study** ..... 20

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## ACRONYMS

<b>AFII</b>	Agroforestry II (1989–1991)
<b>AOP</b>	Agroforestry (1981–1987)
<b>CATIE</b>	Centro Agronómico Tropical de Investigación y Enseñanza
<b>IRG</b>	International Resources Group, Ltd.
<b>IITF</b>	International Institute of Tropical Forestry
<b>OFI</b>	Oxford Forestry Institute
<b>PADF</b>	Pan American Development Foundation
<b>PLUS</b>	Productive Land Use System project (1992–present)
<b>SECID</b>	South East Consortium for International Development
<b>USAID</b>	United States Agency for International Development



## INTRODUCTION

*Swietenia mahagoni* (L.) Jacq., known as West Indies mahogany in the international trade and locally as *kajou*, is one of the most beautiful and sought-after woods in the world. The importance of mahogany to the daily lives of Haitians has its roots in history, as the country was one of the best sources of genuine mahogany in the 18th and 19th centuries (Howard, 1951). Haiti banned the export of logs in 1944 to promote local uses and the export of value-added products (Weil et al., 1973). *S. mahagoni* is primarily used today as a source of wood for souvenirs, turnery, and cabinetry, but also as an important medicinal plant and shade (Timyan, 1996). *S. macrophylla*, also occurring to a limited extent in Haiti, is currently the main source in international trade of true mahogany, being exported from countries within its natural range from Mexico to Brazil (Snook, 1996). *S. macrophylla* (King) is known in Haiti as *kajou etranje* (foreign mahogany) or *kajou venezwela* (Venezuela mahogany) to distinguish it from the local species. A review of both species in Haiti is provided in Timyan (1996). A lesser-known and utilized species, Pacific mahogany (*S. humilis* Zucc.), originates from the Pacific coast of Costa Rica to Guatemala, and exists in Haiti only as an experimental introduction since 1989.

The forest resources of Haiti play a greater role in its domestic economy than in any other country in the Caribbean. The value of the timber sector increased considerably during a 30-year period (1961–1989), rising from \$84 million to \$136 million and representing 10% of the GDP (Dallmeier and Delvin, 1992). The main uses are for fuel, house construction, souvenirs and cabinetry, with mahogany providing reasonable share depending on end use (Barkley, 1983). But the costs are great, as Haiti has also the highest rate of deforestation in the Caribbean (3.8%) and the lowest forest area per capita (0.01 ha).

The uncontrolled harvesting of the popular *S. mahagoni* inevitably leads to genetic erosion resulting from the selective harvesting of the most marketable individuals (Pennington, 1981; Styles and Khosla, 1976). Gene complexes associated with superior form and adaptation are lost, turning a once renewable resource to an exhausted one, akin to mining. Despite the long history of a lucrative international trade in true mahogany, relatively small investments in genetic conservation and tree improvement have been realized in its native range (Newton et al., 1996). It wasn't until 1988, under the USAID-funded Agroforestry II Project, that an effort was initiated to select superior trees of both *S. mahagoni* and *S. macrophylla* and establish their progeny in a series of orchards and arboreta in Haiti (Dvorak, 1989; Timyan, 1993). Progeny of 11 superior trees were established in 3 arboreta and 2 seed orchards in Haiti between 1989–1991 and measured for survival, height and stem diameter parameters. Three seed lots of the *S. macrophylla* x *S. mahagoni* hybrid were also established at this time to compare their survival and growth with the parent species at 2 sites in central Haiti. *S. macrophylla* and *S. humilis* provenances were introduced from Costa Rica and compared for survival and growth at 2 sites in the southwestern part of the country. This report summarizes the 5-year results of these trials with recommendations on managing *Swietenia* genetic resources in Haiti.

## Review of Mahogany Research in Haiti

The extent of past mahogany research in Haiti is scant and has been mostly in the form of species trials associated with the reforestation programs of the Ministry of Agriculture and the USAID-supported natural resource projects during the past several decades (Mooretele, 1979; Bihun, 1982; Dupuis, 1986; Hernandez, 1991). The growth data from these trials are summarized in Timyan (1996). Most of the trials were analyzed at a very young age, which is of dubious worth to long-term management and reinforces a bias in favor of faster growing exotic species without regard to quality. In general, *S. mahagoni* ranks low in early height growth and wood yield compared to lower quality hardwoods such as eucalyptus (*E. camaldulensis* and *E. tereticornis*), neem (*Azadirachta indica*), giant leucaena (*L. leucocephala* subsp. *glabrata*) and cassia (*Senna siamea*). The oldest measured *Swietenia* trials in Haiti are those established by FAO in the mid-1970s at Vaudreuil and O'Gorman, both in the Cul-de-Sac plain. In these trials, *S. mahagoni* and *S. macrophylla* were established along with other native and exotic wood species. At drier sites such as O'Gorman site, *S. mahagoni* outperforms *S. macrophylla*, exhibiting up to a 4-fold advantage in survival and twice the stem diameter growth (Timyan, 1996). However, as one examines a wetter site, such as Vaudreuil, *S. macrophylla* is favored over *S. mahagoni* in wood yield. Comparing the 2 trials, *S. macrophylla* exhibited a 4-fold increase in mean stem growth (0.3 to 1.2 cm yr<sup>-1</sup>) while the mean annual increments only doubled for *S. mahagoni* (0.3 to 0.6 cm yr<sup>-1</sup>). Neem (*Azadirachta indica*) was included in both trials, achieving 100% and 50% more dbh growth than *S. mahagoni* at O'Gorman and Vaudreuil, respectively. It achieved 42% greater dbh growth than *S. macrophylla* at Vaudreuil.

However popular the fast growing tree species are to meet the immediate needs of rural Haiti, peasant farmers select species for long-term production of quality products (Smucker and Timyan, 1995). It is a tragic reality that the rotation age of the quality wood species, such as mahogany, outlasts the time lines of most tree planting efforts in Haiti. Consequently, most of the related research on *Swietenia* reveals only a glimpse of the genus' potential from the perspective of the Haitian farmer and rarely evaluate long term benefits.

Campbell (1994) found that *S. mahagoni* was the fourth most important wood species, in terms of stumpage value (i.e., market value of standing trees), among farmers in the Lascahobas region of Haiti. The species was established mostly as volunteers, either left to grow near the mother tree or transplanted to new sites as bare-root seedlings about a year old. Farmers who realized the value of mahogany integrated the species into their farming framework, but minimized investment risk by keeping input costs low. Though farmer's cultivate mahogany in their own way, the scale of such operations pales in comparison to the cultivation of more lucrative food crops with the result that most land is either in some stage of agricultural production (including short-term fallows) or exhausted. Inevitably, a shortage of high quality lumber trees exists, which is the current situation in Lascahobas as a result of exporting logs to Port-au-Prince in the 1970s.

With no immediate change in exploitation patterns, the genetic quality of local

mahogany populations can only be maintained by the replenishment of the portion of the gene pool that has been depleted. The distribution of improved genetic material to farmers thus becomes a critical part of an overall strategy to ensure the regeneration and growth necessary to sustain a native species. Furthermore, a key to the sustainable management of mahogany in Haiti lies in a more complete understanding of the effects that current patterns of land disturbance has on regeneration processes and how farmers are selecting the appropriate niches for mahogany in the agricultural landscape. Can these niches be improved and expanded to meet both the needs of the farmer, the mahogany tree and the wood industry?

## OBJECTIVES

The overall objective was to improve the genetic quality of germplasm available to farmers through the USAID-funded agroforestry projects and to study the genetic variation of the *Swietenia* genus in Haiti. This objective included the following specific objectives:

- 1) Select the best performing families and seed sources of mahogany for reforestation purposes with a view to improve the economic value of mahogany in Haiti under similar site conditions.
- 2) Compare the performance of hybrid mahogany with the 2 parent species, *S. mahagoni* and *S. macrophylla* at 2 sites in Haiti.
- 3) Compare the performance of big-leaf mahogany (*S. macrophylla*) with Pacific mahogany (*S. humilis*) at 2 sites in Haiti.
- 4) Compare the genetic variation within *S. mahagoni*, *S. macrophylla*, *S. humilis*, and *S. macrophylla* x *S. mahagoni* hybrid for adaptability traits such as survival, height, stem diameter growth and production of merchantable volume.
- 5) Establish seed orchards of *S. mahagoni*, *S. macrophylla* and *S. macrophylla* x *S. mahagoni* hybrids for the production of forestry tree seed and distribution of a wider and improved genetic base to farmers in the PLUS project.

## METHODS AND MATERIALS

### Site Description

The trials were established in 1989–1991 by IRG. They are all located on private land either owned by individuals or non-governmental organizations such as Double Harvest (Roche Blanche), Convention Baptiste (Marmont), and Centre d'Agriculture de St. Barnabas (Terrier Rouge). A summary of site characteristics is provided in Table 1. Figure 1 shows the location of the trials in Haiti.

Table 1. Site description of the *Swietenia* trials in Haiti.

	BERAULT	FAUCHE	LABORDETTE	MARMONT	PAILLANT	TERRIER ROUGE	ROCHE BLANCHE
LATITUDE	18° 13'	18° 25'	18° 27'	19° 04'	18° 25'	19° 38'	18° 33'
LONGITUDE	73° 51'	72° 44'	72° 59'	71° 59'	73° 09'	71° 58'	72° 12'
ELEVATION (m)	25	5	300	265	650	20	25
ANNUAL RAINFALL	1800	1390	1450	1250	1385	1150	900
RAINY SEASON	Mar-May; Aug-Nov	Apr-Oct	Mar-May; Aug-Nov	Apr-May; Aug-Oct	Apr-Oct	May-June; Sept-Nov	Apr-May; Sept-Oct
HOLDRIDGE LIFE	Moist Forest	Moist Forest	Moist Forest	Moist Forest	Moist Forest	Dry Forest	Dry Forest
SLOPE (%)	0-2	0-2	40-50	0-2	40-70	0-2	0-1
SOIL pH	8.2-8.4	NA	8.0-8.2	NA	NA	NA	8.2-8.3
CLAY (%)	10-32.5	NA	10-15	NA	NA	NA	17.5
SOIL P (ppm)	2.5-6.0	NA	9-17	NA	NA	NA	54.0-56.5
ORGANIC MATTER (%)	1.8-2.1	NA	1.8-3.9	NA	NA	NA	2.6-2.7
PARENT MATERIAL	Limestone	Limestone	Limestone	Limestone	Limestone	NA	Limestone

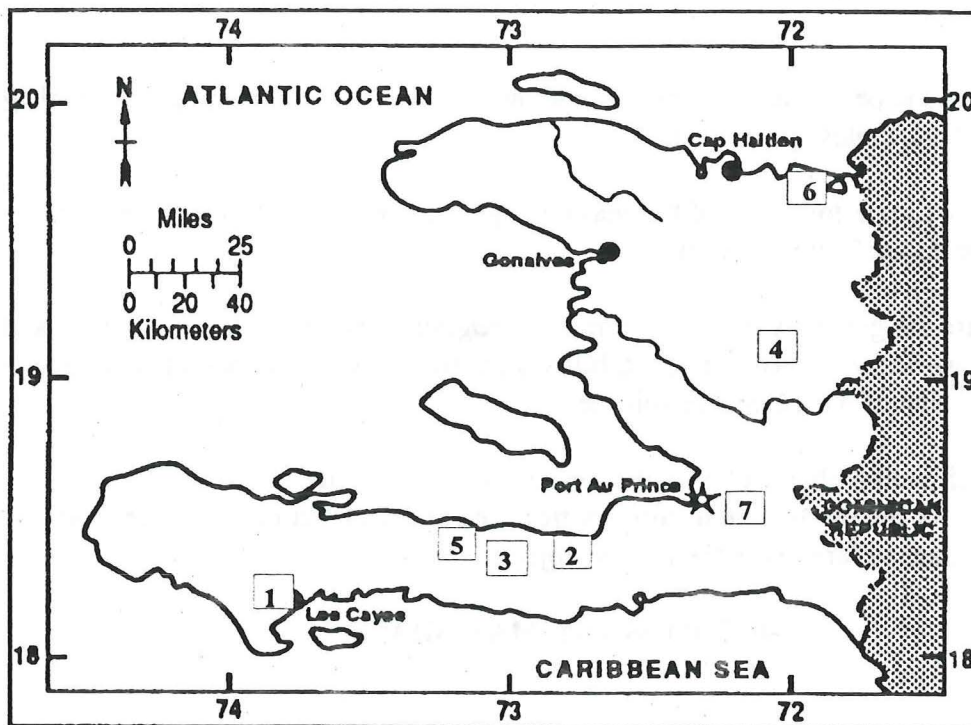


Figure 1. Location of the *Swietenia* trials in Haiti. 1 = Bérault; 2 = Fauché; 3 = Labordette; 4 = Marmont; 5 = Paillant; 6 = Terrier Rouge; 7 = Roche Blanche.

## Seedling Propagation

Seed for the trial was acquired from in-country plus tree selections and 2 international organizations: CATIE (Turrialba, Costa Rica) and IITF (Río Piedras, Puerto Rico). The in-country collections were from plus trees selected for a combination of superior form, vigor and size. Both *S. mahagoni* and *S. macrophylla* parent trees were selected throughout regions of Haiti where the 2 species are being harvested for lumber and sizeable populations of the 2 species are still available for a sufficient selection intensity. Data on the various quantitative parameters of the plus trees are provided in Annex 1. Table 2 provides a summary of information of the seed sources used in this study. All seed is assumed to be collected from open-pollinated trees.

**Table 2. Source information of the *S. mahagoni*, *S. macrophylla* and *S. humilis* germplasm used in this study.**

Sources: C = CATIE, Turrialba, CR; I = IRG, Haiti; P = Institute of Tropical Forestry, Río Piedras, PR.

PROV NO.	<i>Swietenia</i> SPECIES	PROVENANCE (No. Mother Trees)	TEMP (°C)	ALT (m)	LATITUDE	LONGITUDE	RAINFALL (mm)
C 734	<i>S. humilis</i>	Ciruelas, Costa Rica	28.5	100	10° 30' N	84° 50' W	1579
C 2470	<i>S. humilis</i>	Bagaces, Guanacaste, Costa Rica	28.5	500	10° 32' N	85° 15' W	1579
I 461	<i>S. mahagoni</i>	Félician, Lascahobas, Haiti	25.3	185	18° 57' N	71° 56' W	1750
I 463	<i>S. mahagoni</i>	Savanne Laraine, Lascahobas, Haiti	25.7	350	18° 58' N	71° 57' W	1750
I 465	<i>S. mahagoni</i>	Savanne Laraine, Lascahobas, Haiti	25.7	250	18° 58' N	71° 57' W	1750
I 466	<i>S. mahagoni</i>	Félician, Lascahobas, Haiti	25.3	185	18° 57' N	71° 56' W	1750
I 467	<i>S. mahagoni</i>	Savanne Laraine, Lascahobas, Haiti	25.7	250	18° 58' N	71° 57' W	1700
P 477	<i>S. mahagoni</i>	Ponce, Puerto Rico	26.2	35	17° 59' N	66° 40' W	927
I 650	<i>S. mahagoni</i>	La Hatte, Petit Goâve, Haiti	26.2	130	18° 25' N	72° 54' W	1350
P 478	Hybrid	St. Croix, Virgin Islands	26.5	40	17° 45' N	64° 44' W	1133
P 479	Hybrid	Ponce, Puerto Rico	26.2	35	17° 59' N	66° 40' W	927
P 556	Hybrid	Salinas, Puerto Rico	27.2	20	17° 59' N	66° 17' W	1100
I 482	<i>S. macrophylla</i>	Fond-des-Nègres, Haiti	26.5	275	18° 21' N	73° 13' W	1600
I 483	<i>S. macrophylla</i>	Fond-des-Nègres, Haiti	26.5	275	18° 21' N	73° 13' W	1600
I 486	<i>S. macrophylla</i>	Labordette, Petit Goâve, Haiti	24.3	400	18° 22' N	72° 58' W	1450
I 487	<i>S. macrophylla</i>	Modieu, Limbé, Haiti	25.8	35	19° 41' N	72° 25' W	2057
I 489	<i>S. macrophylla</i>	Testas, Jérémie, Haiti	27.0	5	18° 37' N	74° 06' W	1684
I 493	<i>S. macrophylla</i>	Limbé, Haiti	25.8	20	19° 42' N	72° 24' W	2057
I 494	<i>S. macrophylla</i>	Dîrici, Limbé, Haiti	25.8	45	19° 42' N	72° 23' W	2057
I 496	<i>S. macrophylla</i>	Testas, Jérémie, Haiti	27.0	5	18° 37' N	74° 06' W	1684
I 497	<i>S. macrophylla</i>	Testas, Jérémie, Haiti	27.0	5	18° 37' N	74° 06' W	1684
C 1982	<i>S. macrophylla</i>	Turrialba, Catargo, Costa Rica	22.3	602	9° 51' N	83° 37' W	2690
C 2469	<i>S. macrophylla</i>	Chapernal, Punta Arenas, Costa Rica	24.0	1200	9° 51' N	84° 14' W	2250

The mahogany seedlings were propagated by the Double Harvest nursery at Roche Blanche. Seed was sown directly into Winstrip cells, a containerized system designed to develop an air-pruned seedling plug with a well-formed root system that benefits early survival and

seedling development. The potting medium selected for the Winstrip was "Haiti Mix," comprised of decomposed sugarcane bagasse, sphagnum moss and silty loam. Besides the fertilizer added at the time of preparation, a foliar fertilizer was applied regularly with the irrigation of the seedlings during the 16-week nursery period. Fungicides were applied to control damping-off and the seedlings were hardened off prior to outplant for a period of 4 weeks in full sun.

### Experimental Design and Trial Establishment

The trials were established over a 2 year period at 7 sites in Haiti. Field layout of the provenance trials used a randomized complete block design with 18-tree (6 trees x 3 rows) plots of each provenance replicated 3–4 times. Layout of the arboreta was complete randomization of 15-25 tree species, each species represented by a single-tree plot and replicated 21-50 times. The two seed orchards were established with a balanced mix of *S. mahagoni*, *S. macrophylla* and the *S. macrophylla* x *S. mahagoni* hybrid families, each family being randomly placed and represented by a single tree. The number of siblings per family depended on the numbers available at the time of planting, though most families were planted with at least 6 siblings. Table 3 provides a summary of the experimental designs.

**Table 3. Experimental design of the *Swietenia* trials in this study.**

	BERAULT	FAUCHE	LABORDETTE	MARMONT	PAILLANT	TERRIER ROUGE	ROCHE BLANCHE
EST. DATE	April, 1989	July, 1990	May, 1989	August, 1989	April, 1991	June, 1991	September, 1990
TRIAL TYPE	Provenance Trial	Arboretum	Provenance Trial	Arboretum, Seed Orchard	Arboretum	Arboretum	Seed Orchard
SPECIES	<i>S. humilis</i> , <i>S. macrophylla</i>	<i>S. macrophylla</i> , <i>S. mahagoni</i>	<i>S. macrophylla</i> , <i>S. humilis</i>	<i>S. mahagoni</i> , <i>S. macrophylla</i> , hybrid	<i>S. macrophylla</i> , <i>S. mahagoni</i>	<i>S. mahagoni</i>	<i>S. mahagoni</i> , <i>S. macrophylla</i> , hybrid
NO. OF PROVENANCES	734, 2469, 1982, 2470	0	2469, 2470	0	0	0	0
NO. OF FAMILIES	0	465, 466, 497	0	465, 466, 467, 479, 482, 486, 487, 489	467, 494, 497	463, 467	461, 463, 465–467, 477–479, 489, 493, 496, 497, 556, 650
REPLICATIONS	3	20–25	4	4–25	11–27	10	2–24
TREES/REP.	18	1	18	1	1	1	1
SPACING (m)	2.0 x 3.0	3.0 x 5.0	2.0 x 2.5	2.0 x 2.0	2.0 x 2.5	2.0 x 2.0	2.0 x 3.0

All the sites, with the exception of Roche Blanche, were manually cleared of brush prior to the digging of holes with hoes. The Roche Blanche site was plowed and disced with a tractor prior to hole digging. The holes were prepared at the time of planting by marking rows with a string and digging at marked intervals along the string. Care was taken to disturb as little soil as possible on sloping land. Rocks and weed mulch were placed along the perimeter and at the base of the seedlings to retain soil moisture and protect against soil loss. The seedlings were

after the first series of rains under saturated soil conditions. The seedlings were planted with a dibble stick, machete or crowbar and care was taken to insure complete soil compaction around the root plugs. A trial map and labels were installed at the time of trial establishment. Each trial was periodically visited for weed maintenance and security, beginning as early as 2-4 weeks following trial establishment. All trial maintenance costs were the responsibility of I.G./SECID and were mostly conducted during the first 3 years. The trees were planted with the condition that they were the sole property of the landowner, but under advisory control of the SECID team responsible for research and monitoring.

### **Measured Variables and Observations**

Several trials were not measured according to the original time schedule due to constraints during the economic embargo. Paillant was measured at 2 and 3 years; Roche Blanche was measured at 3 years only; and Terrier Rouge was measured at 3 and 5 years. The rest of the trials were measured at 1, 3, and 5 years. The following variables were measured after trial establishment.

- i) Survival, in %, at 1, 2, 3 and 5 years.
- ii) Total tree height, to nearest 0.1 meters, at 1, 3 and 5 years with a telescopic height pole.
- iii) Stem diameter at 1.3 m above ground (DBH), to nearest 0.1 cm, at 3 and 5 years with a cloth diameter tape, overbark.
- iv) Basal diameter at 0.1 m above ground, to nearest 0.1 cm, at 5 years with a cloth diameter tape, overbark.
- v) Stem height, to nearest 0.1 m, at 5 years with a telescopic height pole.

Stem height equaled total height for straight trees. Otherwise, height to the first fork or severe deformity was measured. All trees within a plot were measured for data analyses.

Soil samples were collected at several trials by randomly selecting 5 locations in each block and sampling at 2 depths: 0–20 cm and 20–50 cm. The samples from each block were bulked and each block was analyzed separately. Soil analyses for texture, pH, organic matter and available nutrients were conducted at the Soil Laboratory of Auburn University using standard procedures for calcareous soils. Soil samples were not analyzed for a number of sites – Fauché, Terrier Rouge, Marmont and Paillant – due in part to project cut backs associated with the economic embargo in 1991.

The status of each tree was evaluated during each measurement period and given a code. Damages due to natural causes, like chlorosis, wind or insect attacks, were noted. Trees suffering from damage associated with livestock, weeding or vandalism were deleted from the statistical analyses for growth parameters.

## Statistical Analyses

Field data was entered into the computer using a Lotus 123 spreadsheet. Merchantable volume for means comparison tests was estimated by multiplying stem height by dbh<sup>2</sup> (Butterfield, 1996). These estimates are close to actual volume tables developed for the *S. macrophylla* x *S. mahagoni* hybrid in Puerto Rico (Bauer and Gillespie, 1990). Survival data was transformed to the square root of the arc sine for analysis of variance and mean separation tests, according to procedures outlined in Steele and Torrie (1980). Analysis of variance and means comparison by the Waller-Duncan k-ratio Test ( $\alpha = 0.05$ ) were calculated to detect differences and rank genotypes with SAS 6.04 (SAS, 1988). Plot means were used for both the ANOVA and range tests.

## RESULTS AND DISCUSSION

### *S. humilis* and *S. macrophylla*

#### Survival

The original layout of the Bérault trial included 3 replications of 2 *S. humilis* and 2 *S. macrophylla* provenances. It was necessary to eliminate the entire third block due to a combination of high mortality on extremely rocky terrain exacerbated by periodic invasion of livestock destroying what seedlings remained. Thus only 2 replicates were analyzed for survival and growth parameters.

A similar, but less severe, situation occurred at the Labordette trial. There was extremely poor survival in the portion of the trial adjacent to a path that ran along a mountain ridge and the garden boundary, with additional mortality associated with cropping and livestock foraging activities. Survival is lower than what would be expected if such conditions were avoided. At the same time, this agricultural milieu is typical of the conditions that most trees are subject to in Haiti.

A summary of the survival among provenances for both trials is provided in **Table 4**. Site survival after 5 years, including both *S. macrophylla* and *S. humilis*, was higher at the Bérault trial (59%) than at the Labordette trial (38%). The survival rates at Labordette show a continual decline that is a result of drier conditions and agricultural activity. Those at Bérault are relatively constant after the first year. Statistical differences were detected between species at the 1- and 3-year stage at Labordette and at the 1-year stage at Bérault. At both sites, *S. humilis* showed a higher early survival rate than *S. macrophylla*. This superiority was still evident after 5 years, though not statistically significant at the 0.05 probability level. No statistical differences were observed among the provenances at Bérault. The higher survival rate of *S. humilis* may mean that this species is hardier, originating from regions with a marked dry season and generally lower in rainfall than the *S. macrophylla* provenances represented in this study (see **Table 2**).



**Table 4. Survival of *S. humilis* and *S. macrophylla* at 2 sites in Haiti. Studentized Range Levels at  $\alpha = 0.05$ ; provenance means followed by the same letter are not statistically different.**

No.	Species	Bérault <sup>†</sup>			Labordette		
		12 Mo.	36 Mo.	60 Mo.	12 Mo.	36 Mo.	60 Mo.
		----- % -----					
734	<i>S. humilis</i>	75.0 a	75.0 a	72.2 a			
2470	<i>S. humilis</i>	66.7 a	58.3 a	58.3 a	76.4 a	55.6 a	47.2 a
1982	<i>S. macrophylla</i>	66.7 a	61.1 a	61.1 a			
2469	<i>S. macrophylla</i>	44.4 a	44.4 a	44.4 a	43.0 b	31.9 b	29.2 a
	<b>Trial Mean</b>	<b>63.2</b>	<b>59.7</b>	<b>59.0</b>	<b>59.7</b>	<b>43.8</b>	<b>38.2</b>
	<b><i>S. humilis</i> Mean</b>	<b>70.8</b>	<b>66.5</b>	<b>65.0</b>	<b>76.4</b>	<b>55.6</b>	<b>47.2</b>
	<b><i>S. macrophylla</i> Mean</b>	<b>55.8</b>	<b>53.0</b>	<b>53.0</b>	<b>43.0</b>	<b>31.9</b>	<b>29.2</b>

† Two replications.

### Height Growth

Height growth is an important criteria in evaluating the adaptability of a species to site conditions. The rate of height growth is not only important in terms of wood productivity, but also in terms of escaping the risk of damage from activities associated with livestock and the cultivation of annual crops.

A summary of the height data during the 5-year period for Bérault and Labordette is shown in **Table 5** and illustrated in **Figures 2** and **3**. The difference between the two sites is shown by the average growth of 7.1 m for both species at Bérault compared to 4.4 m at Labordette after 5 years. The Bérault site is a flat, lowland site in the Cayes Plain with alluvial soils and higher rainfall. Labordette is typical of a mid-elevation (400 m) mountainous site with 40–50% slope, shallower soils and less rainfall. These differences in soil depth and moisture balances largely account for the faster growth rates observed at Bérault.

**Table 5. Height growth of *S. humilis* and *S. macrophylla* at 2 sites in Haiti. Studentized Range Levels at  $\alpha = 0.05$ ; provenance means followed by the same letter are not statistically different.**

No.	Species	Trial Site					
		Bérault <sup>†</sup>			Labordette		
		12 Mo.	36 Mo.	60 Mo.	12 Mo.	36 Mo.	60 Mo.
		----- m -----					
734	<i>S. humilis</i>	1.2 a	5.5 a	7.0 a			
2470	<i>S. humilis</i>	1.5 a	5.7 a	7.3 a	0.3 b	1.5 a	3.8 a
1982	<i>S. macrophylla</i>	1.2 a	5.5 a	7.2 a			
2469	<i>S. macrophylla</i>	1.3 a	5.4 a	6.9 a	0.4 a	1.3 a	5.1 a
	<b>Trial Mean</b>	<b>1.30</b>	<b>5.53</b>	<b>7.09</b>	<b>0.31</b>	<b>1.38</b>	<b>4.36</b>
	<b><i>S. humilis</i> Mean</b>	<b>1.40</b>	<b>5.72</b>	<b>7.22</b>	<b>0.27</b>	<b>1.49</b>	<b>3.81</b>
	<b><i>S. macrophylla</i> Mean</b>	<b>1.25</b>	<b>5.50</b>	<b>7.02</b>	<b>0.35</b>	<b>1.26</b>	<b>5.10</b>

† Two replications.

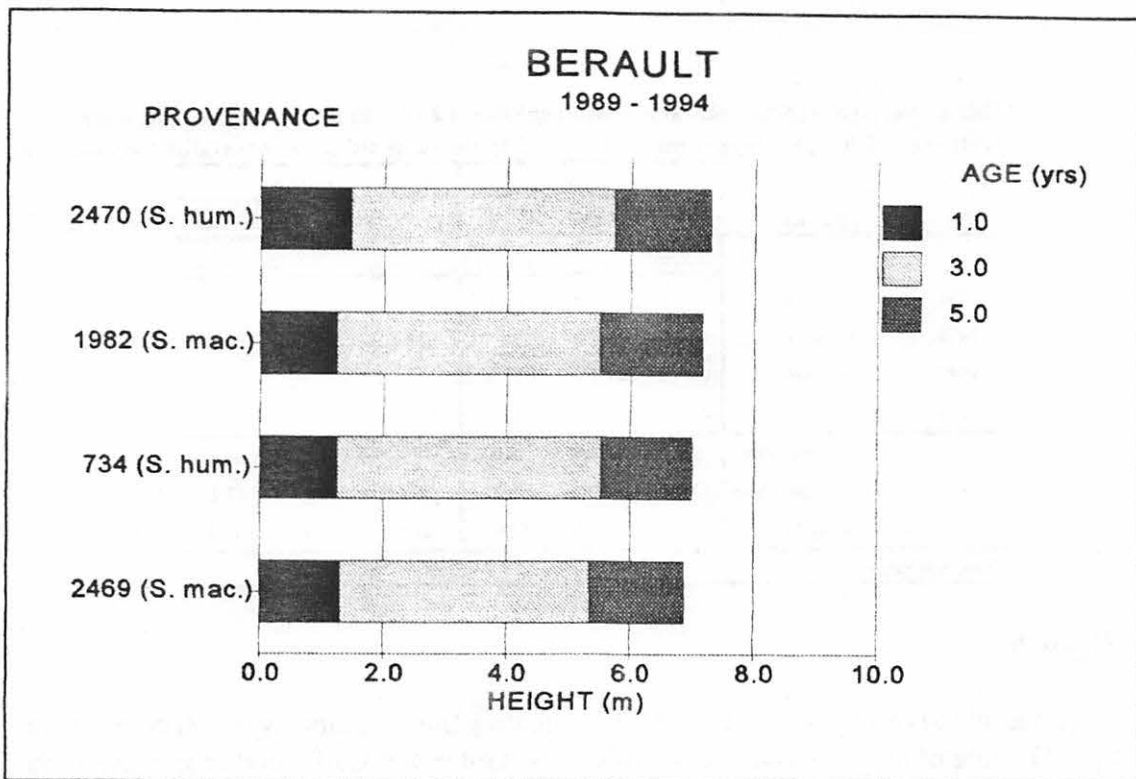


Figure 2. Height growth of *S. humilis* and *S. macrophylla* after 1, 3, and 5 years at Berault.

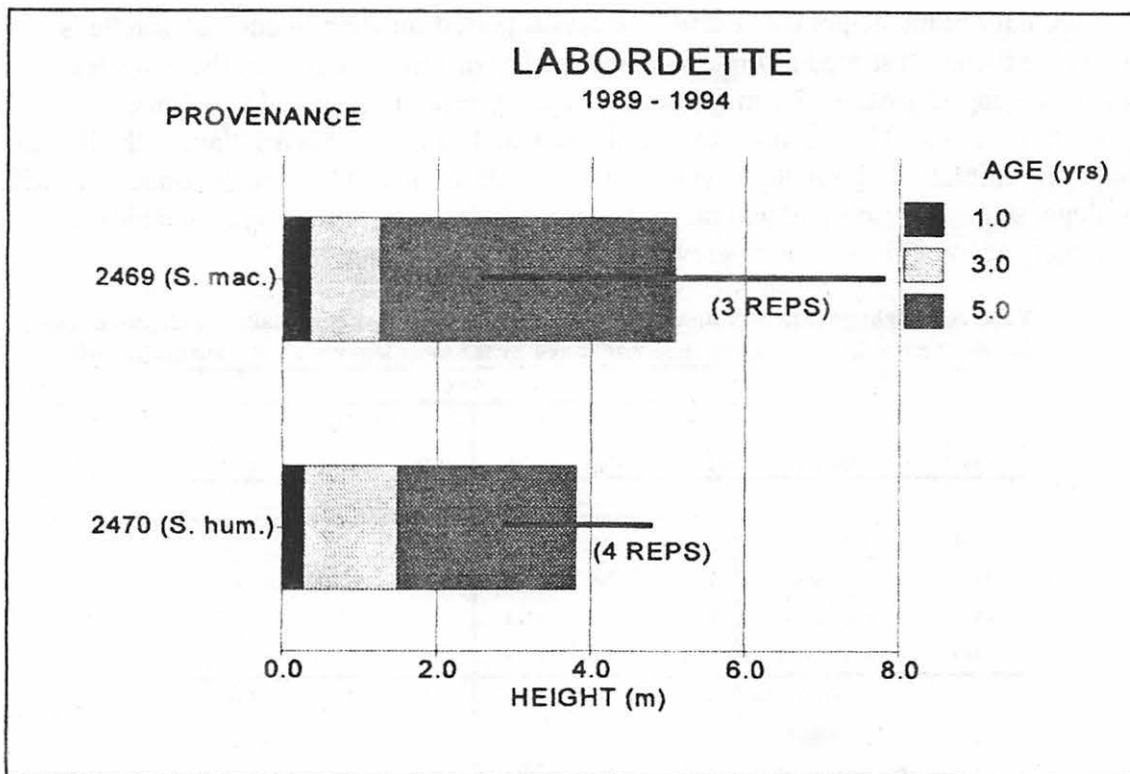


Figure 3. Height growth of *S. macrophylla* 2469 and *S. humilis* 2470 after 1, 3, and 5 years at Labordette.

While the height growth of *S. humilis* and *S. macrophylla* were about the same at Bérault, larger differences between the 2 species was observed at Labordette. *S. macrophylla* 2469 grew faster than *S. humilis* 2470 after 5 years, though the only statistical differences were shown at the 1-year stage analyzing all four replicates. *S. macrophylla* 2469 shows a height advantage at the 5-year stage that is significant at the 0.05 probability level if the portion of the trial that incurred high mortality is eliminated.

### Stem Diameter Growth

Differences in stem diameter growth are important in determining wood volume. The combination of diameter growth and form is analyzed below in terms of merchantable volume. A summary of the stem diameters at 3 and 5 years for the trial is provided in Table 6.

**Table 6. Stem diameter growth and wood volume yield per tree of *S. humilis* and *S. macrophylla* at 2 sites in Haiti. Studentized Range Levels at  $\alpha = 0.05$ ; provenance means followed by the same letter are not statistically different.**

No.	Species	Bérault <sup>†</sup>				Labordette			
		DBH 36 Mo.	DBH 60 Mo.	D <sub>a1</sub> 60 Mo.	Volume 60 Mo.	DBH 36 Mo.	DBH 60 Mo.	D <sub>a1</sub> 60 Mo.	Volume 60 Mo.
		cm/tree		x 10 <sup>-2</sup> m <sup>3</sup>		cm/tree		x 10 <sup>-2</sup> m <sup>3</sup>	
734	<i>S. humilis</i>	6.5 a	10.8 ab	14.5 ab	5.46 a				
2470	<i>S. humilis</i>	7.0 a	11.6 a	15.5 a	6.02 a	1.1 a	5.1 b	8.3 b	1.03 a
1982	<i>S. macrophylla</i>	6.2 a	10.3 ab	14.1 ab	7.28 a				
2469	<i>S. macrophylla</i>	5.9 a	9.0 b	13.0 b	4.33 a	1.3 a	6.3 a	9.6 a	1.89 a
	<b>Trial Mean</b>	6.40	10.45	14.27	5.77	1.17	5.61	8.87	1.40
	<i>S. humilis</i> Mean	6.79	11.17	14.99	5.74	1.12	5.11	8.29	1.03
	<i>S. macrophylla</i> Mean	6.11	9.85	13.71	5.81	1.28	6.28	9.64	1.89

† Two replications.

The site means for dbh at both trials followed a similar pattern as for height growth. After 5 years, the Bérault trial averaged nearly twice the growth rate as the trees at Labordette (10.5 cm compared to 5.6 cm). Differences were shown among provenances at Bérault, but not between the 2 species. *S. humilis* 2470 exhibited the highest mean dbh (11.6 cm) after 5 years, which was statistically different from *S. macrophylla* 2469 (9.04 cm), but not the other 2 provenances. This difference was also shown for basal diameter (15.5 cm versus 13.0 cm). The exact opposite trend occurred at Labordette. *S. macrophylla* 2469 exhibited significantly greater stem growth than *S. humilis* 2470 after 5 years for both dbh and basal diameter. Whether this change in ranks is a result of site differences remains uncertain. The trials would have to be replicated at additional sites to confirm these trends. Given the problems associated with both trials in terms of introduced errors associated with seedling damage, any interpretative significance is cautioned.

## Merchantable Volume

An important economic consideration in the choice of mahogany species and their provenances is merchantable volume yield ( $\text{m}^3 \text{ha}^{-1}$ ). This parameter combines survival, wood production, form and stand uniformity. The species and seed lot that best combines these traits has the greatest likelihood of making an economic impact. (Wood quality, resistance to pests and diseases, tolerance to hurricanes, degree of natural hybridization and regeneration are traits that were not evaluated, but should also be assessed over the long term).

The Bérault site produced triple the wood yield of the Labordette site, on a per tree basis. The site average per tree, including both species, was approximately  $5.77 \times 10^{-2} \text{ m}^3$  at Bérault and  $1.73 \times 10^{-2} \text{ m}^3$  at Labordette.

At Bérault, there was no significant difference between *S. humilis* ( $5.7 \times 10^{-2} \text{ m}^3$  per tree) and *S. macrophylla* ( $5.6 \times 10^{-2} \text{ m}^3$  per tree). The highest yielding provenance was *S. macrophylla* 1982 ( $6.8 \times 10^{-2} \text{ m}^3$  per tree) and the poorest production was exhibited by *S. macrophylla* 2469 ( $4.3 \times 10^{-2} \text{ m}^3$  per tree). Accounting for differences in survival and the proportion of trees considered merchantable, the gap between the two provenances becomes larger when considered on a per hectare basis. *S. macrophylla* 1982 yielded about twice the wood volume as *S. macrophylla* 2469 ( $67.5 \text{ m}^3$  per ha versus  $39.6 \text{ m}^3$  per ha), though this difference was not shown to be significant at the 0.05 probability level.

Though *S. macrophylla* 2469 showed the poorest performance of the 4 provenances at Bérault, it surpassed the volume production of *S. humilis* 2470 at Labordette. This reversal in rank is the same as that for height and stem diameter growth. In general, the provenances that achieved the best height and diameter growth were also the ones that exhibited the highest merchantable volume. Volume data from the two sites is summarized above in **Table 6**.

### ***S. macrophylla* x *S. mahagoni* Hybrid**

*S. macrophylla* x *S. mahagoni* is an important hybrid being tried in several countries because of its form, growth rate, drought resistance and wood quality (Whitmore and Hinojosa, 1977). It is reported to be more drought resistance with better wood quality than *S. macrophylla*, grows faster than either parent and has better form than *S. mahagoni* (Briscoe and Nobles, 1962; Lamb, 1966; Geary et al., 1972). For these reasons, several seed lots of hybrid seed were introduced from Puerto Rico and St. Croix in 1989 and 1990 for testing in Haiti at two sites: Roche Blanche and Marmont. The Holdridge Life Zone of both planting sites can be considered as transitional between Subtropical Dry Forest and Subtropical Moist Forest – the native range of *S. mahagoni*. Though such site conditions would generally be considered too dry for *S. macrophylla*, it was planted for comparative purposes and the possibility of discovering a better-formed genotype adapted to drier site conditions. Under normal circumstances, this requires long time periods to adequately assess genetic differences, if only to ensure that drought-limiting years are included in the evaluation.

## Survival

The hybrid exhibited the highest survival of the 3 *Swietenia* at the Roche Blanche and Marmont seed orchards, but ranked the lowest of the 3 at the Marmont arboretum. In these trials, *S. macrophylla* was mid-ranked at both the Marmont trials, but the lowest ranked at the drier Roche Blanche site. Comparing the two parent species, *S. mahagoni* survived better than *S. macrophylla* at four of five trials (Fauché, Marmont arboretum, Paillant, and Roche Blanche). The trials do not reject the better drought tolerant features of the hybrid as reported in Geary et al. (1972), but neither do they strongly support any differences. While the trials were not designed to test such differences, it appears that the hybrid achieves similar survival rates as the native *S. mahagoni*. A summary of the survival rates among the 3 *Swietenia* and among families within *S. mahagoni* and *S. macrophylla* is presented in **Annex 2**.

## Height Growth

The hybrid grew at a mean annual rate of 1.0 m/yr at Roche Blanche and 1.2 m/yr at Marmont after 3 years. These rates were similar to the trial averages for all genotypes combined.

The hybrid showed no statistical difference from the families of either parent species at the Roche Blanche orchard. No trends in growth rates were available, since the orchard was measured once at 3 years.

The hybrid was inferior in height growth to selected families of both *S. macrophylla* (486) and *S. mahagoni* (465) at the Marmont arboretum after 1 year, but to none of the families of the parent species after 3 and 5 years. At the Marmont seed orchard, the only family that showed statistical differences over the hybrid in height growth was *S. macrophylla* 487 at 1 year. Subsequent years showed no statistical differences among the families of the parent species and the hybrid.

At 5 years, rates dropped at Marmont as height growth stagnated because of a combination of drought-induced dieback and severe competition with the grass *madam michel* (*Themeda quadrivalvis*) between the 3rd and 5th year. During this period, the trial was neglected as political unrest and difficult economic conditions forced a temporary suspension of activities. Mean heights show a decline from 3.6 m to 3.5 m in the Marmont orchard and a small increase from 4.0 m to 4.2 m in the arboretum during this period. Stagnant or declining growth rates was the case for most of the *S. macrophylla* and *S. mahagoni* families as well. It is noteworthy that *S. macrophylla* 486 and 489 showed the best growth during this period rather than the more drought resistant hybrid or *S. mahagoni* families.

A summary of the mean heights of the hybrid at Marmont and Roche Blanche are provided in **Annex 3**. Height comparisons between the parent species and the hybrid for the 3

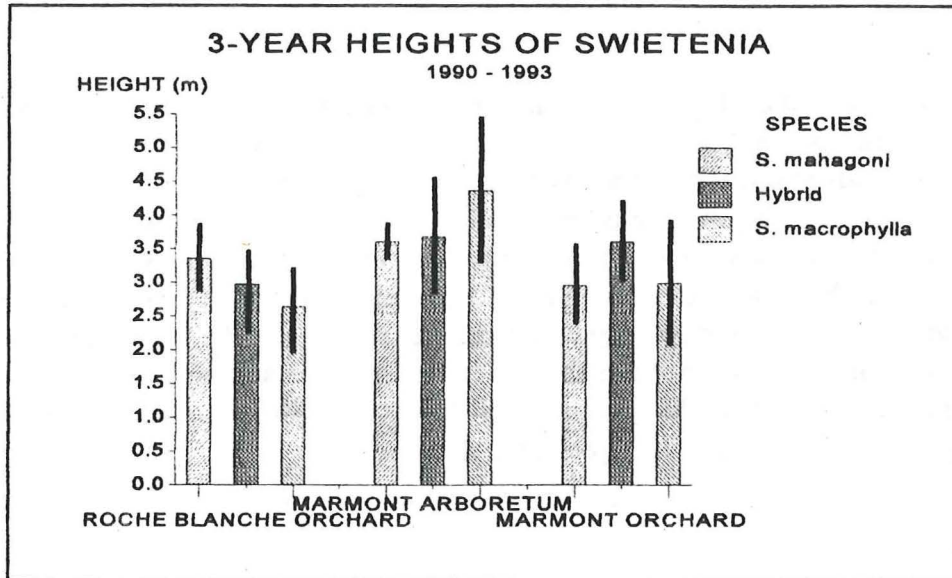


Figure 4. Height growth of the *S. macrophylla* x *S. mahagoni* hybrid, *S. mahagoni* and *S. macrophylla* at Roche Blanche and Marmont after 3 years. The bars indicate the 95% confidence interval of the mean.

trials are illustrated in Figure 4. The overlapping confidence intervals indicate that no statistical difference were shown among the 3 *Swietenia* groups.

### Stem Diameter Growth

The mean annual dbh rate of the hybrid after 3 years was 1.0 cm, 1.1 cm and 1.3 cm at Roche Blanche, Marmont orchard and Marmont arboretum, respectively. The annual rate decreased to 0.05 cm and 0.4 cm at the Marmont orchard and arboretum, respectively, during the 4th and 5th years. This stagnation in growth, as mentioned above, was mostly caused by the severe droughts and grass competition of the trial that occurred during 1994–95.

The mean dbh of the hybrid after 5 years at the Marmont arboretum and orchard was 4.9 cm and 3.7 cm, respectively. The mean dbh of the *S. mahagoni* families was 4.4 cm and 4.6 cm for the arboretum and orchard, respectively. That of the *S. macrophylla* families was 5.3 cm and 4.0 cm for the arboretum and orchard, respectively. These means were not significantly different at the 0.05 probability level.

### *S. mahagoni* and *S. macrophylla*

#### Survival

*S. mahagoni* exceeded the survival of *S. macrophylla* at four of five sites. The greater drought tolerance of *S. mahagoni* is explained in part by its smaller, leathery leaf as compared to

the much larger, more delicate leaf of *S. macrophylla* adapted to wetter conditions. The highest survival of both species occurred at Fauché, the wettest site where both species were planted. The average survival of *S. mahagoni* at five trials was 59.8% after 3 years. That of *S. macrophylla* was 41.6%. A summary of the survival rates at each trial is provided in **Annex 2**.

Four of the trials were arboreta in which mahogany was compared to the survival and growth rates of other common tree species used in Haiti. *S. mahagoni* and *S. macrophylla* were both present at three of these arboreta (Fauché, Marmont and Paillant). Only *S. mahagoni* was included in the Terrier Rouge arboretum.

At Fauché, *S. mahagoni* (81.1%) was the highest surviving species of 15 species after 5 years. *S. macrophylla* ranked 12th with a survival of 45.5% and below the overall site survival of 55.2%. At Marmont, *S. mahagoni* ranked 3rd among 24 species with a survival of 72%. *S. macrophylla* ranked 11th with a survival of 56% and above the overall survival of 50%. The Paillant arboretum was established on an extremely rocky site, exposed to wind and severely eroded. *S. mahagoni* ranked 4th among 23 species with a survival of 70% after 3 years. *S. macrophylla* ranked 11th with a survival of 41%. Overall site survival of the 23 species in the arboretum averaged 42%. At Terrier Rouge, the arboretum was comprised of 20 species that averaged an overall survival of 44% after 5 years. *S. mahagoni* ranked 7th with a survival of 62%. In summary, *S. mahagoni* survives better than *S. macrophylla* and better than the site average of other species commonly used in reforestation. *S. macrophylla* is mid-ranked among other species and survives about the same as the site average. This confirms the hardier nature of *S. mahagoni*. **Figures 5 and 6** compares the survival rates of *S. mahagoni* and *S. macrophylla* at the various sites represented in this study.

### **Height Growth**

The best growth rates were achieved at the wettest site, Fauché (**Annex 3**). At this site, the superior growth rate of *S. macrophylla* compared to *S. mahagoni* was evident. *S. macrophylla* grew at a rate of 2.1 m/yr during the first 5 years, peaking at 2.4 m/yr between the first and third years. The growth rate of *S. macrophylla* almost doubled the growth rate of *S. mahagoni* which averaged about 1.1 m/yr after 5 years, but also peaking between the first and third years at 1.4 m/yr. The difference between the height growth of *S. macrophylla* and *S. mahagoni* was significant at the 0.0001 probability level, though the difference between the two *S. mahagoni* families was not. *S. macrophylla* ranked 3rd in height growth at 10.6 m after *Pterocarpus macrocarpus* (12.6 m) and *Colubrina arborescens* (12.6 m). *S. mahagoni* ranked 14th (5.7 m), next to the bottom-ranked species, *Lysiloma sabicu* (5.1 m).

The other trials, established on much drier sites, showed no difference between the 2 species (**Annex 3**). However, differences were detected between certain families of each species. *S. macrophylla* 486 exhibited the best height growth of any single-tree family at the Marmont arboretum (**Figure 7**). Growth rates of 1.2 m/yr were achieved in the arboretum over a period of 5 years. Height growth of this family exceeded that of the other *S. macrophylla*

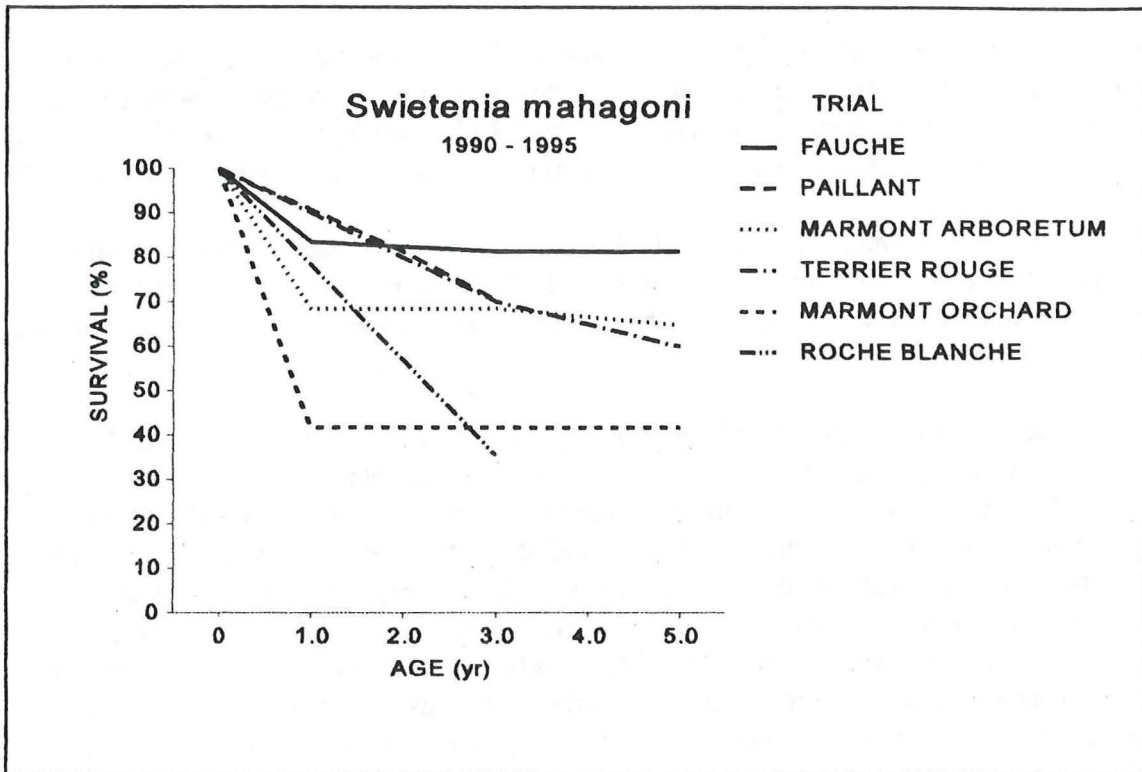


Figure 5. Survival rates of *S. mahagoni* at various trials in this study.

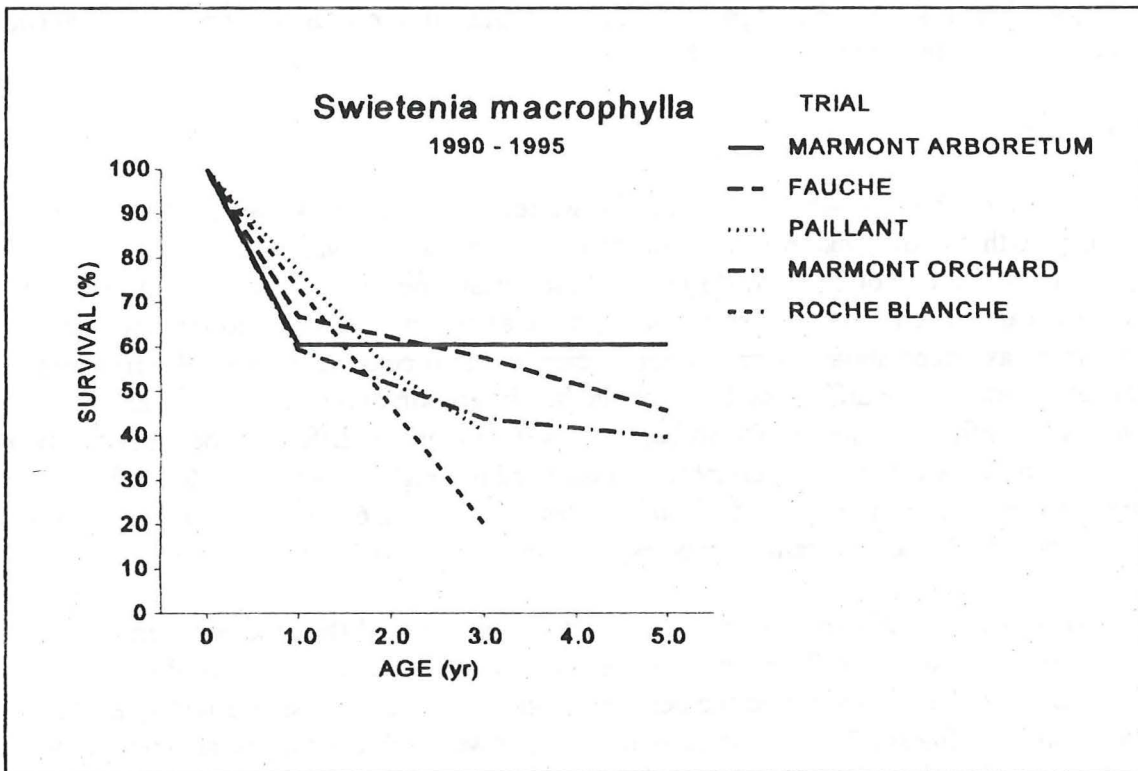


Figure 6. Survival rates of *S. macrophylla* at various trials in this study.



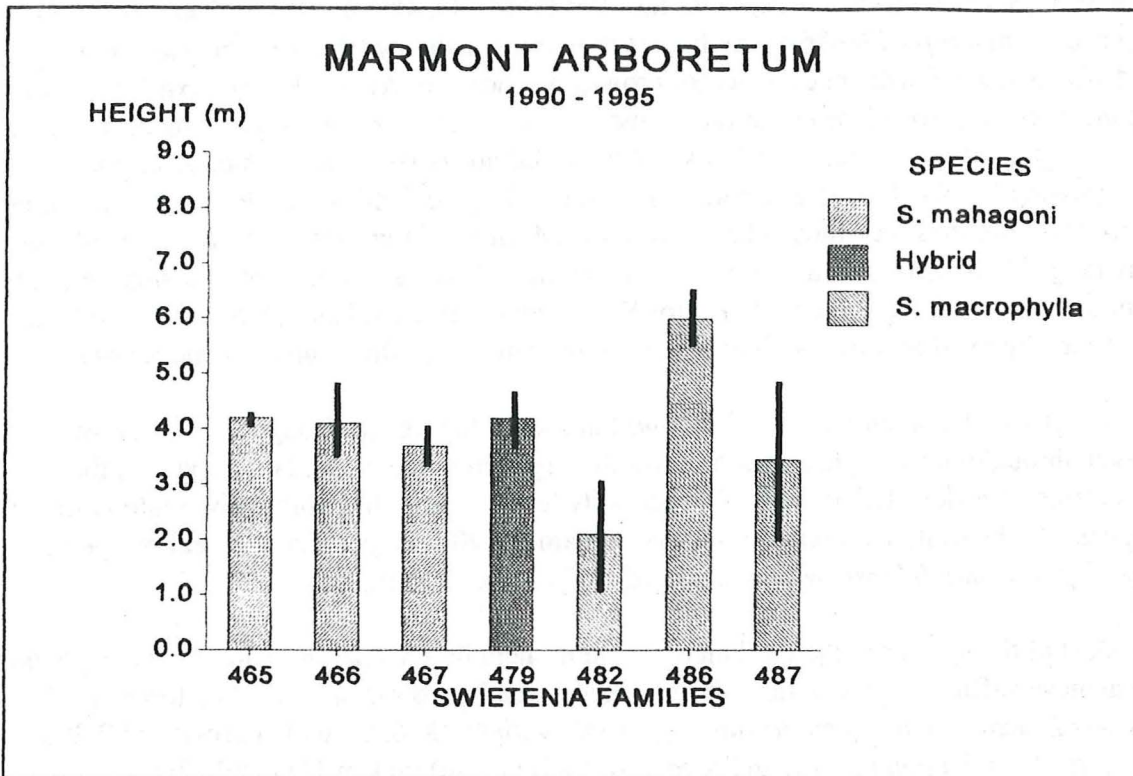


Figure 7. Variation in height growth of *Swietenia* families at the Marmont arboretum after 5 years. Bars indicated the standard error of the mean.

families by as much as 2–3 times at Marmont, even under conditions much drier than that normally preferred by the species. It grew faster than any of the families of *S. mahagoni*, a dominate species in this part of the Central Plateau landscape. *S. macrophylla* 486 showed significantly faster growth than two other *S. macrophylla* families (482 and 487) and one *S. mahagoni* family (466) at the 0.05 probability level. This difference in height growth extended from the first year through the fifth year of the trial. Figure 7 shows the variation in height growth of the *Swietenia* genotypes at the Marmont arboretum after 5 years. Mean height growth of the *S. macrophylla* progeny ranged between 2.1 m and 6.0 m – a difference of 186% – compared to a smaller range of 3.7 m to 4.2 m – a difference of 14% – for *S. mahagoni*.

*S. mahagoni* (4.2 m) and *S. macrophylla* (3.9 m) ranked 11th and 12th, respectively, in height growth with other species in the Marmont arboretum. The top-ranked species was *Eucalyptus camaldulensis* with a height growth of 8.8 m after 5 years. Both *S. mahagoni* and *S. macrophylla* exhibited very little increase in mean height between 3 and 5 years at Marmont because of the high proportion of trees that suffered drought-induced dieback of the terminal stem. This problem appeared to affect *S. macrophylla* more than *S. mahagoni*, and would likely be absent in wetter years at sites similar to Marmont.

*S. macrophylla* 486 also exhibited the best height growth in the orchard, though represented by only one individual at the 3-year stage. This individual showed a significant

height advantage over four *S. macrophylla* families (482, 483, 489 and 497). *S. macrophylla* 489 replaced *S. macrophylla* 486 as the fastest growing mahogany family in the Marmont orchard after 5 years. Differences in height growth, as shown in Annex 3, were exhibited only among the *S. macrophylla* families at the 1- and 3-year stages. The fastest growing *S. mahagoni* family, 467, grew at an average of 0.8 m/yr, but showed no statistical difference from the slowest growing family, 466, after a period of 5 years. Figure 8 shows greater variation among *S. macrophylla* families than those of *S. mahagoni*. Mean height growth of the *S. macrophylla* progeny ranged between 2.5 m and 5.2 m – a difference of 108% – compared to a smaller range of 3.4 m to 4.4 m – a difference of 29% – for *S. mahagoni*. It is evident that *S. macrophylla* is more effected by the drier environment of Marmont than the locally-adapted *S. mahagoni*.

The growth between the 2 *S. mahagoni* families at the Terrier Rouge arboretum was about even throughout the 5-year period. Overall height growth averaged 0.5 m/yr and there were no differences detected at the 0.05 probability level. Comparing this growth rate with the other species in the trial, *S. mahagoni* ranked 16th among 20 species. The top-ranked species was *Eucalyptus camaldulensis* with a height of 11.7 m after 5 years.

Most of the species at the Paillant arboretum, including *S. mahagoni* and *S. macrophylla*, did not achieve sufficient growth rates to be considered adapted for the site. The top-ranked species was *Leucaena leucocephala* subsp. *glabrata* variety, 'K-636,' with a growth of 2.2 m after 3 years. *S. mahagoni* (1.3 m) and *S. macrophylla* (1.1 m) ranked 12th and 17th, respectively. *Cedrela odorata* and *Chrysophyllum cainito* exhibited the slowest growth rates in the trial.

Figure 9 shows the variation in height growth of the *Swietenia* genotypes at the Roche Blanche seed orchard after 3 years. The *S. mahagoni* families at the Roche Blanche orchard grew faster than the *S. macrophylla* families after 3 years, with *S. mahagoni* averaging 3.4 m compared to the 2.6 m height of *S. macrophylla*. Because of the variation among individual heights within each species, no differences were detected at the 0.05 probability level between the 2 species. Contrary to the Marmont trials, the variation in mean height growth among *S. mahagoni* families is similar to that of the *S. macrophylla* families.

The trials indicate that significant genetic variation exists between progenies of both species and that variation in height growth has a genetic basis. It should be noted that neither the orchards or the arboreta were optimally designed to test for such differences. The orchards were designed to maximize the possibility of random mating among progeny of superior phenotypes. The varying and sometimes very low survival of several families in addition to a complete randomization of single-tree plots precluded a rigorous test to compare genotype. The similar design of the arboreta, with single-tree plots of different species, creates border effects that bias growth comparisons among families. The range in variation among *S. macrophylla* and *S. mahagoni* families for mean heights in this study are similar to those reported for progeny trials in Trinidad, Puerto Rico and Costa Rica (Geary et al., 1973; Newton et al., 1996).

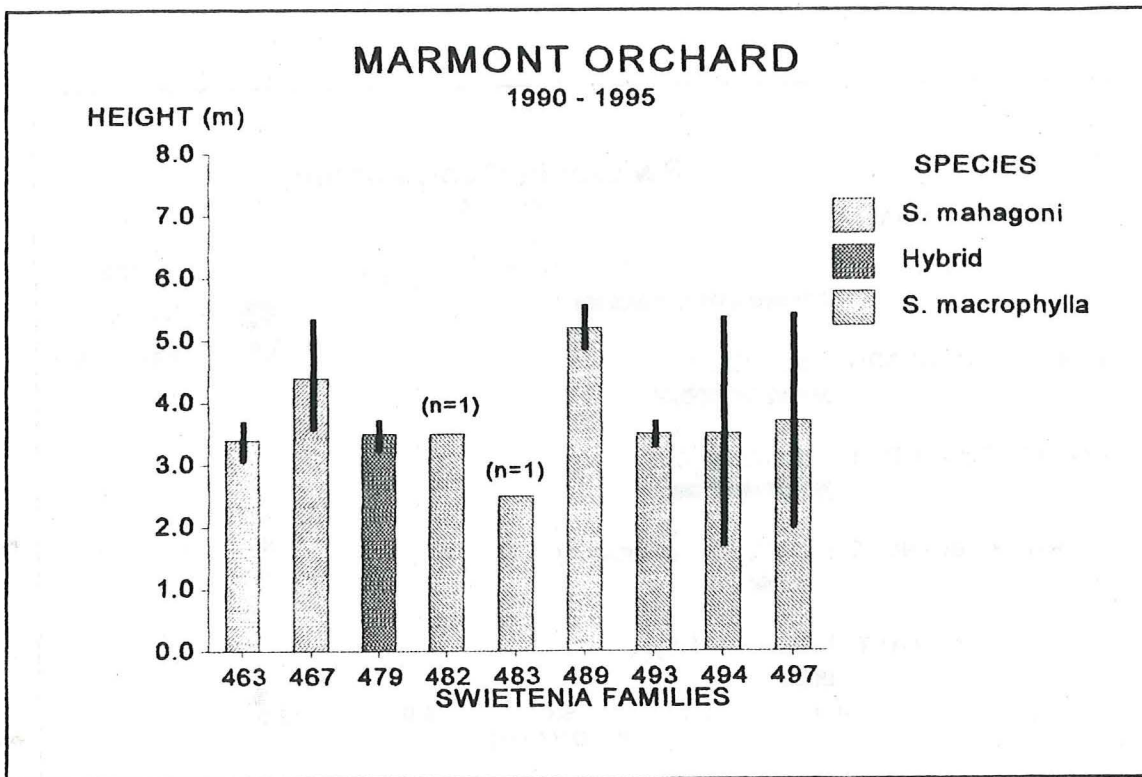


Figure 8. Variation in height among *Swietenia* families at the Marmont orchard after 5 years.

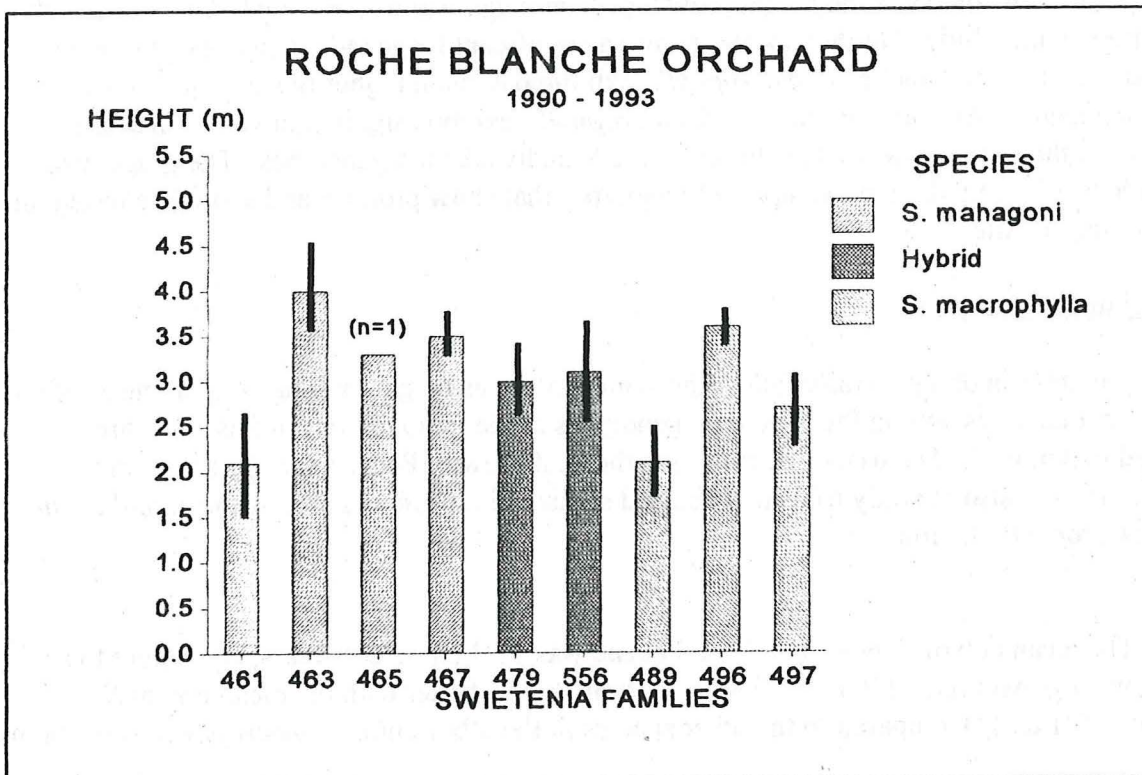


Figure 9. Variation in height among the *Swietenia* families at the Roche Blanche orchard after 3 years.

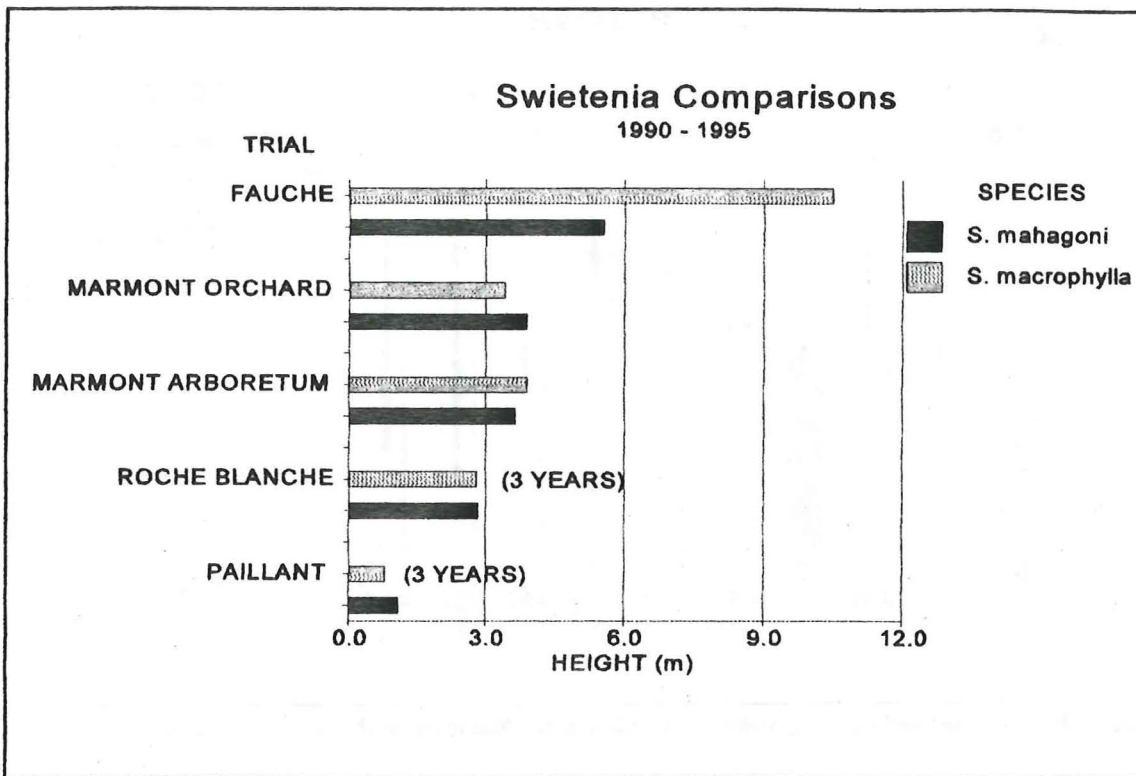


Figure 10. Mean height comparisons of *S. mahagoni* and *S. macrophylla* at various trials in this study.

Figure 10 compares the height growth of *S. mahagoni* and *S. macrophylla*, respectively, at the trials in this study. Neither species shows a significant height advantage, except on the lowland, moist site at Fauché. *S. macrophylla* exhibited a much higher range in height growth than *S. mahagoni*. As noted previously, *S. macrophylla* exhibits significant variation at the family level that may allow for selection of more broadly adapted genotypes. The progeny of *S. macrophylla* 486 and 489 are examples of genotypes that show promise and should be tested on a wider range of sites.

### Stem Diameter Growth

Rankings in dbh generally follow the same pattern as height rankings. A summary of the mean stem diameters among the *Swietenia* genotypes at the various trials in this study are provided in Annex 4. The trials that exhibited the best growth (Fauché and the Marmont arboretum) were also the only trials that showed statistical differences among the *S. mahagoni* and *S. macrophylla* families.

The mean dbh of *S. macrophylla* at Fauché was 11.4 cm after 5 years, equivalent to a mean annual growth rate of 2.3 cm. This was significantly better than the mean dbh of *S. mahagoni* (7.1 cm). Compared to the other species in the arboretum, *S. macrophylla* was 6th in

mean dbh and *S. mahagoni* was 13th, tied with *Chrysophyllum cainito*. The top performer was *Pterocarpus macrocarpus* (15.0 cm) and the lowest ranked species was *Bumelia salicifolia*.

At the Marmont arboretum, *S. macrophylla* 486 was the top-ranked mahogany family after 5 years with a mean dbh of 7.1 cm. Significant differences were exhibited between *S. macrophylla* 486 and the rest of the *Swietenia* genotypes at the 0.05 probability level. *S. macrophylla* 489 was the top-ranked mahogany family in the orchard during the same time period with a mean dbh of 6.8 cm. No differences were shown among the families in the orchard after 5 years at the 0.05 probability level.

The Paillant site exhibited the poorest stem growth of any of the trials. The annual rainfall amounts for the site are a misleading indicator of growth potential because of the extremely poor soil conditions. *S. macrophylla* showed greater stem growth though the difference was not significant at the 0.05 probability level. Neither species would be considered economical choices for this site. The mean dbh of *S. macrophylla* and *S. mahagoni* was 1.0 cm and 0.6 cm, respectively, after 3 years.

Terrier Rouge represents the dry extreme of the native range of *S. mahagoni* in Haiti. After 5 years, a mean dbh of 1.9 cm was achieved for the 2 families. No differences were shown between the 2 families at the 0.05 probability level. This averages less than 0.4 cm/yr.

The Roche Blanche is typical of a transition zone between the dry and moist forest zones that favors *S. mahagoni*. Though *S. mahagoni*, as a species, showed better dbh growth than either the hybrid or *S. macrophylla*, there were no differences among the genotypes at the 0.05 probability level. *S. mahagoni* 463 exhibited the highest mean dbh at 3.8 cm after 3 years, equivalent to an annual growth rate of 1.3 cm. The poorest growth of the genotypes that survived after 3 years was *S. macrophylla* 489 at 1.8 cm.

### Merchantable Volume

The Fauché trial was the only trial of *S. mahagoni* and *S. macrophylla* measured for merchantable stem heights and evaluated for stem volume. The other trials either did not achieve sufficient stem height growth for meaningful volume estimates (Paillant, Terrier Rouge) or were not measured because of management constraints (Roche Blanche, Marmont).

**Table 7** summarizes the differences in stem volume between *S. macrophylla* and 2 half-sib families of *S. mahagoni*. The volume estimates of *S. macrophylla* are about 3 times greater than those of *S. mahagoni* on a per tree basis. Because the survival of the *S. mahagoni* was twice that of *S. macrophylla* at the Fauché trial, estimated volume of *S. mahagoni*, on a per hectare basis, is about half that of *S. macrophylla*. The values in **Table 7** are hypothetical, but should be fairly accurate in terms of the differences between the two species and real values based on actual harvests. Differences in volume yield between the 2 families of *S. mahagoni* were not significant at the 0.05 probability level.

Table 7. Merchantable volume comparisons between *S. mahagoni* and *S. macrophylla* after 5 years at the Fauché trial. Family means followed by the same letter are not statistically different,  $\alpha = 0.05$ .

No.	Species	Volume	Volume
		$10^{-2} \text{ m}^3/\text{tree}$	$\text{m}^3 \text{ ha}^{-1}$
465	<i>S. mahagoni</i>	1.71 b	9.1 b
466	<i>S. mahagoni</i>	1.33 b	7.3 b
497	<i>S. macrophylla</i>	5.93 a	18.0 a
Mean		2.99	
MSD <sub>0.05</sub>		1.02	

## CONCLUSIONS

Genetic conservation and improvement are key elements in the sustainable management of mahogany. The work that has been accomplished to date is the only one of its kind in Haiti. But the reality is that 2 orchards and a few arboreta are not nearly sufficient in scope nor adequate in time to address the magnitude of the genetic erosion problem threatening this native species of national importance. Mahogany continues to be "mined" without the investments required to sustain production. Economic analyses justifying project investments continue to shortchange the biological value of native forests and their component species.

The trials show differences at all levels of the genetic variation found in mahogany. It is clear that these differences are not as great as those found in the provenance trials of *Cedrela odorata* (Béliard et al., 1996) and that genetic gains would not be as rapid through selection. The *Swietenia* trials worked with only a portion of the variation found among mahogany populations found in the wild, limited primarily by manpower, budget and time. However, the trials show that significant improvement in the survival and the volume of merchantable wood can be achieved through proper selection of the best adapted genotypes. *S. macrophylla* can yield up to 3 times the merchantable wood volume of *S. mahagoni* on lowland, moist sites. Height growth can be doubled if *S. macrophylla* is selected at the family level. Improvement in mahogany genotypes coupled with an increased efficiency in tree management at the farm level should result in enhanced economic opportunities that benefit both the farmer and his environment. The promising future of the interspecific hybrids as a cultivated species has been little explored, but may provide high-quality lumber that is more flexible and better adapted at the farm level.

Capturing the genetic differences found in mahogany and economically passing the benefit on to the Haitian community is a key objective of the seed orchards and the PLUS network of nurseries. Progeny from the seed orchards should generate greater gains than that indicated in this report because of the advantages of mass selection, the continued crossing of inbred lines and interspecific hybridization. Seed production from the orchards is fundamental in meeting original USAID objectives (Palmer, 1985; Rios, 1986; Ford, 1986) and the prospect of improving mahogany seed quality, replenishing populations under severe exploitive pressures and increasing the rate of economic returns to the farmer through faster production of improved stem form. An additional feature of seed orchards is that they are managed by organizations that

are isolated from the economic pressures of the individual small farmer barely above subsistence level. The latter is rarely in a position to ensure a steady supply of improved seed or meet the long-term objectives of seed orchard management.

The Roche Blanche and Marmont orchards constitute the broadest genetic base of mahogany at any one site in Haiti. The importance of maintaining such genetic variation must be considered in light of the long-lived nature of trees and the necessity for populations to be able to adapt to changing environmental conditions, pests and diseases. The *S. mahagoni* and *S. macrophylla* progeny in the orchards are of known origin and from plus trees which have been chosen on the basis of their outstanding phenotypic appearance. They represent the first stage necessary to develop certified mahogany seed. The managed distribution of improved germplasm coupled with the capacity to track successive generations of known origin is accomplished most efficiently through centralized nurseries. The distribution of quality germplasm to rural communities is still one of the strongest arguments for the subsidized production of tree seedlings. This is critical if any headway is to be made in the genetic conservation and improvement of economically important tree species such as mahogany.

### RECOMMENDATIONS

Although USAID support for this tree improvement phase of the PLUS project has ended, much needs to be done to protect Haiti's rich heritage of mahogany, and to restore the population of this valuable lumber source by making seed of selected genotypes available to farmers and land owners. The following activities are recommended to avoid jeopardizing the progress that has been accomplished to date.

1) Selectively thin the two seed orchards at Roche Blanche and Marmont by eliminating the inferior individuals and maintaining a balanced number of well-formed individuals of each genotype. The outcrossing of progeny from plus trees and the production of vigorous offspring is the first step in the production of improved seed. Seed production is not forecasted until 12-13 years of age (Lamb, 1966) or 2002.

2) Distribute seed lots from the orchards according to life zone considerations and through centralized nurseries that can track source-identified germplasm. Seed should be collected from the *S. mahagoni* and *S. macrophylla* x *S. mahagoni* hybrids for dry and moist forest regions of Haiti; that of *S. macrophylla* and the hybrids for moist to wet forest zones. Efforts should be made to study the flowering patterns of the orchard trees and observe the variability of their progeny in the nursery. Mahogany is largely pollinated by insects and normally outbreeds, but can set a high quantities of seed by self-pollination (Yang, 1965; Styles and Khosla, 1976). The orchards should be rogued based on the field performance of their progeny.

3) Selectively thin the arboreta and the *S. humilis*/*S. macrophylla* provenance trials to encourage development of the best-formed individuals. These trees should be selected based on

desirable characteristics such as 1) stem form and volume, 2) pest and disease resistance, 3) symmetrical crowns and ideal crown:dbh ratio, and 4) overall survival and vigor. The *S. humilis* provenances are the only representatives of the species in Haiti and should be observed carefully vis-à-vis the *S. macrophylla*. The *S. macrophylla* provenances may be an important addition to the genetic diversity of the species in Haiti since most of what has spread in Haiti originates from the narrow genetic base of the stands at Franklin and Bayeux.

4) If additional orchards are established, select a wide base of plus trees, including second generation individuals located in the arboreta and orchards, and vegetatively propagate them via procedures outlined in Howard et al. (1988) and Leakey et al. (1990). Vegetative propagation of a selected genotype reduces the risk of introducing less desirable gene complexes that result from outbreeding of the mother trees.

5) Progeny trials, designed to optimally test for genetic differences among families, should be installed and monitored for a rotation age (at least 20 years) with a wide selection of genotypes from the orchards to prove their superiority over unselected genotypes. This step is critical to fulfill the requirements of certified seed. Characteristics qualifying genetic stock for the level certified must be carefully spelled out, as are the environmental conditions under which a particular genotype is expected to give above-average performance. These trials can later be rogued and converted to seed orchards for improved lines of mahogany in Haiti. They should be established with the support of the Service des Ressources Forestières, satisfying long term security and supervision requirements.

6) Monitor any natural regeneration or seedlings originating from the orchards to confirm the pattern and degree of heterosis (i.e., hybridization) and its effects on survival, growth rates and form. Most mahogany currently cultivated by Haitian farmers are pure *S. mahagoni*. However, demand for the hybrid may increase because of its superior form and faster growth rates on selected sites. Gene banks of pure *S. mahagoni*, selected throughout Haiti and the island of Hispaniola, should be established to continue efforts to conserve the remaining gene pool of a species that has economic importance, but that has been seriously high-graded throughout the history of Haiti.

7) Inform the Service des Ressources Forestière (MARNDR) of the importance and urgency to develop a long-term strategy, integrating genetic conservation and improvement of *S. mahagoni* as a native species of economic value. Coordinate the transfer of information from the wide range of international organizations involved with genetic conservation and improvement of mahogany in Central America and the Caribbean, particularly efforts undertaken by CATIE and IITF in collaboration with universities and international organizations (Glogiewicz, 1986; Newton et al., 1993). The government should encourage private sector investment in the certified production of mahogany wood products and seed with a view of developing management guidelines that combine conservation with production.



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**Annex 1a. Characteristics of *S. mahagoni* plus-tree candidates selected in Haiti. Family numbers refer to both the mother tree and progeny established in the arboreta and seed orchards reported in this study.**

<b>West Indies Mahogany (<i>Swietenia mahagoni</i> Jacq.)</b>								
<b>FAMILY NO.</b>	<b>LOCATION (Commune)</b>	<b>ELEV. (m)</b>	<b>DBH (cm)</b>	<b>TOTAL HEIGHT (m)</b>	<b>MERCH. HEIGHT (m)</b>	<b>CROWN HEIGHT (m)</b>	<b>CROWN DIAMETER (m)</b>	<b>DBH:CROWN RATIO</b>
461	Felician (Lascahobas)	240	29.0	18.4	7.6	10.8	7.5	3.9
462	Fauché (Port Margot)	58	66.5	24.0	8.2	18.0	15.2	4.4
463	Savane Laraine (Lascahobas)	350	44.0	16.6	12.2	11.8	9.2	4.8
464	Gilbeau (Jean Rabel)	215	43.0	18.0	6.8	11.2	9.8	4.4
465	Savane Laraine (Lascahobas)	250	39.5	16.6	6.2	10.4	8.8	4.5
466	Felician (Lascahobas)	185	32.7	14.0	8.0	11.0	7.1	4.6
467	Savane Laraine (Lascahobas)	250	25.0	13.0	6.0	7.0	6.5	3.8
468	Chomaj (Bainet)	220	44.0	19.0	9.0	11.4	10.2	4.3
469	Bake (Mirebalais)	160	31.7	17.2	6.6	10.4	7.0	4.5
650	La Hatte (Petit Goâve)	22	30.0	14.4	9.0	7.3	5.4	5.6
651	Léon (d'Aquin)	370	28.5	17.6	7.0	9.8	5.8	4.9
	<b>Mean</b>	211	37.6	17.2	7.9	10.8	8.4	4.5
	<b>Maximum</b>	370	66.5	24.0	12.2	18.0	15.2	5.6
	<b>Minimum</b>	22	25.0	13.0	6.0	7.0	5.4	3.8

**Annex 1b. Characteristics of *S. macrophylla* plus-tree candidates selected in Haiti. Family numbers refer to both the mother tree and progeny established in the arboreta and seed orchards reported in this study.**

<b>Mahogany Hybrid (<i>S. macrophylla</i> x <i>S. mahagoni</i>)</b>								
<b>FAMILY NO.</b>	<b>LOCATION (Commune)</b>	<b>ELEV. (m)</b>	<b>DBH (cm)</b>	<b>TOTAL HEIGHT (m)</b>	<b>MERCH. HEIGHT (m)</b>	<b>CROWN HEIGHT (m)</b>	<b>CROWN DIAMETER (m)</b>	<b>DBH:CROWN RATIO</b>
481	Fond des Nègres	290	29.0	17.4	12.0	10.0	5.0	5.8
<b>Big-Leaf Mahogany (<i>Swietenia macrophylla</i> King)</b>								
482	Fond des Nègres	275	33.0	17.8	13.5	12.1	6.1	5.4
483	Fond des Nègres	275	29.5	14.0	11.0	9.8	5.1	5.8
484	Fond des Nègres	275	25.0	15.7	9.5	10.2	6.2	4.0
486	Labordette (Petit Goâve)	375	38.0	17.8	9.6	7.2	7.3	5.2
487	Modieu (Limbé)	35	27.0	19.6	19.6	9.6	5.6	4.8
488	Habitation Préval (Limbé)	15	20.5	17.8	17.8	4.0	4.0	5.1
489	Testas (Jérémie)	5	31.3	22.0	10.4	11.6	7.9	4.0
491	Franklin (Anse d'Hainault)	170	57.0	25.1	15.9	9.2	12.1	4.7
492	Franklin (Anse d'Hainault)	170	46.0	30.0	15.5	14.4	10.5	4.4
494	Dirici (Limbé)	45	64.0	22.2	11.8	14.4	8.4	7.6
496	Testas (Jérémie)	5	37.0	23.2	9.2	7.0	2.9	12.8
548	Fond des Nègres	290	31.0	17.0	5.6	6.2	6.3	4.9
549	Fond des Nègres	290	33.8	16.8	5.4	11.4	3.6	9.4
553	Pémel (Fond des Nègres)	260	38.2	18.0	8.8	9.2	9.0	4.2
<b>Mean</b>		210	36.5	19.8	11.7	9.7	8.2	5.6
<b>Maximum</b>		375	64.0	30.0	19.6	14.4	12.1	12.8
<b>Minimum</b>		5	20.5	14.0	5.4	4.0	2.9	4.0

Annex 2. Survival means of *S. mahagoni*, *S. macrophylla* and *S. macrophylla* x *S. mahagoni* hybrid families and seed lots at various ages and sites in Haiti.

No.	Species	Fauché Arboretum			Marmont Arboretum			Marmont Orchard			Paillant Arboretum		Terrier Rouge Arboretum		Roche Blanche Orchard
		12 Mois	36 Mois	60 Mois	12 Mois	36 Mois	60 Mois	12 Mois	36 Mois	60 Mois	24 Mois	36 Mois	36 Mois	60 Mois	36 Mois
482	<i>S. macrophylla</i>				75.0	75.0	75.0	66.7	66.7	66.7					
483	<i>S. macrophylla</i>							33.3	33.3	33.3					
486	<i>S. macrophylla</i>				100.0	100.0	100.0	33.3	33.3	0.0					
487	<i>S. macrophylla</i>				66.7	66.7	66.7	66.7	0.0	0.0					
489	<i>S. macrophylla</i>				0.0	0.0	0.0	100.0	66.7	66.7					30.4
493	<i>S. macrophylla</i>							75.0	50.0	50.0					0.0
494	<i>S. macrophylla</i>							50.0	50.0	50.0	54.5	36.4			
496	<i>S. macrophylla</i>														16.7
497	<i>S. macrophylla</i>	66.7	57.6	45.5				50.0	50.0	50.0	54.5	45.5			33.3
461	<i>S. mahagoni</i>														50.0
463	<i>S. mahagoni</i>							50.0	41.7	41.7			70.0	60.0	41.1
465	<i>S. mahagoni</i>	80.0	80.0	80.0	75.0	75.0	75.0								16.7
466	<i>S. mahagoni</i>	87.0	82.6	82.6	75.0	75.0	75.0								0.0
467	<i>S. mahagoni</i>				55.6	55.6	44.4	33.3	33.3	33.3	81.5	70.4	70.0	60.0	90.9
477	<i>S. mahagoni</i>														0.0
650	<i>S. mahagoni</i>														50.0
478	Hybrid <sup>1</sup>														100.0
479	Hybrid				56.0	52.0	36.0	66.7	66.7	66.7					65.2
556	Hybrid														27.3
<b>Swietenia Mean</b>		73.3	67.4	67.4	55.4	54.1	47.3	55.1	47.8	46.4	69.4	57.1	70.0	60.0	38.5
<b><i>S. mahagoni</i> Mean</b>		83.0	81.1	81.1	68.0	68.0	64.0	41.7	37.5	37.5	81.5	70.4	70.0	60.0	42.1
<b><i>S. macrophylla</i> Mean</b>		66.7	57.6	45.5	41.7	41.7	41.7	59.3	44.4	40.7	54.5	40.9	-	-	23.6
<b>Hybrid Mean</b>		-	-	-	56.0	52.0	36.0	66.7	66.7	66.7	-	-	-	-	51.4

<sup>1</sup>Hybrid 478 was planted at Roche Blanche in 1989 and achieved a survival rate of 80% after 4 years.

Annex 3. Total height means of *S. mahagoni*, *S. macrophylla* and *S. macrophylla* x *S. mahagoni* hybrid families and seed lots at various ages and sites in Haiti. Means followed by the same letter are not significantly different according to the Waller-Duncan k-ratio Test,  $\alpha = 0.05$ .

No.	Species	Fauché Arboretum			Marmont Arboretum			Marmont Orchard			Paillant Arboretum		Terrier Rouge Arboretum		Roche Blanche Orchard
		12 Mo.	36 Mo.	60 Mo.	12 Mo.	36 Mo.	60 Mo.	12 Mo.	36 Mo.	60 Mo.	24 Mo.	36 Mo.	36 Mo.	60 Mo.	36 Mo.
482	<i>S. macrophylla</i>				0.4 e	3.1 b	2.1 b	1.1 ab	2.1 b	3.5 a					
483	<i>S. macrophylla</i>							0.4 c	2.1 b	2.5 a					
486	<i>S. macrophylla</i>				1.8 a	5.3 a	6.0 a	0.8 abc	5.3 a	-					
487	<i>S. macrophylla</i>				0.9 d	3.3 b	3.5 b	1.2 a	-	-					
489	<i>S. macrophylla</i>				-	-	-	0.7 abc	2.7 b	5.2 a					2.1 a
493	<i>S. macrophylla</i>							1.0 abc	4.2 ab	3.5 a					
494	<i>S. macrophylla</i>							0.5 bc	2.8 ab	3.5 a	0.5 b	0.7 b			
496	<i>S. macrophylla</i>														3.6 a
497	<i>S. macrophylla</i>	1.37 b	7.1 a	10.6 a				1.0 abc	2.5 b	3.7 a	0.7 b	1.5 a			2.7 a
461	<i>S. mahagoni</i>														2.1 a
463	<i>S. mahagoni</i>							0.7 abc	2.9 ab	3.4 a			1.9 a	2.8 a	4.0 a
465	<i>S. mahagoni</i>	1.85 a	4.3 b	5.6 b	1.5 ab	3.7 b	4.2 ab								3.3 a
466	<i>S. mahagoni</i>	1.69 ab	4.1 b	5.7 b	1.4 bc	3.5 b	4.1 ab								
467	<i>S. mahagoni</i>				1.2 bcd	3.7 b	3.7 ab	0.6 abc	3.1 ab	4.4 a	1.1 a	1.3 a	1.4 a	2.1 a	3.5 a
477	<i>S. mahagoni</i>														
650	<i>S. mahagoni</i>														1.3 a
478	Hybrid <sup>1</sup>														
479	Hybrid				1.0 cd	4.0 ab	4.2 ab	0.5 bc	3.6 ab	3.5 a					3.0 a
556	Hybrid														3.1 a
X		1.64	5.20	7.30	1.17	3.79	3.95	0.76	3.12	3.68	0.77	1.16	1.66	2.35	2.86
SE		0.14	0.97	1.66	0.17	0.27	0.43	0.08	0.32	0.25	0.19	0.26	0.26	0.06	0.26
Pr > F		0.0784	0.0001	0.0001	0.0001	0.0161	0.0359	0.0384	0.1184	0.6319	0.0002	0.0462	0.1850	0.2417	0.1252
MSD <sub>0.05</sub>		0.45	0.61	0.84	0.45	1.37	2.31	0.66	2.59	-	0.31	0.66	0.82	1.19	2.88

<sup>1</sup>Hybrid 478 was planted at Roche Blanche in 1989 and achieved a mean height of 6.3 m after 4 years.

Annex 4. Stem diameter (DBH and  $D_{0.1}$ ) means of *S. mahagoni*, *S. macrophylla* and *S. macrophylla* x *S. mahagoni* hybrid families and seed lots at various ages and sites in Haiti. Means followed by the same letter are not significantly different according to the Waller-Duncan k-ratio Test,  $\alpha = 0.05$ .

No.	Species	Fauché Arboretum			Marmont Arboretum			Marmont Orchard			Paillant Arboretum	Terrier Rouge Arboretum			Roche Blanche Orchard
		DBH 36 Mo.	DBH 60 Mo.	$D_{0.1}$ 60 Mo.	DBH 36 Mo.	DBH 60 Mo.	$D_{0.1}$ 60 Mo.	DBH 36 Mo.	DBH 60 Mo.	$D_{0.1}$ 60 Mo.	DBH 36 Mo.	DBH 36 Mo.	DBH 60 Mo.	$D_{0.1}$ 60 Mo.	DBH 36 Mo.
		cm													
482	<i>S. macrophylla</i>				3.3 b	5.0 ab	6.7 b	3.9	4.7 a	7.0 a					
483	<i>S. macrophylla</i>							2.1	2.5 a	5.4 a					
486	<i>S. macrophylla</i>				5.7 a	7.1 a	10.1 a	4.1	-	-					
487	<i>S. macrophylla</i>				2.9 b	3.9 b	6.3 b	-	-	-					
489	<i>S. macrophylla</i>				-	-	-	2.1	6.8 a	9.7 a				1.8 a	
493	<i>S. macrophylla</i>							4.6	3.1 a	6.2 a					
494	<i>S. macrophylla</i>							2.3	2.9 a	5.5 a	-				
496	<i>S. macrophylla</i>													3.4 a	
497	<i>S. macrophylla</i>	6.6 a	11.4 a	15.8 a				2.0	3.9 a	6.3 a	1.0 a			2.3 a	
461	<i>S. mahagoni</i>													1.9 a	
463	<i>S. mahagoni</i>							2.9	3.8 a	6.4 a		1.2	1.8 a	4.3 a	3.8 a
465	<i>S. mahagoni</i>	4.5 b	7.1 b	9.2 b	3.5 b	4.4 b	6.6 b							2.4 a	
466	<i>S. mahagoni</i>	4.1 b	6.9 b	9.0 b	3.3 b	4.4 b	6.7 b								
467	<i>S. mahagoni</i>				3.6 b	4.5 b	7.3 b	2.6	5.3 a	8.8 a	0.6 a	0.7	2.0 a	5.1 a	3.4 a
477	<i>S. mahagoni</i>													-	
650	<i>S. mahagoni</i>													-	
478	Hybrid														
479	Hybrid				3.5 b	4.9 b	7.5 b	3.8	3.7 a	7.2 a				2.9 a	
556	Hybrid													3.1 a	
	<b>X</b>	5.05	8.48	11.32	3.68	4.87	7.31	3.02	4.08	6.93	0.80	0.91	1.88	4.67	2.78
	<b>SE</b>	0.77	1.48	2.23	0.35	0.40	0.49	0.31	0.44	0.48	0.20	0.25	0.10	0.39	0.24
	<b>Pr &gt; F</b>	0.0005	0.0001	0.0001	0.0035	0.0112	0.0055	0.5274	0.4060	0.5515	0.0534	0.4261	0.7009	0.0945	0.5273
	<b>MSD<sub>i</sub></b>	0.83	1.36	1.44	1.50	2.24	2.16	-	-	-	0.41	1.41	1.12	0.94	-

<sup>1</sup>Hybrid 478 was planted at Roche Blanche in 1989 and achieved a mean dbh of 7.5 cm after 4 years.