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Five Year Results of a Neem (*Azadirachta indica*)
Trial at Roche Blanche, Haiti

by
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FOREWORD

Neem (*Azadirachta indica* Adr. Juss.) is a species that is attracting increased scientific and commercial interest around the world because of its content of the chemical azadirachtin, which is a natural insecticide and which also has fungicidal, anti-bacterial and anti-viral properties (National Research Council, 1992). At least two companies in the United States now manufacture commercial insecticides derived from neem. Because neem grows well in Haiti, there is significant opportunity to market and export Haitian azadirachtin. If, as initial tests suggest, there are differences in azadirachtin content within neem populations, the trial described in this report presents an opportunity to identify such differences, select genotypes with high azadirachtin concentration and yield and to disseminate the superior neem varieties in Haiti. This could provide Haiti with a comparative advantage in azadirachtin production and a chance to develop neem as a new agribusiness in Haiti.

Resource constraints did not allow the testing of azadirachtin yield in these trials before the Tree Improvement Program was terminated. However, the trial remains, and can still be utilized to make these determinations, provided that funding is available to carry out the analyses. This is an opportunity that should not be missed.

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SUMMARY

Neem (*Azadirachta indica* Adr. Juss.) is planted in Haiti for its hardiness and multiple purposes of shade, medicinal uses, wood, aesthetics and pest control. A neem trial at Roche Blanche was established in October, 1991 as a collaborative effort of SECID/Auburn University, Agridyne (now Biosys) and Double Harvest. Fourteen seed sources of neem from Africa and the Caribbean were established in a randomized complete block design to examine differences in azairachtin production. Research was discontinued in 1991 when USAID suspended AFII activities, though Double Harvest continued to manage the trees. SECID/Auburn University resumed measuring the trial at 2, 3, and 5 years after trial establishment. This report summarizes the preliminary results of the trial 5 years after its establishment in 1991.

The Roche Blanche neem trial is unique for several important reasons. It is the first trial in Haiti designed to optimize the production of neem fruit rather than wood. Secondly, it is the only trial in Haiti designed to study the genetic variation of neem. Thirdly, the trial marks the first time that neem was introduced and propagated vegetatively in Haiti. This offers a practical alternative to seed as a means of introducing improved genetic material to Haiti.

The data reported here allow an assessment of the trees as a source of wood, but do not permit an assessment of the provenances as sources of the bio-insecticide, azadirachtin. Because of resource constraints, it was not possible to evaluate these neem provenances for fruit and azadirachtin yields within the time allocated for the termination of the Tree Improvement Program.

Survival

Site survival for all seed sources was 91.3% after 5 years. After an initial decline of 10% during the first 2 years, survival rates remained constant to 5 years. There were no statistical differences detected among seed sources during any of the measurement periods, which ranged from 75–100%. The survival exhibited at Roche Blanche is above average for the rates reported elsewhere in Haiti, though about the same for those in the Cul-de-Sac.

Height Growth

The site mean of all seed sources was 9.1 m after 5 years. After an annual growth of 2.2 m/yr during the initial 2 years, mean annual increments have slowly declined to 1.8 m at the 5-year stage. Mean annual increments ranged from 1.7–1.9 m/yr. The only statistical differences detected among seed sources was at 3 years. At this stage, the fastest growing seed source, No. 7 from Niger, showed a significant advantage in height over the slowest seed source, No. 14 from Burkina Faso. Mean annual increments peaked at 2 years (2.1–2.4 m/yr) and will continue to decline toward the 1 m/yr rate as suggested by the data from 3 older FAO trials established nearby in the Cul-de-Sac.

Diameter Growth and Wood Yield

The mean DBH of the site was 12.1 cm after 5 years, ranging from 10.9–13.1 cm among the seed sources. There were no statistical differences shown at 3 and 5 years for DBH. Statistical differences were detected between the top four seed sources and the bottom one for basal or stump diameter. The site average for basal diameter was 16.4 cm, ranging from 13.9–17.4 cm among seed source means.

The site average for wood yield was 34.1 kg/tree, slightly less than the average of the control (34.7 kg/tree). Wood yield means ranged from 28.1 kg/tree for No. 2 (Puerto Rico) to 40.8 kg/tree for No. 10 (Burkina Faso). There were no statistical differences among the seed sources for wood yield, either on a kg/tree or metric ton/ha basis. Yields on a per tree basis are about average compared to other trials established in the Cul-de-Sac. An average of 7.15 metric tons/ha was observed for all seed sources. However, the low tree density of the trial (227 trees/ha) was not designed to optimize wood production and wood yields on a per hectare basis are far below potential yields at a higher density.

Conclusions

The trial at Roche Blanche showed a remarkable uniformity among neem seed sources for survival, height and diameter growth and wood yields. Though the trials contain the broadest genetic base of the species in Haiti, this base may still be relatively narrow compared to populations found within its native range. It is reasonable that some of the low variation may be due to a narrow genetic base inherent in neem populations where the species is not native (such as Africa and the Caribbean). It also may indicate that the genetic variation in the species is not large, though this awaits a rigorous test of provenances from the species' natural range.

The trial was successful in testing an alternative method for introducing and propagating new neem genotypes. The shipping of neem seed has been a barrier in the past to successful introductions. However, stump material, processed according to international phytosanitary regulations, appears to be a more practical solution, particularly for improved genetic stock that may be expensive. The 10 m spacing between the double rows of neem allowed flower and fruit production to occur as early as 2 years. Optimal spacing and management procedures for fruit production are still unknown and remain a challenge for future research.

The uniformity among neem seed lots should be confirmed for fruit and azadirachtin yields at the earliest time possible. The screening of genotypes for azadirachtin yield and determination to what degree this attribute is inherited is perhaps the most important priority at this time. Given this information, it would make sense to distribute improved germplasm through containerized nurseries to farmer producer groups and organize such efforts to gain an export advantage relative to other countries in the Caribbean for Haiti.

Recommendations

(1) Compare the fruit yield and azadirachtin concentrations of the seed sources to discover any differences that may exist among seed sources within the trial. The yields of each tree should be kept separate and processed according to the methods used to harvest the seed for azadirachtin production. Random sub-samples of the seed would be selected from each seed source and block for azadirachtin assays. Conduct the assays with independent laboratories in case there are differences in handling and analytical procedures. Bear in mind that the production of azadirachtin and oils in the seed kernel may have greater economic potential than wood and shade production.

(2) Select at the individual level the best-formed individuals for both fruit production and wood production. Selective criteria should be tree form, fruit yield and seed quality. Multiply superior genotypes by root cuttings or grafting to shorten the time required for economic fruit yield and enlarge the production base of improved genotypes.

(3) Prune selected trees for strong primary branches that can support large fruit crops and eliminate any diseased wood by burning. Prune the canopy branches sufficiently to allow a balanced penetration of sunlight to ensure optimal flower pollination and fruit set.

(4) Investigate optimal tree density for fruit production and investment opportunities for a combination of oil and azadirachtin processing in Haiti. Schedule management inputs to yield an optimal marketing mix for conditions in Haiti. Determine marketing constraints of neem products from the context of decentralized production.

(5) Incorporate an improved genetic base of neem into the PLUS extension system via containerized nurseries of PADF and CARE. Experiment with both seed and vegetative material. Keep careful nursery and distribution records to allow tracking of improved genetic stock.

(6) Procure true provenance collections from countries of origin (e.g. India and Burma), establish these collections on secure sites as in-country seed sources, and begin distributing this mix along with what is already being used. Establish contact with the International Neem Network through USAID via Winrock International's F/FRED project in Thailand, DANIDA, CIRAD-Forêts for available provenance-wide seed collections and assistance in expediting germplasm to Haiti. Purchase stumps or cuttings of the best genetic material available, packed in sterile peat moss. This is a better alternative than seed and has a greater likelihood of success in establishing new or improved provenances of *A. indica* in Haiti.

(7) Continue monitoring the trial for a longer period, particularly for resistance to disease, pests and hurricanes, wood quality and other parameters that effect its potential economic impact to Haitian farmers. Keep abreast of new pathogens, maintaining correspondence with the Arid Forest Research Institute (Jodhpur, India) and literature searches conducted at US universities. AFRI produces the Neem Newsletter which is a good information source for neem.

RESUME

Le Neem (*Azadirachta indica* Adr. Juss) est planté en Haiti pour sa rusticité et de multiples usages: arbre d'ombre, médicament, produits ligneux, arbre ornemental et pesticide. Un essai sur le neem à Roche Blanche a été établi en octobre 1991, dans le cadre d'un effort conjoint SECID/Université d'Auburn, Agridyne (actuellement Biosys) et Opération Double Harvest. Quatorze sources de semences de neem venant d'Afrique et des Caraibes ont été installées, utilisant un dessin expérimental de blocs complètement au hasard, pour examiner les différences dans la production d'azadirachtin. La recherche s'est interrompue en 1991 quand l'USAID a suspendu les activités de l'AFII, bien que Double Harvest ait continué à gérer les arbres plantés. SECID/Université d'Auburn recommença à effectuer des mensurations à 1, 3 et 4 ans après l'établissement de l'essai. Ce rapport résume les résultats préliminaires de l'essai, 5 ans après son établissement en 1991.

L'essai de neem de Roche Blanche est unique pour plusieurs raisons. C'est le premier en Haiti conçue pour optimiser la production des fruits de neem plutôt que le bois. Deuxièment, c'est le seul visant à étudier la variation génétique du neem. Troisièmement, il met en évidence pour la première fois, que le neem a été introduit et propagé végétativement en Haiti, ce qui offre une alternative pratique à la propagation par semences, un moyen d'introduire du matériel génétique amélioré en Haiti.

Les chiffres rapportés ici permettent une évaluation des arbres comme source de bois, mais pas une évaluation des provenances comme source de bio-insecticide, l'azadirachtin. A cause de contraintes de ressources, il n'a pas été possible d'évaluer ces provenances de neem pour les rendements en fruits et en azadirachtin à cause du peu de temps alloué pour terminer le Programme d'Amélioration Génétique Forestière.

Survie

La survie du site pour toutes les sources, a été de 91,3% après 3 ans. Après un déclin initial de 10% pendant les deux premières années, les taux de survie sont restés constants jusqu'à 5 ans. Il n'y a pas eu de différences significatives détectées entre les sources de semences au cours de la période de mensurations. Les chiffres se sont rangés entre 75 et 100%. Les taux de survie accusés à Roche Blanche sont au dessus de la moyenne, par rapport à ceux enregistrés ailleurs en Haiti, bien qu'ils soient similaires à ceux trouvés dans la Plaine du Cul de Sac.

Croissance en Hauteur

La moyenne du site pour toutes les sources de semences a été de 9,1 m après 5 ans. Après une croissance annuelle de 2,2 m/an pendant les 2 premières années, les accroissements annuels moyens ont lentement décliné à 1,8 m à l'âge de 5 ans, entre 1,7 - 1,9 m/an. Les seules différences statistiques entre les sources de semences ont été détectées à 3 ans. A ce stade, le lot de semences le plus rapide, No. 7 du Niger, a montré un avantage significatif en hauteur sur celui à croissance la plus lente, No. 14 de Burkina Faso. Les accroissements annuels ont atteint leur apogée à 2 ans (2,1 - 2,4 m/an) et déclineront à 1 m/an, comme indiqué par les données recueillies des 3 essais précédemment établis par la FAO près de la Plaine du Cul de Sac.

Croissance en diamètre et Rendement en bois

Le DHP moyen pour le site a été de 12,1 cm après 5 ans, se rangeant de 10,9 à 13,1 cm entre les sources de semences. Des différences statistiques n'ont pas été détectées à 3 et 5 ans pour le DHP. Il y en a eu entre les quatre lots de semences les plus performants et le dernier pour le diamètre basal ou de souche. La moyenne du site pour le diamètre basal a été de 16,4 cm, se rangeant de 13,9 à 17,4 cm entre les moyennes des provenances.

La moyenne du site pour le rendement en bois a été de 34,1 kg/arbre, légèrement inférieure à la moyenne du contrôle (34,7 kg/arbre). Les moyennes pour le rendement en bois se sont rangées de 28,1 kg/arbre pour le No.2 (Porto Rico) à 40,8 kg/arbre pour le No. 10 (Burkina Faso). Il n'y a pas eu de différences significatives entre les sources de semences pour le rendement en bois, tant sur une base de kg/arbre qu'en tonne métrique/ha. Les rendements par arbre sont moyens, comparés aux résultats obtenus dans d'autres essais établis dans la Plaine du Cul de Sac. Une moyenne de 7,15 tonnes métriques/ha a été observée pour toutes les sources de semences. Cependant, la faible densité des arbres de l'essai (227 arbres/ha) ne visait pas à optimiser la production ligneuse, et les rendements en bois à l'hectare sont très en dessous des rendements potentiels à une densité plus élevée.

Conclusions

L'essai à Roche Blanche a montré une remarquable uniformité entre les sources de semences de neem pour la survie, la croissance en hauteur et en diamètre, et les rendements en bois. Bien qu'il ait la base génétique la plus large possible trouvée en Haiti, cette base peut être relativement étroite comparativement aux populations trouvées dans l'aire de distribution naturelle de l'espèce. Il est raisonnable de penser que ce bas taux de variation peut être quelque peu dû à la base génétique étroite inhérente aux populations de neem là où l'espèce n'est pas originaire (comme en Afrique et dans les Caraibes). Il peut aussi indiquer que la variation génétique dans l'espèce n'est pas grande, bien que cette hypothèse demanderait un test rigoureux des provenances issues de l'aire naturelle de l'espèce.

L'essai a réussi dans le test d'une méthode alternative pour l'introduction et la propagation de nouveaux génotypes de neem. L'expédition de semences de neem a été une barrière dans le passé pour mener à bien des introductions. Cependant, le matériel de souche, conditionné selon les règlements phytosanitaires internationaux, semble une solution plus pratique, particulièrement pour le stock génétique amélioré qui peut coûter cher. L'espacement de 10 m entre les double rangées de neem a permis la production précoce de fleurs et de fruits à 2 ans. L'espacement optimal et les procédures de gestion pour la production de fruits sont encore inconnus et restent à déterminer par les recherches futures.

L'uniformité entre les lots de semences devraient être confirmée pour les rendements en fruits et azadirachtin le plus tôt possible. La sélection de génotypes pour le rendement en azadirachtin et la détermination du degré d'héritage de cet attribut, est peut être la priorité la plus importante pour le moment. A partir de ces informations, du germoplasme amélioré, en utilisant des plantules en pots, pourrait être distribué à des groupements de planteurs, et en organisant de tels efforts, Haiti pourrait gagner dans l'exportation du neem, un avantage comparatif par rapport à d'autres pays de la Caraibe.

Recommandations

(1) Comparer les rendements en fruits et les concentrations en azadirachtin des lots de

semences pour découvrir des différences qui pourraient exister entre les sources testées. Les rendements de chaque arbre devraient être tenus séparément et traités selon les méthodes de récolte des semences pour la production d'azadirachtin. Des sous-échantillons de semences pris au hasard devraient être sélectionnés pour chaque source de semences et blocs pour des analyses d'azadirachtin. Les faire étudier dans des laboratoires indépendants, au cas où il y aurait des différences dans les procédures d'analyse et de manipulation. Se rappeler que la production d'azadirachtin et d'huile dans les graines de neem, peut avoir un plus grand potentiel économique que la production de bois et d'ombre.

(2) Sélectionner les meilleurs individus, tant pour la production de fruits que pour la production de bois. Les critères de sélection devraient être la forme de l'arbre, le rendement en fruits et la qualité des semences. Multiplier les génotypes supérieurs par le bouturage de racines ou le greffage pour raccourcir le temps requis pour le rendement économique en fruits et augmenter la base de production des génotypes améliorés.

(3) Tailler les arbres sélectionnés pour obtenir des branches primaires vigoureuses qui peuvent supporter de bonnes récoltes de fruits et éliminer tout bois malade par le feu. Tailler adéquatement les branches du feuillage pour permettre une pénétration équilibrée de la lumière afin d'assurer une pollinisation de fleurs et une production de fruits optimales.

(4) Mener des recherches sur la densité optimale des arbres pour la production de fruits et sur les opportunités d'investissements dans l'extraction d'huile et d'azadirachtin en Haiti. Programmer les intrants de gestion pour atteindre l'optimum dans la commercialisation de ces produits dans les conditions rencontrées en Haiti. Déterminer les contraintes du marché pour les produits du neem, en considérant le contexte de production décentralisée.

(5) Incorporer une base génétique améliorée du neem dans le système d'extension de PLUS, via des pépinières en pots de PADF et de CARE. Expérimenter tant les semences que le matériel végétatif. Enregistrer soigneusement les données recueillies en pépinière pour permettre d'assurer un suivi du stock génétique amélioré.

(6) Se procurer de collections de vraies provenances des pays d'origine (e.g. Inde et Burma), établir ces collections sur des sites sûrs comme sources de semences pour le pays et commencer à faire la distribution de ce mélange en même temps que ce qui est déjà utilisé. Etablir des contacts avec le Réseau International de Neem à travers l'USAID, via le Projet F/FRED de Winrock International, DANIDA, CIRAD-Forêts, pour obtenir des collections de semences de provenances disponibles à base assez large et de l'assistance dans l'expédition du germoplasme vers Haiti. Acheter des souches ou boutures du meilleur matériel génétique disponible, emballées dans de la tourbe stérile. C'est une meilleure alternative que celle des semences, qui est plus susceptible de réussir pour l'établissement de provenances nouvelles ou améliorées d'*A. indica* en Haiti.

(7) Continuer à évaluer l'essai sur une plus longue période, particulièrement pour la résistance aux maladies, pestes et ouragans, la qualité du bois et autres paramètres qui affectent l'impact du potentiel économique au niveau des planteurs haitiens. Se tenir au courant de nouveaux pathogènes, maintenant la correspondance avec l'Institut de Recherches Forestières en Zones Arides (Jodhpur, Inde) et des recherches de littérature menées dans les universités américaines. AFRI publie le Bulletin du Neem, qui est une bonne source d'informations sur l'espèce

TABLE OF CONTENTS

Foreword ii

Summary iii

Résumé vi

Acknowledgments xi

Acronyms xii

Introduction 1

Objectives 1

Materials and Methods 2

- **Study Site** 2
- **Germplasm Collection and Propagation** 3
- **Trial Establishment and Experimental Design** 3
- **Measured Variables and Observations** 4
- **Statistical Analysis** 4

Results and Discussion 5

- **Survival** 5
- **Height Growth** 6
- **Diameter Growth and Wood Yield** 7
- **Observation on Optimal Tree Density for Fruit Production** 9

Conclusions 10

Recommendations 10

References 11

LIST OF TABLES

Table 1. Site characteristics of the *A. indica* trial at Roche Blanche 2

Table 2. Country sources of the *A. indica* accessions at the Roche Blanche trial. 3

Table 3. Experimental design of the *A. indica* trial at Roche Blanche 3

Table 4. Survival means of *A. indica* seed sources after 2, 3, and 5 years at Roche Blanche. . . . 5

Table 5. Total height means of *A. indica* seed sources at Roche Blanche 6

Table 6. Stem diameter and wood yield means of *A. indica* seed sources after 3 and 5 years at Roche Blanche 8

LIST OF FIGURES

Figure 1. Location of the *A. indica* trial at Roche Blanche, Haiti 2

Figure 2. Design of the *A. indica* trial at Roche Blanche 4

Figure 3. Comparison of height growth among *A. indica* seed sources after 2, 3 and 5 years at Roche Blanche 7

Figure 4. Five-year wood yield comparisons among *A. indica* seed sources at Roche Blanche . . 9

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ACRONYMS

AFII	Agroforestry II
AOP	Agroforestry Outreach Project
IRG	International Resources Group, Ltd.
ODH	Operation Double Harvest
PADF	Pan American Development Foundation
PLUS	Productive Land Use System
SECID	South East Consortium for International Development
USAID	United States Agency for International Development

INTRODUCTION

Azadirachta indica Adr. Juss. is a medium-sized tree of the mahogany family (Meliaceae) that is native to India and southeast Asia. It was introduced to Haiti in the late 1960s, from seed believed to have originated in Senegal, and has spread throughout the country largely as a result of the roadside plantings supported by the Ministry of Agriculture and agroforestry extension efforts funded by USAID (Timyan, 1996). Most of the neem that occurs throughout Haiti is likely derived from the narrow genetic base of the handful of seed from Senegal. Efforts to enlarge the genetic base in Haiti have largely been unsuccessful due in part to seed germination problems, poor seed yield of imported provenances and project discontinuities.

The tree is primarily planted for its hardiness, fast growth, deep shade and a multiple range of additional benefits, including a natural and renewable control of household and agricultural pests. The tree produces several compounds, notably azadirachtin, that is toxic to many insect pests that cause substantial crop loss. In Haiti, neem is used to protect tomato, papaya, cabbage, cucurbits and other vegetables against a host of insect pests. The tree has been researched for its various benefits in Haiti and a summary of this research is found in Timyan (1996). Most of this research was conducted as part of the USAID-funded AOP (1981–1987) and the AFII (1988–1992) and covered growth studies (Bihun, 1982; Dupuis, 1986a), biomass studies (Timyan, 1983; Ehrlich, 1985; Timyan, 1987), utilization and wood products (Welle et al., 1985; Grosenick, 1986; Rouzier, 1990), silviculture (Larson et al., 1985; Dupuis, 1986b; Tourigny, 1987; Josiah, 1989; Runion et al., 1990; Hernandez, 1991; Reid, 1991), seed handling (Timyan, 1991), and azadirachtin levels (Timyan and Walter, 1990).

A neem trial at Roche Blanche was established in October, 1991 as a collaborative effort of SECID/Auburn University, Agridyne and Double Harvest. The original objective was to examine differences in azadirachtin production of fourteen seed sources originating in Africa and the Caribbean. Unfortunately, USAID support for the trial was abruptly curtailed as a result of the coup d'état in September, 1991, the ensuing economic embargo and a shift in USAID focus away from tree research. Research was discontinued, though Double Harvest continued to manage the trees. SECID/Auburn University resumed measuring the trees in 1993 for survival, height and diameter parameters. This report summarizes the first 5 years of tree growth, though the research cannot be considered complete until azadirachtin yields have been sufficiently measured once the trees are in full production. USAID support of research on tree improvement, as part of the PLUS project, was terminated effective September 30, 1996.

The neem trial at Roche Blanche is unique for several important reasons. It is the first trial designed to optimize the production of fruit rather than wood. Secondly, it is the first time in Haiti that the genetic variation of neem has been examined. Thirdly, the trial marks the first time that neem was introduced and propagated vegetatively in Haiti. This offers a practical alternative to seed as a means of introducing improved genetic material to Haiti.

OBJECTIVES

(1) Examine a broad genetic base of *A. indica* for differences in survival, growth characteristics and azadirachtin production.

(2) Expand the opportunities to broaden the genetic base of *A. indica* in Haiti by importing germplasm collected in West Africa and the Caribbean.

(3) Confirm early seed production of *A. indica* at low stem densities (227 trees/ha).

MATERIAL AND METHODS

Study Site

The trial is located in the Cul-de-Sac Plain near Croix-des-Bouquets. Land use in the area is primarily irrigated crop land – a mix of sugarcane, vegetables, tomatoes, sorghum, corn and beans. The soil is an alluvial sandy loam overlaying calcareous rock and clays. Rainfall in the area is sub-humid, with fairly constant northeasterly trade winds. The area was formerly covered with subtropical dry forest that is now dominated by *Prosopis juliflora* on the drier sites and a mix of native and exotic trees species around habitations, roads, irrigation canals and farm boundaries. Double Harvest, involved with neem since the late 1970s, allocated land for the trial in 1991 at their Roche Blanche farm. The following table summarizes the site characteristics at Roche Blanche (**Table 1**). The location of the trial is shown in **Figure 1.**

Table 1. Site characteristics of the *A. indica* trial at Roche Blanche.

LATITUDE	**18º 32'**
LONGITUDE	**72º 11'**
ALTITUDE (m)	**25**
RAINFALL (mm/yr)	**900**
RAINY SEASON	**April–May, Sept-Oct**
HOLDRIDGE LIFE ZONE	**Subtropical Dry Forest**
SLOPE (%)	**0-1**
SOIL pH	**8.2 - 8.3**
% CLAY	**17.5**
ppm P	**54.0 - 56.5**
% ORGANIC MATTER	**2.6 - 2.7**

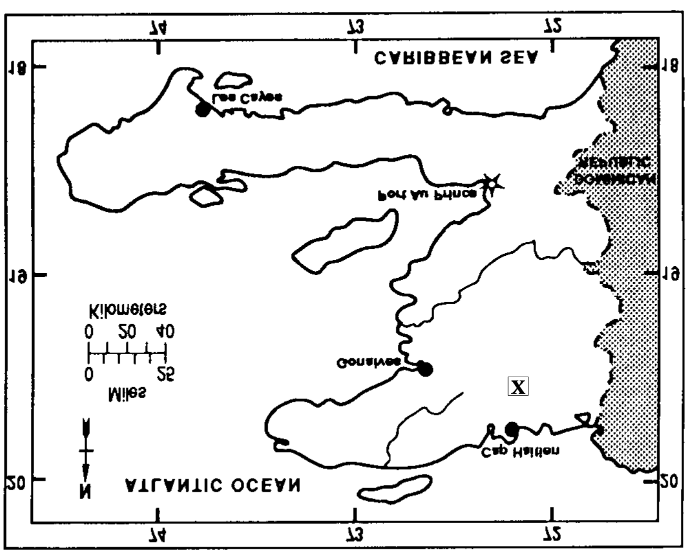

Figure 1. Location of the *A. indica* trial at Roche Blanche, Haiti.

Germplasm Collection and Propagation

Seed was collected by Biosys (formerly Agridyne and Native Plants) in April, 1991 during a study of neem seed sources in West Africa and the Caribbean (**Table 2**). Because of the rapid deterioration of the seed at ambient temperature and humidity, the collections were hand carried to Salt Lake City, UT and immediately propagated in containers at the Biosys greenhouse. Four month-old seedlings were prepared for transport to Haiti by pruning the roots and shoots to a 20-cm stump, washing off all soil, and packing each lot separately in moist, sterilized peat moss. The stumps were potted at the Roche Blanche nursery in large Winstrip containers filled with a mixture of loam and "Haiti Mix," a potting medium composed of decomposed bagasse, vermiculite, peat moss and silty loam. Loam was taken from beneath a stand of neem trees to encourage the inoculation, if any, of mycorrhizae and other soil factors that might enhance outplanting success. The rooted stumps were raised under greenhouse conditions for 3 months prior to a hardening-off period of 3 weeks in full sun, decreased fertilization and watering. The control was harvested from trees near Ganthier that showed an unusually high percentage of double kernels and large seeded fruit. This may be a trait that is favorable for azadirachtin production. The seed was sown in May, 1991 and were about the same age and root collar diameter as the seedlings produced by Biosys.

Table 2. Country sources of the *A. indica* accessions at the Roche Blanche trial.

LOT NO.	COUNTRY	LOT	COUNTRY
2	Puerto Rico	9	Burkina Faso
3	Dominican	10	Burkina Faso
4	Senegal	12	Burkina Faso
5	Togo	13	Burkina Faso
6	Niger	14	Burkina Faso
7	Niger	15	Burkina Faso
8	Burkina Faso	17	Haiti

Trial Establishment and Experimental Design

Prior to trial establishment, the soil was cleared of all woody stumps, plowed, disced and furrowed to align and properly space the tree rows. The trees were planted in double rows, 2.0 m apart between the rows and 10 m apart between the double rows. Holes were dug at 2.0 m distances within each row and in triangular fashion. The trials were established as randomized complete block designs with 4 blocks. The blocks ran east/west and perpendicular to row orientation. A plot consisted of 5 trees (3 trees in one row and 2 trees in the other), each accession being randomly assigned the location within each double-row. All trees within plot were measured throughout the study period. Table 3 summarizes the information regarding each trial. An illustration of the trial layout is shown in **Figure 2.**

Table 3. Experimental design of the *A. indica* trial at Roche Blanche.

ESTABLISHMENT DATE	**October 30, 1991**
NO. OF ACCESSIONS	**14**
NO. OF REPLICATIONS	**4**
TREES/PLOT	**5**
ROW SPACING (m)	**2.0 x 2.2**
DOUBLE ROW SPACING (m)	**10.0**

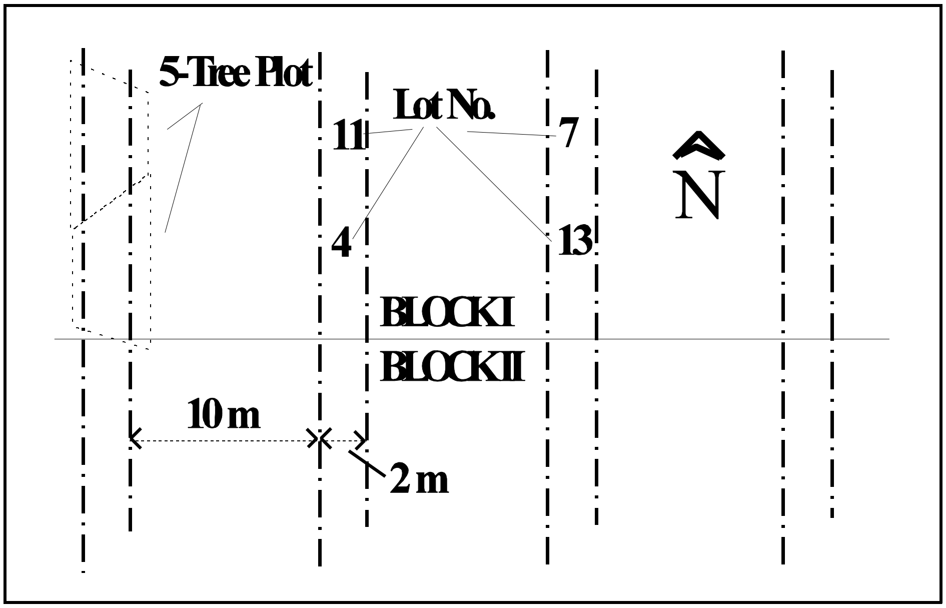

Figure 2. Design of the *A. indica* trial at Roche Blanche.

Measured Variables and Observations

The trial was measured at 2, 3 and 5 years from the establishment date. The first year measurements were not taken for reasons cited above. The parameters considered for measurement were as follows:

1) Survival, in %, at 2, 3 and 5 years.

2) Total height, to nearest 0.1 meter, measured with a telescopic height pole at 2, 3 and 5 years.

3) Diameter at 1,30 m above ground, to nearest 0.1 cm, measured with a cloth diameter tape at 3 and 5 years. This diameter is given as DBH.

4) Basal or stump diameter at 0.1 m above ground, to nearest 0.1 cm, measured with a cloth diameter tape at 5 years. This diameter is given as $D_{0.1}$.

Additionally, the status of each tree was evaluated and assigned a code that corresponded to a range of possible factors affecting its status. Any tree that was damaged due to non-natural causes, mostly human or animal damage, was eliminated from the data used to determine height and diameter statistics. The 3-year seed harvest was sampled and analyzed for azadirachtin levels by 2 laboratories (Biosys and W. R. Grace) in the US. However, the seed was not sampled correctly to analyze for seed source differences and the results are not included in this report.

Statistical Analysis

The field data was entered into Lotus 123 spreadsheet and prepared for statistical analyses using SAS 6.04 (SAS, 1988). Survival data required an arcsin transformation procedure, as provided in Steele and Torrie (1980). Analysis of variance procedures were conducted for survival, total height, stem diameters and wood yields. The Waller-Duncan k-ratio test was selected for means comparisons. Wood yields, for wood greater than 1-cm diameter, were estimated by a regression equation based on biomass studies conducted at Thomazeau (Timyan, 1996). For *A. indica*, this equation is as follows: wood yield (kg) = 0.282*(DBH^2) - 0.707*(DBH), where DBH is equal to stem diameter at 1.3 m above ground level. Graphics were prepared with DrawPerfect 1.1 and this document was compiled with WordPerfect 6.1.

RESULTS AND DISCUSSION

Survival

Site survival for all seed sources was 91.3% after 5 years. After an initial decline of 10% during the first 2 years, survival rates remained constant to 5 years. There were no statistical differences detected among seed sources during any of the measurement periods. Survival ranged from a low of 75% for No. 9 from Burkina Faso to a high of 100% for 4 seed sources from Senegal (No. 4), Niger (No. 7) and Burkina Faso (No. 12 and No. 15).

There is no evidence that seed source has any effect on survival. It should be noted however, that the seed sources are all from countries where *A. indica* is an exotic. Thus, the genetic base that is being tested could be quite narrow relative to the variation found from provenances within the native range of the species. A summary of the survival data among *A. indica* seed sources is provided in **Table 4**. The survival exhibited at Roche Blanche is above average for the rates generally reported elsewhere in Haiti, though about the same for those reported in the Cul-de-Sac (Timyan, 1996). In general, *A. indica* is a high survivor and problems only occur if a severe drought or excessive early weed competition occurs.

Table 4. Survival means of *A. indica* seed sources after 2, 3, and 5 years at Roche Blanche. Means followed by the same letter are not significantly different according to the Waller-Duncan k-ratio Test, a=0.05 of the arc-sine transformed data.

		2 YEARS	3 YEARS	5 YEARS
LOT NO.	SOURCE	(%)		
2	Puerto Rico	80.0 a	80.0 a	80.0 a
3	Dominican Republic	95.0 a	95.0 a	95.0 a
4	Senegal	100.0 a	100.0 a	100.0 a
5	Togo	85.0 a	85.0 a	85.0 a
6	Niger	85.0 a	85.0 a	85.0 a
7	Niger	100.0 a	100.0 a	100.0 a
8	Burkina Faso	90.0 a	90.0 a	90.0 a
9	Burkina Faso	80.0 a	75.0 a	75.0 a
10	Burkina Faso	85.0 a	85.0 a	85.0 a
12	Burkina Faso	100.0 a	100.0 a	100.0 a
13	Burkina Faso	95.0 a	95.0 a	95.0 a
14	Burkina Faso	90.0 a	90.0 a	90.0 a
15	Burkina Faso	100.0 a	100.0 a	100.0 a
17	Haiti	95.0 a	95.0 a	95.0 a
	MEAN	91.64	91.3	91.3
	SE	1.85	1.99	1.99
	Pr > F (arc-sine transformed data)	0.2224	0.2061	.2061

Height Growth

The site mean of all seed sources was 9.1 m after 5 years. After an annual growth rate of 2.2 m/yr during the first 2 years, mean annual increments have slowly declined to 1.8 m at the 5-year stage. A summary of the height growth data is provided in **Table 5**. A comparison of the differences among seed sources is illustrated in Figure 3.

No. 7, from Niger, was the leader in height growth after 3 and 5 years, averaging 1.9 m/yr over a period of 5 years. The only statistical difference detected among seed sources was at the 3-year stage. At this stage, No. 7 showed an advantage over the slowest seed source, No. 14 from Burkina Faso. The Haitian control averaged close to the same height as the site mean during each measurement period and showed no statistical difference from the other seed sources. The growth of the seed lots at Roche Blanche show remarkable uniformity. There is no way of knowing whether this is due to the narrow genetic base of the seed sources in Africa and the Caribbean or if the species as a whole exhibits low levels of variation.

The slowest growing seed sources averaged 1.7 m/yr and originated from Puerto Rico (No. 2), Togo (No. 5) and Burkina Faso (No. 14). The difference between the slowest and fastest growing seed sources remained constant throughout the trial and averaged 1 m.

Table 5. Total height means of *A. indica* seed sources at Roche Blanche. Means followed by the same letter are not significantly different at the 95% probability level, according to the Waller-Duncan k-ratio Test.

		2 YEARS	3 YEARS	5 YEARS
LOT NO.	SOURCE	(m)		
2	Puerto Rico	4.1 a	5.6 ab	8.6 a
3	Dominican Republic	4.3 a	5.6 ab	9.0 a
4	Senegal	4.8 a	6.3 ab	9.4 a
5	Togo	4.3 a	5.7 ab	8.7 a
6	Niger	4.3 a	5.9 ab	9.3 a
7	Niger	4.7 a	6.5 a	9.7 a
8	Burkina Faso	4.5 a	6.1 ab	9.3 a
9	Burkina Faso	4.5 a	6.1 ab	9.3 a
10	Burkina Faso	4.7 a	6.3 ab	9.5 a
12	Burkina Faso	4.6 a	6.1 ab	9.1 a
13	Burkina Faso	4.5 a	6.2 ab	9.3 a
14	Burkina Faso	4.4 a	5.5 b	8.7 a
15	Burkina Faso	4.7 a	6.1 ab	9.2 a
17	Haiti	4.5 a	6.2 ab	9.1 a
	MEAN	4.50	6.03	9.17
	SE	0.05	0.07	0.08
	Pr > F	0.4147	0.1149	0.3312
	Minimum Significant	0.88	0.96	1.33

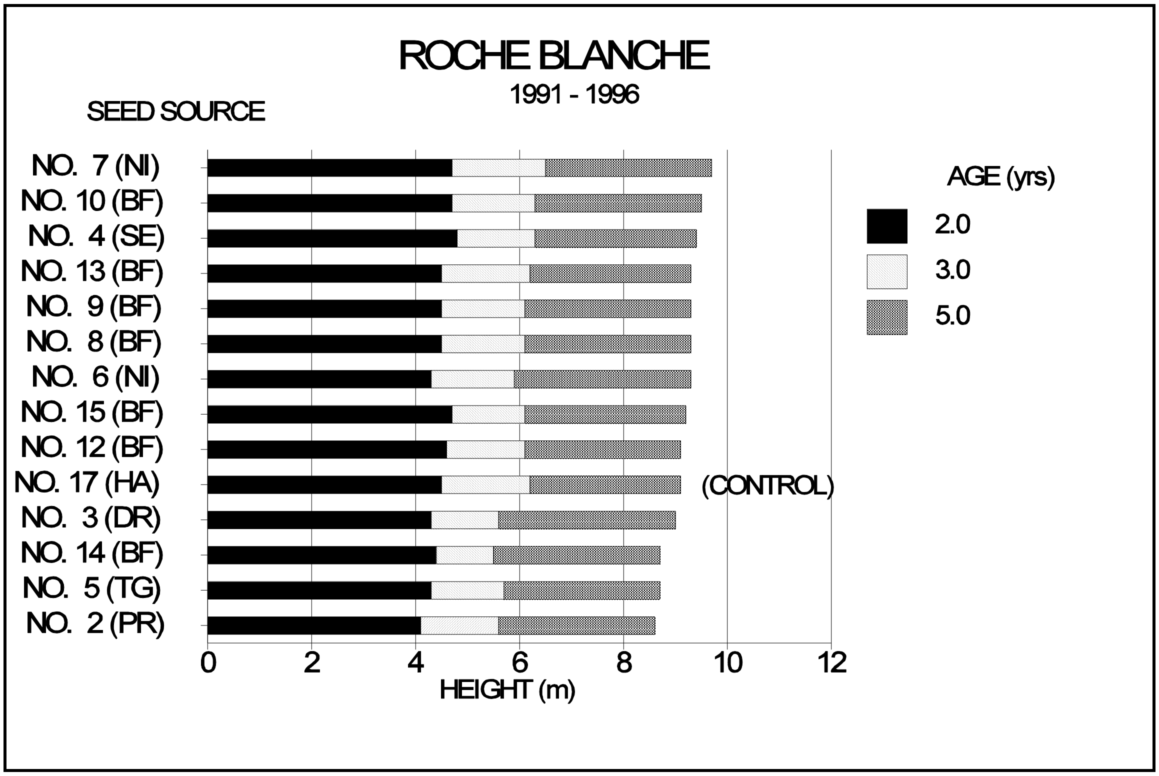

Figure 3. Comparison of height growth among *A. indica* seed sources after 2, 3, and 5 years at Roche Blanche.

The growth rates observed at Roche Blanche are about average compared to other trials in Haiti of the same age (Timyan, 1996). These include *A. indica* trials at Mirebalais (1.8 m/yr after 3.2 years), Limonade (1.4 m/yr after 3.5 years) and Terrier Rouge (1.7 m/yr after 2.9 years). It is possible that the more fertile soil conditions at Roche Blanche compensate for the higher rainfall at the Mirebalais trial. Mean annual increments (MAI) will continue to decline toward the 1 m/yr rate, as suggested by the data from 3 trials established by FAO (Hernandez, 1991). The MAI for these trials, measured at between 9 and 10 years, ranged from 1.0–1.2 m/yr.

Diameter Growth and Wood Yield

The mean DBH of the site was 12.1 cm after 5 years. The largest diameter growth was exhibited by a Burkina Faso seed source (No. 10), attaining an average of 13.1 cm after 5 years. The smallest average stem diameter was shown by the Senegalese seed source, No. 4 (10.9 cm) and No. 2 (11.0 cm) from Puerto Rico. There were no statistical differences detected among the seed sources for DBH (**Table 6**). The Haitian control ranked 9th and averaged 12.1 cm, the same as the site mean for DBH.

In general, the rankings for basal diameter followed the same pattern as for DBH. No. 10 from Burkina Faso was the leader and No. 2 from Puerto Rico was the smallest. Statistical differences were shown between the top four seed sources and the bottom one. The Haitian control was ranked near the bottom (12th) and averaged less than the site mean. The differences among seed sources for basal diameter show a greater significance than for DBH, due in part by

Table 6. Stem diameter and wood yield means of *A. indica* seed sources after 3 and 5 years at Roche Blanche. Means followed by the same letter are not significantly different at the 95% probability level, according to the Waller-Duncan k-ratio Test.

		DBH (2 YRS)	DBH (3 YRS)	DBH (5 YRS)	$D_{0.1}$ (5 YRS)	WOOD YIELD	
LOT NO.	SOURCE	(cm)				(kg/tree)	(mt/ha)
2	Puerto Rico	3.6 b	6.9 a	11.0 a	13.9 b	28.1 a	5.4 a
3	Dominican	4.6 ab	7.8 a	12.5 a	16.4 ab	37.1 a	7.9 a
4	Senegal	5.1 a	7.5 a	10.9 a	14.9 ab	26.6 a	6.0 a
5	Togo	4.4 ab	7.8 a	12.1 a	17.2 a	33.9 a	7.0 a
6	Niger	4.5 ab	8.0 a	12.4 a	17.3 a	36.1 a	7.1 a
7	Niger	5.3 a	8.8 a	12.8 a	16.7 ab	38.2 a	8.7 a
8	Burkina Faso	4.9 a	8.1 a	12.3 a	16.5 ab	35.1 a	7.3 a
9	Burkina Faso	4.9 a	8.0 a	12.2 a	16.8 ab	33.7 a	5.8 a
10	Burkina Faso	4.4 ab	8.5 a	13.1 a	17.4 a	40.8 a	7.9 a
12	Burkina Faso	5.1 a	7.9 a	12.3 a	16.9 a	34.9 a	8.0 a
13	Burkina Faso	4.8 ab	8.0 a	11.8 a	16.1 ab	32.7 a	7.0 a
14	Burkina Faso	4.0 ab	7.3 a	11.3 a	16.4 ab	28.9 a	5.9 a
15	Burkina Faso	4.9 a	8.3 a	12.4 a	16.5 ab	35.7 a	8.1 a
17	Haiti	4.8 ab	8.2 a	12.1 a	15.6 ab	34.7 a	7.6 a
	MEAN	4.68	7.95	12.11	16.37	34.14	7.15
	SE	0.10	0.14	0.16	0.22	0.99	0.27
	Pr > F	0.0789	0.5878	0.2139	0.1165	0.2430	0.4803
	MSD, a=0.05	1.27	–	2.54	3.00	15.00	4.91

the low-forking habit of neem. The plots varied tremendously in the proportion of multi-stemmed individuals at DBH, causing variation that contributed to a larger error term.

The site average for wood yield was 34.1 kg/tree, slightly less than the average of the control (34.7 kg/tree). Wood yield means ranged from 28.1 kg/tree for Puerto Rico No. 2 to 40.8 kg/tree for Burkina Faso No. 10. At the extremes of the range, wood yield follows the same ranking pattern as for height growth and stem diameters. Otherwise, for most of the seed sources the rankings are mixed. There was no statistical differences among the seed sources for wood yield. A comparison of the wood yields among the seed sources is illustrated in **Figure 4**.
The mean annual wood yield of the Roche Blanche trial (6.8 kg/tree/yr) exceeded the production rate at the two O'Gorman trials (2.3 and 3.3 kg/tree/yr), but was less than the rate at the Vaudreuil trial (7.4 kg/tree/yr). Vaudreuil and O'Gorman are located near Roche Blanche in the Cul-de-Sac Plain.

Taking into account the differences in survival, an average of 7.15 metric tons (MT)/ha was observed for all seed sources. The top seed source, No. 7 from Niger, averaged 8.65 MT/ha and the lowest, No. 2 from Puerto Rico, averaged 5.43 MT/ha. Despite a difference in wood yield of 3.2 MT/ha, this was not significant at the 95% level of probability. It should be noted that the low stem density of the trial, 227 trees/ha, was not selected to maximize wood yields, but to optimize flower and fruit production. Management of the trees for wood production would follow a completely different silvicultural regime.

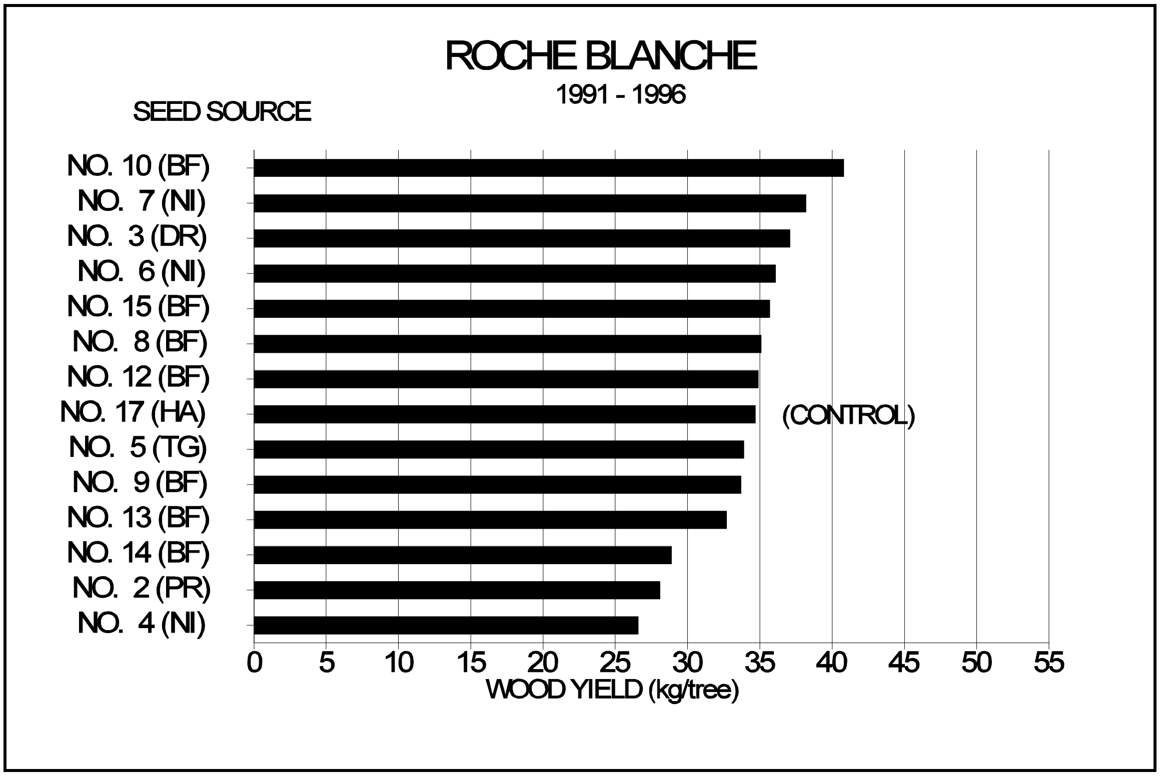

Figure 4. Five–year wood yield comparisons among *A. indica* seed sources at Roche Blanche.

Observations on Tree Density to Optimize Fruit Production

One of the main considerations in the establishment of widely-spaced double rows at the Roche Blanche trial was to favor environmental factors conducive to early flower and fruit production. Fruit yields of neem have been shown to be sensitive to stem density. The poor to negligible fruit yields of neem planted in pure monocultural plantations at high stem densities (1,667–2,500 trees/ha) led some foresters in Haiti to suspect that auto-toxicity was a problem. However, the problem appears to be a high requirement of the tree canopy for sunlight throughout the day. The good fruit yields of neem planted along the national highways in Haiti suggests that wide spacing is necessary. However, the optimal density to maximize fruit yield, on a per hectare basis, remains uncertain.

The triangular spacing (2.0 m x 2.2 m) of the double row increases the number of trees available for a combination of genotype and microsite selection. The 10.0 m spacing between double rows insures that enough sunlight, nutrients and moisture is available for fruit production of the selected trees. Furthermore, the wide spacing allows an opportunity to intensively manage the soil for more lucrative annual crops, especially during the initial years of orchard establishment. The double row of neem, in this case, would provide a windbreak, thereby conserving water and possible increasing crop yields. It is possible to decrease the 10 m spacing, though this would decrease the time before cropping is suspended as a result of shading.

The trees produced their first fruit crop within two years after the trial was established. Though no seed harvests were measured, the trees appeared to produce excellent seed crops for their age. The literature supports a later maturity, with only 25% of 3-year old trees, representing

38 provenances, producing fruit in India (Gupta et al., 1995). It is normal for neem to reach reproductive maturity at 5–6 years and to become fully productive in 10–12 years with annual yields of 35–50 kg of fresh fruit per tree (Ahmed et al., 1984; National Research Council, 1992; Jattan et al., 1995).

CONCLUSIONS

The original objectives of determining the genetic variation of azadirachtin production and fruit quality have yet to be realized. However, it is not too late to combine this phase of research with management designed to optimize fruit yield. PLUS will be forfeiting an excellent opportunity if this phase is not accomplished, which in turn, will limit the potential to help farmers improve their crop management and food yields. Azadirachtin is a renewable resource and probably both safer and environmentally more friendly than many of the imported chemical pesticides now entering Haiti. Furthermore, the production of azadirachtin in Haiti supports self-sufficiency, stimulates local markets and does not require purchasing costly imports with hard currency. These economic aspects alone justify further investments to improve the efficiencies in azadirachtin production. Other marketable products include neem leaf, wood products and oil that is a by-product of azadirachtin processing.

The trials contain the broadest genetic base of the species in Haiti, though this base may still be relatively narrow compared to populations found within its native range. The trial at Roche Blanche showed a remarkable uniformity among neem seed sources for survival, height and diameter growth and wood yields. It is reasonable that some of the low variation may be due to a narrow genetic base inherent in neem populations where the species is not native (such as Africa and the Caribbean). The literature indicates that there exists a large genetic variation in various yield parameters and seed quality where neem is native (Rengaswamy, 1984; Pal, 1995; Veerendra, 1995). Statistical differences have been shown for azadirachtin levels among trees, sites and seasons in Haiti (Timyan and Walter, 1990). It should be noted that the uniformity in growth parameters may not be true for seed quality criteria. A continuing challenge for the future is to introduce as wide a genetic base as possible or import improved genetic material from tree improvement programs in order to begin in-country selections based on adaptation to the unique environmental conditions of Haiti.

The trial was successful in testing an alternative method for introducing and propagating new neem genotypes. The shipping of neem seed has been a barrier in the past to successful introductions. However, stump material, processed according to international phytosanitary regulations, appears to be a more practical solution. The 10 m spacing between the double rows of neem allowed flower and fruit production to occur as early as 2 years. How close can neem be spaced without impairing seed production? What are the optimal management techniques to promote early flowering and maximize fruit yields? These questions not fully answered anywhere in the world and remain a challenge of research.
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RECOMMENDATIONS

The following recommendations should be implemented to continue improving the status of *A. indica* in Haiti:

(1) Compare the fruit yield and azadirachtin concentrations of the seed sources to discover any differences that may exist among seed sources within the trial. The yields of each

tree should be kept separate and processed according to the methods used to harvest the seed for azadirachtin production. Random sub-samples of the seed would be selected from each seed source and block for azadirachtin assays. Conduct the assays with independent laboratories in case there are differences in handling and analytical procedures. Bear in mind that the production of azadirachtin and oils in the seed kernel may have greater economic potential than wood and shade production.

(2) Select at the individual level the best-formed individuals for both fruit production and wood production. Selective criteria should be tree form, fruit yield and seed quality. Multiply superior genotypes by root cuttings or grafting to shorten the time required for economic fruit yield and enlarge the production base of improved genotypes.

(3) Prune selected trees for strong primary branches that can support large fruit crops and eliminate any diseased wood by burning. Prune the canopy branches sufficiently to allow a balanced penetration of sunlight to ensure optimal flower pollination and fruit set.

(4) Investigate optimal tree density for fruit production and investment opportunities for a combination of oil and azadirachtin processing in Haiti. Schedule management inputs to yield an optimal marketing mix for conditions in Haiti. Determine marketing constraints of neem products from the context of decentralized production.

(5) Incorporate an improved genetic base of neem into the PLUS extension system via containerized nurseries of PADF and CARE. Experiment with both seed and vegetative material. Keep careful nursery and distribution records to allow tracking of improved genetic stock.

(6) Procure true provenance collections from countries of origin (e.g. India and Burma), establish these collections on secure sites as in-country seed sources, and begin distributing this mix along with what is already being used. Establish contact with the International Neem Network through USAID via Winrock International’s F/FRED project in Thailand, DANIDA, CIRAD-Forêts for available provenance-wide seed collections and assistance in expediting germplasm to Haiti. Purchase stumps or cuttings of the best genetic material available, packed in sterile peat moss. This is a better alternative than seed and has a greater likelihood of success in establishing new or improved provenances of *A. indica* in Haiti.

(7) Continue monitoring the trial for a longer period, particularly for resistance to disease, pests and hurricanes, wood quality and other parameters that effect its potential economic impact to Haitian farmers. Keep abreast of new pathogens, maintaining correspondence with the Arid Forest Research Institute (Jodhpur, India) and literature searches conducted at US universities. AFRI produces the Neem Newsletter which is a good information source for neem.

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