Breeding sustainable energy crops for the developing world

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Contacts:

Please contact Gael Pressoir, ghp5@cornell.edu, for any enquiry regarding this pre-proposal.
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Gael Pressoir, Ph.D
Institute for Genomic Diversity
Biotechnology Building, Room 175
Cornell University
Ithaca, NY 14853-2703
USA
ghp5@cornell.edu
Ph: +1 (607) 255-1809
FAX: +1 (607) 254-6379

Jacky Lumarque, Professor and President
Université Quisqueya
BP 796, Port-au-Prince,
HAITI
jlumarque@yahoo.com

SUMMARY

The goal of this proposed research is the development of an efficient sustainable energy-crop agro-system to provide an alternative source of energy in developing countries. This system would rely on *Jatropha curcas* (hereafter '*Jatropha*') nuts, which are rich in oil that has proven to be highly suitable for the production of bio-diesel (methyl or ethyl-esters); additionally, the straight vegetable oil can be burned directly in slightly modified diesel engines. Recent changes in the global energy market mean that the oil-rich nut of *Jatropha* could create significant wealth for farming communities and for the economy of the world's poorest countries. We propose a program aimed at the release of improved *Jatropha* varieties and corresponding seed and propagation technologies that will allow for the development and establishment of successful *Jatropha* agro-systems.

INTRODUCTION

Jatropha curcas

Jatropha is a drought-resistant shrub with a set of unique properties. It is a drought-resistant shrub that helps alleviate soil degradation and prevents wind and water soil erosion, allowing reforestation and restoration of degraded land. Additionally, *Jatropha* sheds its leaves during the dry season, allowing for soil enrichment and long-term improved soil fertility. It is often used as a living hedge or fence by farmers in the developing world. The physic nut is a bush that can grow in most regions around the equator. It has few requirements with respect to its environment. Because of this, the physic nut can grow in areas that are unsuitable for other plants, because they are too dry or too arid, or because they have been left by humans because of soil depletion.

The need for energy crops in the developing world

Because of rising oil prices, for the first time, making energy from biomass seems increasingly economically sound. Many developing countries have missed what is now known as the 'green revolution'. Today, we are on the verge of a new green revolution. Will these same countries be left behind again?

Developed nations are prepared to invest considerable resources into the development of energy crops for the production of biodiesel and bioethanol. The urgency of this effort was reflected both in its recent mention by the President of the United States of America in his most recent State of the union address and in the fact that Chevron, one of the world's leading oil companies, announced major investment for renewable energy such as ethanol and biodiesel. Countries like Brazil have taken the lead in developing energy crops and the agro-industry that goes along with it. In all of these countries, biofuels are now considered an important piece of national security efforts. This international trend, driven both by the high prices of energy and the need for a more secure energy source, suggests that the demand for biofuels is set to increase dramatically.

There is a great risk that the developing world will fail to develop appropriate crops and an economically sustainable agro system in response to this need. Once again, the poorest countries would be out-competed by emerging or developed countries that are now starting to make the investments for tomorrow's energy crops. History, however, need not repeat itself. The best place to produce biomass all year long is under the tropics. The developing world is a natural home for this industry, and yet (with the noteworthy exception of sugarcane/ethanol in Brazil), there is no one developing the varieties for these latitudes!

The development of bio-energies would also be of great benefit to the domestic economy. The enormous amounts of money used for the import of refined oil products could be diverted toward the farmers and a local biofuel agro industry (most under-developed countries do not import oil but refined oil products). Even in the poorest third-world country, gas, diesel and fuel always represents a significant market and moreover a large share of these countries' imports. Most third world countries are heavily dependent on foreign fuel imports and the impact of this dependence on the national currency as well as the balance of payments is considerable.

India has taken the lead in *Jatropha* cultivation because of its great potential for making biodiesel. As in Brazil's development of sugarcane, the Indian focus on physic nut has been driven by a strong political will as well as long-term vision for the country's wealth and energy independence. Can we foster this new energy crop for the least developed countries that need it the most?

Making agricultural cultivation sustainable on the land again

In sub-Saharan Africa, Haiti and many other poor countries, farmland is rapidly becoming barren and incapable of sustaining an already-hungry population. Farmlands are plagued by severe land degradation and erosion. We need to find a way to make agricultural cultivation sustainable on the land again in tandem with the development of a local agro-industry in small towns. These changes are necessary to end the tradition of migration to major urban centers of the country, where only miserable poverty and brutal crime await the migrants no matter how much they may hope for jobs.

Jatropha is not only a potential new cash crop for farmers of the developing world; it is also an opportunity for developing new local agroindustries and is a tool for soil enrichment and, more generally, in the fight against soil degradation and depletion. We will also add its positive role for the environment by allowing carbon sequestration and reforestation of degraded land.

Goals and projected outputs

The aim of this project is to evaluate the genetic resources of the tropical shrub *Jatropha* (physic nut) as an energy crop suitable for marginal and degraded lands of the tropics and to establish a corresponding breeding program.

- We aim at establishing an efficient *Jatropha* germplasm repository (live collection) and the development and release of germplasm (new improved varieties) adapted to the new needs of the developing world.
- We will systematically evaluate the germplasm and make the results readily available. These results and all the germplasm evaluated will be made available to all lesser developed countries as well as to countries who contributed germplasm to the project.
- We will be releasing physic nut varieties aimed at biofuel (biodiesel) production and adapted to the marginal areas and degraded land of developing countries. We aim to produce non-toxic varieties with enhanced yield, oil content in percent of dry matter, and high oil oxidative stability.

Why do we need to breed *Jatropha*? (Why can't we just use available ecotypes and clones?)

Plant breeding is the most cost-effective way to achieve an increased and stable yield. While native *Jatropha* or outstanding individuals that can readily be cloned offer an already-substantial yield and drought tolerance, plant breeding would allow for continuous increase and release of ever more productive varieties. In industrial terms, this increase will translate to, for example, oil with increased oxidative stability and other properties that will lower the cost of making biodiesel and enhance its quality. Varieties with higher oil content in percent of dry weight will also provide increased revenue per working-hour for the farmers. The development of non-toxic varieties will allow farmers to have additional markets for their product (not just biodiesel). The 'green revolution' for major cereals would not have been made possible without the release of outstanding varieties. A new green revolution will require also new outstanding energy crop varieties.

A *Jatropha* breeding program in Haiti,
breeding and releasing *Jatropha* varieties for the whole developing world

Our research program will be based in Haiti, which has a wide range of habitats and presents many environmental and economic problems that can be addressed by our research.

Haiti's climate is mainly tropical with some semiarid regions conditions where mountains, in the east, cut off the trade winds. Haiti is located within the *Jatropha*'s natural range (Central America, South America, and the Caribbean). Rainfall patterns range from as low as 400 mm of water per year to above 2000 mm, and altitudes range from sea level to above 2,500 meters covering the germplasm and breeding needs for most regions of sub-Saharan Africa, the Caribbean, Central America, and India.

AN ENVIRONMENTALLY FRIENDLY TREE CROP ON HAITI'S HILLSIDES AND WATERSHEDS

The environmental need for *Jatropha* in Haiti

Haiti is very mountainous and very prone to erosion and soil depletion. Over the decades, the Haitian peasants have deforested the mountains to make charcoal for cooking. On many of Haiti's watersheds, there are virtually no trees and little topsoil left to soak up rainwater and prevent it from racing downhill; most of them are now barren to such extent that valleys and plains face flooding catastrophes such as those that recently made international headlines including mudslides in Gonaives in September 2004 and in Mapou in May 2004; together, these events cost thousands of lives, and left thousands more homeless. If nothing is done, Haiti will face more flooding catastrophes and large-scale death tolls. Hillside land is often so degraded that even sorghum will no longer grow, leaving the farmers with no staple source of food. It is urgent to provide Haitian's peasants with an environmentally friendly cash tree crop that will grow and stabilize Haiti's most impoverished soils.

The economic need for *Jatropha* in Haiti

Poverty-stricken Haiti is totally deprived of natural resources. Because of the lack of foreign currency to buy imported fuel, Haiti faces acute energy shortages. In 2005, Haiti imported over 250 million dollars worth of fuel; over half of it was diesel; some 35 to 50 percent of Haiti's hard currency is required to cover the cost of petroleum imports. In Haiti, fuel is one of the largest markets; it represents about one fifth to one sixth of the country's total imports. These figures are ones of a country plagued by energy shortages; current diesel imports are far from covering the country's electrical needs. (Most of the electricity is produced from diesel fuel and last year the country covered less than 25% of its needs.)

Haiti is also the poorest country in the Western hemisphere; more than half its inhabitants survive on less than $1 per day. Haiti needs new crops that will provide revenues to its poorest peasants and be friendly to the environment. It also needs new crops that will stimulate a local agroindustry and job creation outside of the major urban centers.

A new crop to shape Haiti's future

As mentioned earlier, *Jatropha* provides solutions to many of these challenges. *Jatropha* plantations and the biodiesel agro-industry could help improve the livelihood of poor people in local communities and could contribute to Haiti reforestation and land reclamation as well as soil improvement (currently less then 1.5% of Haiti's surface is covered by forest) and finally help ease the burden on oil imports on the country's finance and economy.

BREEDING AND GERMPLASM EVALUATION OF *JATROPHA CURCAS*

Jatropha has unique advantages that will facilitate breeding. It is naturally an outcrosser, has a short maturity cycle for a tree (just over one year), and can be vegetatively propagated. The latter characteristic allows duplicating individuals across replications and locations in order to precisely estimate its genotypic value for traits of agronomic interest.

Traits that will be evaluated in the germplasm and for breeding

Yield or oil quality related traits, including:

- Yield
- Increased oil in percent of dry seed weight
- Oxidative stability of the oil and the fruit
- Oil composition and quality (cetane number, iodine value, cloud point, saponification number, etc…)
- Fruit and seed size
- Number of fruit per inflorescence
- Number of inflorescence per plant

Seed toxicity (there are many reports of non toxic ecotypes; for example phorbol ester free ecotypes from the State of Quintana Roo in Mexico):

- Diterpen phorbol esters content
- Curcin content

Interaction between seed-toxicity with grazing and insect resistance will also be investigated.

Plant evaluation in both the breeding program and the germplasm evaluation will be done in multiple locations covering the diverse ecologies and climates of the tropics.

The current project in its first phase contains five major components

1) Establishing a live collection of *Jatropha curcas*

Plants will be collected across the species' natural range in the Americas. While we will make sure to cover the whole range of the species, a significant emphasis will be given to the collection of ecotypes or individuals with special traits (non toxic accessions for example).

The collection will be made available upon request to all lesser developed countries and countries contributing germplasm to the collection.

2) Evaluation of the collection

The collection will be evaluated for its genetic variation for agronomic traits, in order to understand how this genetic variation is partitioned across the species' natural range, and allow estimation of the expected breeding response and breeding values in the germplasm collection. We will use the latest development in partitioning genetic variance for quantitative traits using information from molecular markers to estimate key genetic parameters such as narrow sense heritability, genetic correlations, establishment of breeding index, breeding values, using new mixed linear model approaches with marker based estimates of relatedness. These methods will allow the estimation of these key genetic parameters very early on in the program before generating controlled crosses; we will use off the shelf and inexpensive genotyping (DART, SHIP or HIPS technologies for example). For example, genotypic correlation between traits at a juvenile stage and at the plants full yielding potential as well as yield achieved across the plants life span will be investigated using existing populations where adult and young *Jatropha* plants coexist (the previously mentioned marker-based methodologies are particularly useful for that purpose as they allow analysis of these currently existing plantations saving time, money and effort).

3) 'Fast track' breeding program to respond to the immediate needs and to stakeholder's demand

Outstanding clones for yield and oil content (percent of dry mass) identified in the germplasm evaluation will be selected as scion. We will identify rootstock populations adapted to the soils and conditions prevailing in Haiti hillsides and watersheds (*Jatropha* is a native plant to Haiti and natural wild populations are commonly found). This is similar strategy to the one adopted in India were *Jatropha* clones with an oil content above 45% of dry weight have been released. In the heart of the species' natural range, we will have access to much broader genetic variation for this early selection program.

4) Mutagenesis as a tool for *Jatropha* domestication.

Plant domestication is considered as the process of altering, through directed breeding and selection, the genetic makeup of a species so as to increase the species usefulness to humans. Major domestication traits are generally the consequence of large effect mutations that humans selected thousands of years ago. Today we can repeat this same experiment, which our ancestors carried thousands of years ago during the Neolithic, in *Jatropha*.

Most modern oleaginous cultivars have been developed using mutagenesis to increase the oxidative stability of the oil by decreasing the levels of linoleic acid (C18:2) and increasing, in the same proportions, the levels of oleic acid (C18:1). Increases in oleic acid content can potentially be achieved by reducing the activity of oleate desaturase the enzyme which converts oleate into linoleate in the developing seed. EMS mutants have been successfully obtained which raise oleic acid up to 80%, these modern varieties do not produce linoleic acid. A decrease in linoleic acid content increases the oil's and biodiesel oxidative stability.

Curcin is a lectin that specifically inactivates mammalian ribosome, which makes it particularly toxic to goats, cows and humans. These lectins can be completely inactivated by heat treatment (66% moisture, 121 degree C for 30 min). But a curcin free seed would greatly improve *Jatropha* economics by opening a new market to the *Jatropha* raw meal. Because they are of potential interest to finding a cure to certain forms of cancer, the curcin genes of *Jatropha* have been cloned (Qin *et al*, 2005, J. Biosci. 30: 351-357). There are two curcin genes; one is expressed in the seeds and the other in the vegetative parts of the plants (especially in leaves). Mutagenesis could be used to knock out the curcin gene expressed in the seeds.

Mutagenenesis (EMS, X or Gamma rays) will be used to generate mutants disrupting key genes of the fatty acids pathway as well as the seed specific curcin gene. We will make *Jatropha* seeds fully edible to mammals and with an enhanced oxidative stability.

5) Setting a pool for recurrent selection

We will develop a breeding strategy based on the germplasm evaluation results, and identify a subset of the germplasm evaluated for implementation of this strategy. The idea is to fully integrate germplasm evaluation with the first cycles of breeding in order to speed-up creation of breeding material. A recurrent selection scheme on the appropriate germplasm pool(s) will be established. Recurrent selection on pools and populations will allow continuous gain in agronomic performance and the release of ever more productive varieties.

Jatropha can be propagated vegetatively; therefore, we will establish the varietals release both as open pollinated varieties (OPVs, population) and as vegetatively propagated elite clones or scion.

Expected response to selection

Jatropha is genetically diverse for many of the traits of interest (clones with oil content as high as 47% have been reported in India; as for yield, 17 fold yield differences have been measured for *Jatropha* individuals evaluated under same common garden in Madagascar). Plant breeding and recurrent selection will allow the creation of varieties with outstanding performance for all the traits being selected. Due to *Jatropha curcas*' high genetic diversity, we expect to make major gains from breeding.

PROPAGATION TECHNOLOGY AND THE DELIVERY OF IMPROVED VARIETIES

Jatropha can be propagated through seeds, plantlets from tissue culture, from grafting and finally from cuttings. Grafting shortens time to maturity and harvest by 4 months allowing individuals to yield within the first year. Cuttings and tissue culture allow for the rapid mass production of plantlets; however, the plantlets produced may not develop a true tap-root (tap-root may play a non-negligible role in adult plant drought adaptation).

The project will aim at testing and developing the required technology and techniques for mass seed and/or plantlet production. Effect of these strategies on agronomic performance, yield and drought tolerance will be evaluated. We will ensure that adequate training is provided to partner NGOs, seed companies and farmers organizations for mass seed or plantlets production.

Insuring the delivery of outstanding improved germplasm to farmers, to NGOs or agencies involved in reforestation programs and to private companies or ventures investing in *Jatropha* plantations for biodiesel production

We will ensure the delivery of plants to commercial growers; whether they are small scale farmers, communities harvesting Physic nuts from areas under reforestation or large commercial growers, an efficient breeding program will have to deliver products adapted to their needs. To evaluate varieties before they are released and better respond to growers needs, we will collaborate with seed companies, *Jatropha* growers as well as NGOs working with peasants or local communities (participatory plant evaluation). Collaboration is also being established in Haiti with a small company with know-how in tissue culture propagation for mass-production of plantlets; *in vitro* propagation will also facilitate the production of disease-free elite material that can be shipped to other countries. We will also foster the establishment of an international testing network as soon as improved varieties are made available.

A MARKET FOR *JATROPHA*'S OIL

If we are to develop a new crop, we need to ensure that there is a market for the growers' product.

There is a strong demand in Haiti which annually imports 240 million US dollars of fuel. This is one of the largest existing markets in Haiti. Making bio-diesel requires little investment. This investment can be made in a small town; companies like BioKing sell a whole processing system for less then $ 20,000.00. New technologies are rapidly emerging that could even drive this price down further.

When we start releasing varieties or set up trials with farmers, we will also establish small bio-diesel pilot plants. By no means is this intended to substitute for investment from the private sector; rather, these pilot plants will be established as demonstration facilities for testing technologies and training of technical staff from potential investors in bio-diesel manufacturing. While the initial investment will be made by the project, these facilities are intended to be self sustaining (selling bio-diesel). A chemical or petroleum engineer working for the project will also be responsible for the technological and strategic intelligence as well as for the development and/or implementation of locally adapted/adaptable technologies.

EDUCATION AND TRAINING

Twenty percent (20%) of the '*Jatropha* team' members' time is to be dedicated to education and training. While we will teach at Haiti's participating universities and school of agronomy, the project will take the lead in four crucial areas targeted at professionals working or planning to work in the *Jatropha* agro-business:

1) Training skilled grafters and *Jatropha* propagators

The audience for this formation is technicians or employees of NGOs working in agriculture, seed companies as well as members of farmers' organizations. Its focus will be on applied 'seed' technology such as grafting, quality scion production, rootstock seed multiplication and planting.

2) Seminar and workshop on the economics of oil agro-industry

The target audience is all stakeholders and local entrepreneurs potentially interested in developing such an agro-industry. It will aim at providing information on the economics of the *Jatropha oil* business. It is meant as an introduction to the following workshop.

3) Oil production and processing workshop

The target audience for this formation is local entrepreneurs about to invest in an oil processing facility (adequate funding and a business plan are required). This workshop will be focused on the production of quality biodiesel and its high market-value by-products (glycerol and soap).

4) Electricity generation from straight *Jatropha* vegetable oil or from biodiesel

This workshop aims at fostering small or mid-size power generation facility for villages and small towns (all of which have currently no access to the 'existing' electric grid). Experience in mechanics and sponsorship by a local community or local government with the adequate funding along with plans to establish such a facility will be required.

ESTIMATED COSTS

The establishment of the collection and initiation of the breeding program will require: a geneticist and plant breeder (Gael Pressoir), a botanist (Jean Vilmond Hilaire, head of Haiti's herbarium) will contribute to the initial collection establishment phase, two agronomist (one working in *Jatropha* breeding, the other in propagation technology), two field assistants, a chemical or petroleum engineer that will head the laboratory (evaluating oil content, oil quality, biodiesel quality, seed toxicity, development and/or implementation of technologies for using biodiesel or straight vegetable oil), two lab assistants, and twelve field technicians. The positions will be based in Haiti at one of the participating and supporting institutions.

The estimated costs for salaries, equipment, for establishing and maintaining the collection (fields, irrigation), the multi-location trial sites, germplasm evaluation, breeding, training and setting of pilot plants are estimated around $ 500,000 per year.

REFERENCES

While there are few published articles on *Jatropha curcas*, we have found the following books, documents and web sites, all available over the internet, particularly useful when writing the current pre-proposal.

Heller J. 1996. Physic nut, *Jatropha curcas*. Promoting the Conservation and Use of Underutilized and Neglected Crops. International Plant Genetic Resources Institute (IPGRI), Rome, Italy. http://www.ipgri.cgiar.org/publications/pdf/161.pdf

Portnoff M. 2006. Prospects for biodiesel and pure plant oil in Haiti. (Draft)

Tamil Nadu Agricultural University, TNAU. Jatropha production technology. http://tnau.ac.in/tech/swc/evjatropha.pdf

'The Jatropha system'. Web site dedicated to Jatropha resources over the web. http://www.jatropha.de/

The Ecoport *Jatropha curcas* web page http://ecoport.org/ep?Plant=1297&entityType=PL****&entityDisplayCategory=full

FREQUENTLY ASKED QUESTIONS (FAQs)

Why *Jatropha curcas*?

Crop	kg oil/ha
corn (maize)	145
cashew nut	148
cotton	273
soybean	375
euphorbia	440
pumpkin seed	449
mustard seed	481
sunflowers	800
cocoa (cacao)	863
peanuts	890
opium poppy	978
rapeseed	1000
olives	1019
castor beans	1188
pecan nuts	1505
jojoba	1528
jatropha	**1590**
macadamia nuts	1887
brazil nuts	2010
avocado	2217
coconut	2260
oil palm	5000

Of all the oil producing crops with the highest yield potential, *Jatropha* is the only one adapted to depleted soils in tropical semi-arid regions. Of the top six species in the list presented above, *Jatropha* is the only drought tolerant.

Amazingly, *Jatropha* achieves a high yield despite being a non-domesticated plant. Given the genetic makeup of this species, we can expect to dramatically improve this yield (kg of oil/ha).

Due to this potential, in India, eleven millions ha of presently unused lands are to be cultivated with Jatropha (that is more then four times Haiti's total land mass!)

Why would you also breed for an edible cake meal?

Sunflower plants yield more than twice the amount of oil per unit area than do soybean plants, and yet sunflower oil is still more expensive than soybean oil. That is because the soybean cake meal has a considerable value on the market. *Jatropha* cake meal is protein rich, making it a highly attractive animal feed. Making *Jatropha* seeds edible will increase its economic value (two worthy products instead of one).

Why not ethanol as in Brazil or as planned in the USA?

- Haiti presently imports over twice as much diesel fuel as gasoline (ethanol is a substitute of gasoline).
- Haiti heavily depends on diesel for the production of electricity.
- Ethanol requires distillation, which is very energy-intensive.
- Oil processing and production of bio-diesel is far less demanding in terms of technology and investments.
- Plant oil can be used directly; pure plant oil may be used to operate modified diesel engines for local electric power generation, grinding mills, seed crushing operations, water pumps, irrigation, and small industry. There is precedent for this in Africa and Asia.

THE PARTICIPATING INSTITUTIONS

A. Université Quisqueya

Jacky Lumarque, Professor and President
Université Quisqueya
BP 796, Port-au-Prince
HAITI
jlumarque@yahoo.com

B. The Institute for Genomic Diversity, Cornell University

Stephen Kresovich, Professor and Director
Institute for Genomic Diversity
130 Biotechnology Building
Cornell University
Ithaca, NY 14853-2703
sk20@cornell.edu
Ph: +1 (607) 254-7261
FAX: +1 (607) 254-6379

C. Université d'état d'Haiti

Jean vilmond Hilaire, MSc
Ecole Normale Supérieure, Responsable d'activité Herbarium National
hvilmond@yahoo.fr

STAKEHOLDERS

List of institutions, Seed Company, and other *Jatropha* stakeholders that have expressed interest in collaborating with this project (this list is non-exhaustive as new partnerships and collaborations are being established)

A. List of Institutes, in the Dominican Republic

Frantz Flambert
Instituto Dominicano de Desarollo Integral, IDDI,
Web site: http://www.iddi.org
E-mail: drflambert@douyon.com

IDDI is a non-profit organization created in 1984 with the sole purpose to fight poverty, in urban as well as rural areas. IDDI manages a GTZ (German developing agency) funded *Jatropha* plantation project on the Haitian/Dominican border.

B. Potential collaborators within the private sector

In vitro micropropagation of plantlets

Bio Récolte SA

Bio Récolte SA is the only seed company in Haiti capable of tissue culture for mass production of plantlets; it has recently heavily invested in staff training in micropropagation techniques for vegetative multiplication (currently micropropagating: plantains, potato and sweet-potato). Its sister company is PermAgri SA described bellow.

Permagri SA

Permagri SA, has a wide span of activities, including vitroplants acclimatization, field production, agri processing (tuber and roots, and cabbage) and energy from biomass production (biogaz and biodiesel).

Permagri SA is currently under contract by the Haitian government to manage a project involving fifty small scale (<2 ha), fifty middle scale (between 2 and 20 ha) and 5 large scale (over 20 ha) *Jatropha* growers.

Permagri SA and Bio Récolte SA
Joel Ducasse, President and CIO
Cell phone: +509 404 2025
Phone: +509 257 0396
E-mail: biorsa@yahoo.com

Joel Ducasse is a Haitian agronomist with a diversified group of agri-business holdings (including Bio Recolte Sa and PermAgri SA). His agricultural experience has been wide ranged from consulting and field management to husbandry and agricultural processing.

C. NGOs working with small scale farmers or reforestation who showed interest in this project

Floresta

Scott C. Sabin, Executive Director
Floresta, USA
Phone: 858-274-3718
Web site: http://www.floresta.org
E-mail: ssabin@floresta.org

Bob Morikawa, Technical Director
Phone: 416-724-2441
E-mail: robertmorikawa@yahoo.ca

Floresta USA and its Dominican sister organization, Floresta Incorporada were founded in 1984, out of a new vision for economic development that would be sustainable and benefit the environment. Floresta sought to make lasting change through development that restored productivity to degraded land and dignity to the rural poor, while providing opportunities for upcoming generations. Floresta currently has programs running in the Dominican Republic, Haiti and Tanzania.