FORESTRY PLANTATIONS OF *Pinus caribaea* IN VENEZUELA AS A SOLAR ENERGY COLLECTOR

Eduardo D. Greaves, Yelitza Marin, Francisco Visaez and José Vicente Hernández E.

SUMMARY

*The Caribbean pine (*Pinus caribaea *var.* hondurensis*) is a species that has demonstrated its capacity for successful diffusion in areas which were originally extensive savannas with oligotrophic sandy soils of low fertility, acid pH, and a wide variety of soil and pluviometric conditions. A reforestation program in Venezuela has planted a 550000ha artificial forest, significantly changing the ecology of the area and creating an important biomass resource by effectively harnessing the energy of the sun at a yearly collecting power of 1710MW. The change of the albedo of large areas of the territory, the sequestering of* 113×10^6*ton/year of atmospheric* CO_2 *and the production of useful biomass make this species of special interest for its propagation in tropical and subtropical areas of the north of Africa, the Middle East and Asia. The infrastructure created in Venezuela for the propagation of the Caribbean pine and the extensive experience gained in over 40 years of development are a resource that could be used to 'paint in green' the deserted areas of the planet, in order to improve the land, collect the energy of the sun, sequester* CO_2*, help reduce the greenhouse effect of the atmosphere and produce social welfare to the inhabitants.*

Introduction

Forests currently occupy $\sim4\times10^9$ha, representing ~31% of the planet's surface (FAO, 2010). They are one of the natural mechanisms that gather the energy of the sun. However, the progressive increase of the world population and its economic activity has been accompanied by a greater ability by humanity to manipulate the world environment. In tropical countries, the need for long-fiber wood for the building and paper industries, and the lack of tradition in forest plantations has led to a harmful impact on natural forests. Recent years have seen in Latin America the disappearance of almost 5×10^6ha of tropical forest (Marín, 1997). To recover the energetic and other benefits of the loss of natural forest, requires a global level and aggressive reforestation program that not only restores the losses but also attempts to increase the surface under vegetation and reduce desert and semi deserted areas of the world. To this end the Caribbean pine has been successfully used in reforestation programs in Latin America. The Caribbean pine (*Pinus caribaea*) is a rapidly growing species originating in Central America, where it grows between 18º N (Belice) to ~12º N (Bluefields, Nicaragua), at

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PLANTACIONES DE *Pinus caribaea* EN VENEZUELA COMO RECOLECTOR DE ENERGÍA SOLAR
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RESUMEN

*El pino caribe (*Pinus caribaea *var.* hondurensis*) es una especie que ha demostrado su capacidad para su difusión en áreas que eran originalmente extensas sabanas con suelos arenosos oligotróficos, de baja fertilidad, de pH ácido, y con una variedad de condiciones pluviométricas y de suelos. Un plan de reforestación en Venezuela ha creado un extenso 'bosque artificial' de unas 550000ha que han cambiado la ecología del área y ha creado un recurso de biomasa importante que atrapa efectivamente la energía solar con una capacidad anual de 1710MW. El cambio del albedo de grandes áreas del territorio, el secuestrado de 113×10^{6}ton/año de CO_2 atmosférico y la producción de biomasa útil, hacen de esta especie de interés especial para su propagación en áreas semidesérticas tropicales y subtropicales del norte de África, el Medio Oriente y Asia. La infraestructura creada en Venezuela para la propagación del pino caribe y la experiencia obtenida en mas de 40 años de desarrollo son recursos que pudieran usarse para 'pintar de verde' las áreas desérticas del planeta, con la finalidad de mejorar las tierras, recolectar la energía solar, fijar el CO_2, ayudar a la reducción de gases de efecto invernadero que afectan la atmósfera terrestre y contribuir al bienestar social.*

PLANTAÇÕES DE *Pinus caribaea* NA VENEZUELA COMO COLETOR DE ENERGIA SOLAR
Eduardo D. Greaves, Yelitza Marin, Francisco Visaez e José Vicente Hernández E.

RESUMO

*O pinheiro caribe (*Pinus caribaea *var.* hondurensis*) é uma espécie que tem demonstrado sua capacidade para sua difusão nas áreas que eram originalmente extensas savanas com solos arenosos oligotróficos, de baixa fertilidade, pH ácido, e com um leque de condições pluviométricas e de solos. Um plano de reflorestamento na Venezuela tem criado um extenso 'bosque artificial' com aproximadamente 550.000ha que tem mudado a ecologia da área e tem criado um recurso de biomassa importante que captura efetivamente a energia solar com uma capacidade anual de 1710MW. A mudança do albedo de grandes áreas do território, o sequestro de 113×10^{6}ton/ano de CO_2 atmosférico e a produção de biomassa útil, fazem desta espécie de interesse especial para sua propagação em áreas semidesérticas tropicais e subtropicais do norte da África, o Oriente Médio e Ásia. A infraestrutura criada na Venezuela para a propagação do pinheiro caribe e a experiência obtida em mais de 40 anos de desenvolvimento são recursos que poderiam ser usados para 'pintar de verde' as áreas desérticas do planeta, com a finalidade de melhorar as terras, coletar a energia solar, fixar o CO_2, ajudar à redução de gases de efeito estufa que afetam a atmosfera terrestre e contribuir com o bem-estar social.*

~850masl and mean rain of 950-3500mm per year, exhibiting a dry season of two to three months and temperatures between 24 and 27°C. Three varieties of the species exist: *Pinus caribaea* var. *hondurensis* from Honduras, *P. caribaea* var. *caribaea* from Cuba and *P. caribaea* var. *bahamensis* from Bahamas (Salazar and Jøker, 2000).

The properties of this species have determined its massive use in reforestation programs in Venezuela (CVG-PROFORCA, 1996; Molina Peñaloza, 2006; Castillo, 2003; Maderas del Orinoco, 2014) and Brazil (Pongitory *et al*., 2001), and in a smaller scale in plantations reported in 28 other countries (Le Maitre, 1998; Ugalde and Pérez, 2001). Caribbean pine plantations began in Venezuela with experiments in 1961 and 1965, when the Ministry of Agriculture initiated trials in Cachipo (north of Monagas state) with seeds from Honduras and from Brazil. *P. caribaea* var. *hondurensis* was the variety that showed the best results due to its adaptability and fast growth in the savannas of the Monagas and Anzoátegui states (Visaez, 1988). The success attained in these first experiments resulted in a large forestry development program at Uverito in 1969 and at Chaguaramas and Centella in 1972 (both south of Monagas state) followed later at Coloradito and Mesa de Los Hachos (south of Anzoátegui state). See Figure 1. These large plantations were followed in more modest scale in many other locations in the country: in the Andean states at different altitudes, the occidental plains, Carabobo, Yaracuy and Guayana states, including also the Caracas valley. In December 2009 the central government approved the 'Socialist Forestry Program of Venezuela' (CVG-PROFORCA, 2009). This program aims to extend the 0.55×10^{6}ha of planted forest to 2×10^{6}ha, an increase of 350% by the year 2029. Species contemplated are *Pinus caribaea* var. *hondurencis* as well as other species, notably

Figure 1 Plantation of *Pinus caribaea* var. *hondurensis* at Uverito, Monagas state, Venezuela (~6º39'57"N, 62º38'26"W).

Eucalypt (*Eucaliptus urophylla*), Acacia (*Acacia mangium*) and Teca (*Tectona grandis*). The plan contemplated the production by year 2014 of 5×10^5ton of paper pulp, 2.5×10^5m^3 of sawn timber and 5×10^5ton of boards. There are currently two seed orchards with an area of 194ha for Caribbean pine seeds, with national production of 2000kg/year of improved seeds capable of providing the national and international market and production in nursery (Figure 2) of 42×10^6 nurse plants/year.

The planted area is currently increasing at a rate of 40000ha/year (CVG PROFORCA, 2012). This program has turned large parts of Venezuela's savannas that were underutilized in one of the largest solar energy collectors artificially created in the planet. These plantations constitute a large anthropogenic production of biomass. The wood volume production is estimated at 5.5×10^6m^3/year. The yearly solar energy capture (see below) if converted to wood and biomass that could be used as fuel, has a heat content estimated at 5.39×10^{16}J/year equivalent to 1710MW collected every year. These Caribbean pine plantations capture an estimated 113Mton/year of CO_2 (Emilio J. Vilanova, personal communication) and release 82.2Mton/year of O_2, which helps reduce the concentration of greenhouse gases associated with global climate change. The purpose of this paper is to describe and publicize internationally the Venezuelan experience in this field, the socioeconomic, industrial and environmental effects it has had, and to propose a program increasing the spread of this species in arid land, particularly in tropical and subtropical areas of Africa, the Middle East and Asia as a way to harness solar energy with environmental, economic and socially positive effects.

Caribbean Pine

Taxonomy and nomenclature (Salazar and Jøker, 2000; ICRAF, 2012).

Family: Pinaceae

Varieties: *Pinus caribaea* var. *bahamensis* (Griseb.) W.H.G. Barrett & Golfari, *P. caribaea* var. *caribaea*, *P. caribaea* var. *hondurensis* (Sénéclauze) W.H.G. Barrett & Golfari.

Current name: *Pinus caribaea* Family: *Pinaceae*. Authority: Morelet.

Synonym(s): *Pinus bahamensis* (Griseb.), *Pinus hondurensis* (Seneclauze). *Pinus recurvata* (Rowlee), *Pinus taeda* var. *heterophylla* (Elliott), *P. recurvata*, (Rowlee).

Vernacular/common names. English: Caribbean pine, Caribbean pitch pine, Cuban pine, Honduras pine, Nicaragua pine, Pitch pine, Slash pine; French: Pin jaune, Pin mate; German: Karibische kiefer; Spanish: Ocote blanco, Pino amarillo, Pino caribaea de Honduras, Pino colorado, Pino cubano, Pino de cuaba, Pino de la costa, Pino macho; Venezuela: Pino caribe; Swahili: Msindano; Trade name: Honduran yellow pine.

Figure 2. Forestry research station at El Merey, Monagas state, showing a *Pinus caribaea* nursery (left) and young trees growing in the alluvial weathered soils savannas of the Mesa formation at Uverito, Monagas state (right).

Distribution and habitat

Native to Central America and the Caribbean, widely planted throughout the American, Asian and African tropics and subtropics. *P. caribaea* var. *caribaea* is confined to Cuba and the Isla de la Juventud, *P. caribaea* var. *bahamensis* is indigenous to certain islands of the Bahamas and the Caicos groups, and *P. caribaea* var. *hondurensis* can be found in the eastern half of Central America south-east from the Yucatan peninsula. It grows best in frost-free areas up to 700masl on more fertile sites with good drainage and annual rainfall of 1000-3000mm.

Botanical description

Pinus caribaea is a tree 20-30m tall, often reaching 45m, with a diameter of 50-80cm and occasionally up to 1m. Trunk generally straight and well formed; lower branches large, horizontal and drooping; upper branches often ascending to form an open, rounded to pyramidal crown, young trees with a dense, pyramidal crown. Leaves needlelike, crowded and spreading at ends of twigs, remaining attached for 2 years, in fascicles of 3-5, mostly 15-25cm long, 1.5mm broad or less, rigid serrulate, dark or yellowish-green, slightly shiny, with stomata in whitish lines on all surfaces. Strobili appear before the new leaves; male strobili many and sessile in whorled, short, crowded clusters near ends of twigs, mostly in lower part of the crown; mature cones usually reflexed, symmetrical; cone scales reflexed or wide spreading, thin, flat, dark chocolate-brown on inner surfaces; seeds narrowly ovoid, about twice as long as broad, pointed at both ends, three angled, averaging less than 6mm long, 3mm wide, black, mottled grey or light brown. 'Pinus' is from the Greek word 'pinos' (pine tree), possibly from the Celtic term 'pin' or 'pyn' (mountain or rock), referring to the habitat of the pine.

Fruit and seed description

The seed is about twice as long as broad, triangular and pointed at the ends. (Figure 3). On average less than 6mm long, 3mm broad and black to grey or brown. The membranous wing is up to 20mm long, sometimes fused with the seed coat but becoming detached when moistened. There are 35-40 seeds per cone and 59000-72000 dewinged seeds/kg, depending on the variety. In natural conditions the seed has aerodynamic properties retarding its fall to the ground and helping dissemination by the wind. However, in certain areas (such as eastern Venezuela) there is asynchrony between female and male strobili, impeding the pollination process and resulting in no production of seed. Due to this the seed orchards of Maderas del Orinoco C.A. are located in Santa Cruz de Bucaral (Falcon state) and San Antonio de Maturin (Monagas state).

Propagation

When considering possible areas for the spread of Caribbean pine the most important aspect are the ecological conditions of the area: weather conditions such as periods of rainy season and

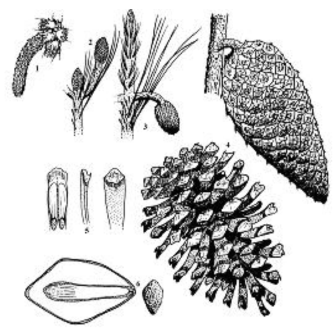

Figure 3. 1: mature male strobili, 2: female strobili at receptive stage, 3: female strobili two months old, 4: mature cones, 5: cone scales, and 6: seeds. Reproduced from ICRAF (2012).

droughts, amount of precipitation during the rainy season, rainfall occurrences. Soils: horizons characterization, study of soils, fertilization, etc. Other important conditions are altitude, latitude and wind speed.

Climate requirements

Salazar and Albertin (1973) set thermal limits and water requirements in the areas of origin and areas of introduction of *P. caribaea*, identifying favorable behavior in annual temperature ranges between 24 and 28°C, and only moderate growth in temperatures from 20 to 24°C. Water limits are: maximum of 1000-3000mm/year and minimum of 100-600mm/year. In its original regions it grows on lands with elevations below 800masl in frost-free climates with a marked, well defined dry season (Sierra and Hernandez, 2011). The range of temperatures is between 24 and 27°C in the coastal regions with tropical climate, abundant rainfall up to 3500mm/year and a short period of 2-3 months of drought (rainforest). In the inner regions with a subtropical climate average annual temperature 20-24°C and low rainfall (~950mm/year with a long drought period of 6 months), corresponding to dry woodlands (Barrett and Golfari, 1962).

Soil requirements

Pinus caribaea var. *hondurensis* fits a variety of soils. It grows well in poor soils of lateritic origin (red, brown, red and yellow), which have been developed on different parent rocks, such as granite, shale and sandstone (British Honduras), andesite (interior of Honduras) and dolomite (Guatemala), however not in shallow soils with poor drainage. In the coastal regions the pines grow on alluvial soils formed by fine sand sometimes with silt presence (British Honduras) or coarse sand (Nicaragua). The drainage varies from good, in the region dominated by hills in the interior, to poor in coastal regions due to the low altitude and the frequent presence of impermeable clay subsoil. The reaction of the soil is acidic, with pH varying between 6.5 (Honduras) to 4.3 (Nicaragua) according to Barret and Golfari (1962), quoted by Sierra and Hernandez (2011). In Venezuela, the Caribbean pine usually grows on the alluvial weathered soils of the Mesa formations, highly washed with a high sand content, low moisture retention capacity and scarce nutrients in the surface layers (Fassbender *et al.* 1979a). The potential transpiration exceeds precipitation, resulting in a deficit of water for most of the year; winds in the area are moderate but steady, with an average speed of 10km/h, maximum monthly average speeds occurring generally from January to June and in December (MARNR, 1982).

Associated vegetation in Venezuela

The areas where the pine has been planted are predominantly natural savanna with herbaceous vegetation of grass, shrubs and small trees with predominance of hairy straw (*Trachypogon plumosus*) and 'zaeta' (*Trachypogon* sp.) among others. Associated with the mixture of grasses in the savannas are various low-slung tree components found in degraded soils that are highly resistant to fire. The most representative of these species are *Curatella americana* (chaparro), *Bowdichia virgilioides* (alcornoque), (*Anacardium occidentalis*) (merey), *Byrsonima crassifolia* (manteco) and (*Piptadenia oblicua* (yopo) among others. These areas also exhibit a vegetal formation known as 'morichal', gallery forests associated with the course of rivers or stagnant water outcrops; they are evergreen formations able to tolerate periodic flooding conditions. The most representative species are moriche palm (*Mauritia flexuosa*), 'palma llanera' (*Copernicia tectorum*) and 'barbacoa' (*Axonopus compressus*), among others (Quintero and Olivares, 1992).

Pests and diseases

Caribbean pine shows acceptable survival and adequate growth rates, mainly due to improved production techniques in nursery plants and planting technology, even when propagated in soils that are very poor (Fassbender *et al*., 1979b). According to these authors certain conditions such as water deficit, estimated at an annual 2000mm, the existence of extensive monocultures and low soil quality, confers high fragility. In the case of *P. caribaea* tree plantations in Venezuela several pest have been reported as a limitation to the establishment and development of the pine forest, in such way that sometimes pest impact may produce important economic damage.

In the case of insects the most important are leaf-cutting ants, specifically *Atta laevigata* and *A. sexdens* (Hymenoptera: Formicidae). A colony of these ants can destroy during a night up to 8ha of recently planted pine trees. In the case of adult plantations <10 years old, they can diminish significantly the volume of wood produced per surface area. However, in plantations of >10 years the presence of this species of ants stimulates the production of wood per surface area. This phenomenon is a result of the extra supply of nutrients to the soil and to the improvement of the physical structure of the ground due to ant's activities (Hernández and Jaffé, 1995).

The second important group of pest insects belongs to the order Coleoptera, family Curculionidae, subfamily Scolytidae, commonly called 'wood borers' among which the most significant species are *Xyleborus ferrugineus* and *X. afinis*. Their fundamental importance is that they can make massive attacks on live pines and furthermore, being xilomicetofage insects, they are vectors for the phytopathogen *Lasiodiplodia theobromae*, which produces massive cases of regressive death or sudden death (see below). Under conditions of hydric stress the pine plantation becomes more susceptible to this assault combined with the Scolytidae and phytopathogen fungus attack.

Sudden death syndrome ('dieback')

This is a complex syndrome that has been reported in the Caribbean pine plantations in Uverito, Monagas State, Venezuela. The disease occurs in Venezuela and in other African countries (Holmquist, 1988). It manifests itself in a variety of ways and with different symptoms: progressive death, regressive death, general deterioration and sudden death, as described by Gonzalez (1980). Other symptoms reported are: widespread or patchy yellowing, dry branches and poor growth in height and diameter. Also, dead trees can be observed in isolation (Holmquist, 1990). Holmquist (1988) reports *Lasidiplodia theobromae* Patonillard (Botryodiplodiaceae) as the causative agent of the disease. This is a fungal pathogen, not particularly aggressive, but characterized by entering the host and remaining latent and pathogenic until the plant is in physiological stress. Factors predisposing the disease include high stand density, long periods of drought or dry season and poor soil quality.

Impact of the Caribbean Pine Plantations

Biomass creation and energy capture

The mean annual (volume) increment (MAI) is one of the useful indices for species selection for reforestation. The MAI measures for a plantation the increase in the volume of wood per hectare per year. MAI values for different species vary greatly, between 1-2$m^3 \cdot ha^{-1}$/year to 25-50$m^3 \cdot ha^{-1}$/year. Table I shows the value of the MAI for different species in different regions.

TABLE I
PRODUCTIVITY AND ROTATION LENGTH FOR PINE PLANTATIONS IN SELECTED TROPICAL COUNTRIES

Species	Region	Country	Rotation length (years)	MAI (m^3 ha^{-1}/year)
Eucalypt	S. America	Brazil	8-10	18-20
	Africa	Burundi	8	1-2
		Congo	7	30
		Rwanda	8	8.5
Pine	S. America	South Africa	8-10	18-20
		Brazil	16-25	15-25
		Venezuela	10-20	12*
		Chile	20-30	24
	Africa	Malawi	20-25	17
		Madagascar	15-18	6-10
		Mozambique	18-25	11
Teak	Asia	Bangladesh	60	2.6-3
		India	70	2.5
		Indonesia	50-70	1.3-2

* Source: Ugalde and Perez (2001) CVG - PROFORCA (2003).

Plantations of *Pinus caribaea* var. *Hondurensis* has been reported in 28 different countries where the MAI shows ranges between 2 and 50$m^3 \cdot ha^{-1}$/year compared to values of 10-20$m^3 \cdot ha^{-1}$/year for *P. caribaea* var. *caribaea* (Ugalde and Pérez, 2001). The MAI value depends on many factors among which are characteristics of the plant species, environmental conditions such as rainfall, altitude, soil fertility and age of the sown field. The index is small for young plants, increases with age reaching a peak with the maturity of the plantation and then generally levels off or decreases. MAI index values reported for Caribbean pine in Venezuela varies widely: 2 to 3.9$m^3 \cdot ha^{-1}$/year (Molinari and Jurado Blanco, 1994), 7$m^3 \cdot ha^{-1}$year (SEFORVEN, 1993) and higher values of 4-14$m^3 \cdot ha^{-1}$/year are also reported (IFLA, 1991); Vilanova (2015) found 13,7$m^3 \cdot ha^{-1}$/year to be the average of 14 years. A value of 20$m^3 \cdot ha^{-1}$/year was quoted by Schroeder (1992) for carbon sequestration calculations. For economic evaluation of the plantation in eastern Venezuela the value of 12$m^3 \cdot ha^{-1}$/year has been selected by Maderas del Orinoco (CVG - PROFORCA (2003). Table II shows MAI behavior *vs* time for a locality in Trinidad, West Indies. In this work a value of 10$m^3 \cdot ha^{-1}$/year as average for the whole plantation has been chosen for calculation purposes.

The total timber volume divided by the number of growth years gives annual average growth. The highest point of this value gives what is conventionally regarded as the most appropriate time for harvest.

It is possible to convert MAI values stated in volume (V) per unit area (A) per unit time (t) in mass (m) values using an estimation of the density (ρ= m/V). However, estimating true density values is difficult because the sun's energy is converted through photosynthesis into a variety of organic materials with greatly different densities, compositions and humidity content. Nevertheless, the MAI index is not a physical unit but rather an economic unit referring to the actual rate of wood volume production in m^3 obtained in the plantations. Hence an estimation of organic mass collection rate based on published MAI index values gives conservatively lower values of the actual rate of biomass production of a plantation.

TABLE II
MEAN ANNUAL VOLUME INCREMENT OF *PINUS CARIBAEA* VAR. *HONDURENSIS* IN TRINIDAD, W.I., AS RELATED TO AGE AND SITE QUALITY

Age (years)	MAI ($m^3 \cdot ha^{-1}$/year)
Site I	
10	14
15	17
20	19
25	20
Site II	
12	12
18	14
24	16

Source: Ugalde and Perez (2001).

Defining V: volume of wood (m^3) created, A: unit surface area (ha), and t: time (years), the MAI index is defined as

$$MAI=\frac{V}{At}\left(m^3 \cdot ha^{-1} / year\right)$$

and for a density of wood of ρ ($g \cdot cm^{-3}$ or $kg \cdot m^{-3}$), the rate of mass collected is given by

$$\frac{dm}{dt}=(MAI)\rho=\frac{V\rho}{At}\left(kg \cdot ha^{-1}/year\right) \quad (1)$$

Then, the total rate of mass collected in a plantation of total area A_t is

$$\frac{dm}{dt}=(MAI)\rho A_t\left(kg/year\right) \quad (2)$$

In order to express this mass collection rate in energy units it is possible to use, for estimation purposes, an average heating value of wood and biomass. This quantity depends on a number of factors including the species, biomass composition and various other conditions of the conversion process or plant design (Jenkins *et al*., 1998).

Using a heating value (energy per unit mass) of H_v (J/kg) the rate of energy collection $\frac{dE}{dt}$ is

given by $\frac{dE}{dt}=\frac{dm}{dt}H_v$ and, hence,

$$\frac{dE}{dt}=(MAI)\rho A_t H_v\left(J/year\right) \quad (3)$$

In order to obtain a rough estimate of the total yearly energy collection of the forestry plantations in Venezuela we have used Eq. (3) with the following values: the reported total area of the plantation in 2009 of A_t= 550000ha, a conservative MAI index of 10$m^3 \cdot ha^{-1}$/year and an air-dried density of the wood (Table III) of ρ= 560$kg \cdot m^3$. Heating values are reported in Jenkins *et al*. (1998) as ranging from ~15 to 20$MJ \cdot kg^{-1}$. We have chosen a intermediate value of wood and biomass material at 17,5$MJ \cdot kg^{-1}$ or H_v= 17,5×$10^6 J \cdot kg^{-1}$. These values in Eq. 3 yield an energy accumulation rate of 5.39×10^{16}J/year, which is equivalent to a yearly collecting power of about 1710MW.

This is a very large value which may be placed in perspective by mentioning that the yearly electrical energy production of a large nuclear power plant is about 1000 MW. However, this is an estimation of the potential heating value calculated only for the purpose of emphasizing the energetic value of collecting sunlight with the use of forestry plantations. In an energy rich country such as Venezuela, with large oil production and considerable hydroelectric power already developed, the heating value of the plantation is a minor consideration of its value compared to its environmental impact or as a wood resource for industrial applications. Nevertheless, just as the development of these plantations have produced welfare and living standards improvement to the population of these areas, the energy value of the biomass produced may be a valuable asset in other arid regions of the world that do not enjoy such conditions.

Creation of a resource for construction and industry

Caribbean pine wood is similar, but of lower quality because of color, density, size and orientation of the fiber, to that of southern pines of the

TABLE III
COMPARISON OF PROPERTIES OF CARIBBEAN PINE AND HARD PINES FROM SOUTHERN US*

Property	1 Caribbean pine (*P. caribaea*)	2 Shortleaf pine (*P. echinata*)	3 Slash pine (*P. elliotti*)	4 Longleaf pine (*P palustris*)	5 Loblolly pine (*P. taeda*)	6 Radiata pine** (*P. radiata*)	7 Average cols 2-6	8 St. Dev. cols 2-6
Tree height (m)	20-30	20-30	18-30	30-35	30-35	24-30	28.2	5.5
Diameter (m)	0.6-1	0.6-1	0.6-1	0.6-1	0.4-1.5	0.6-1	0.83	0.3
Average dry weight (kg·m^{-3})	625	570	655	650	570	515	592.0	59.6
Janka hardness (N)	4.920	3.070	3.380	4.120	3.070	3.150	3.4	0.4
Rupture modulus (MPa)	92.0	90.3	112.4	100.0	88.3	79.2	94.0	12.6
Elastic modulus (GPa)	10.06	12.10	13.70	13.70	12.30	10.06	12.4	1.5
Crushing strength (MPa)	54.4	50.1	56.1	58.4	49.2	41.6	51.1	6.6
Radial shrinkage	6.3%,	4.6%,	5.4%,	5.1%	4.8%	3.4%	4.7%	0.8
Tangent. shrinkage	7.8%,	7.7%,	7.6%	7.5%	7.4%,	6.7%	7.4%	0.4
Volume shrinkage	12.9%	12.3%	12.1%	12.2%	12.3%	10.7%	11.9%	0.7

* Data from Mayer (2014).
** See also Scott (1954).

US such as longleaf pine (*Pinus palustris*), shortleaf pine (*P. echinata*), loblolly pine (*P. taeda*); or the Chilean Monterey pine (*P. radiata*). The physical properties of Caribbean pine can be compared with the data from other pine species and their average and standard deviation, which are shown in Table III. Caribbean pine has uses in the fields of construction, interior and exterior carpentry, in furniture and toys, for dovetail joints, moldings, hardwood courts, pallet manufacturing, packaging, shuttering and formwork. Its treated wood is safe and reliable for use outdoors, or immersed in water. In construction it can be applied in bridges, docks, roofing trusses, beams, studs, joists, posts and pilings.

It can also be used as interior finishing materials, coverings and flooring. In the Venezuelan market it has the advantages of standard dimensions, known mechanical properties, remarkably affordable prices, guaranteed durability treatment according to international standards and immediate and long-term availability given the size of the plantings.

In addition to timber the plantations provide raw material for a variety of other uses. The organic matter becomes raw material for other industrial products, some presently implemented such as pulp for paper and carton and for the domestic paper industry, and others planned for the future. Some examples are the production of resins and oils of pine for the oil, agro-chemical, cosmetics and paint industries and the production of ethanol as a transport fuel.

Changes in the ecosystem

Caribbean pine plantations and other species in large areas of semi-arid savannas have produced very significant changes in the ecosystems. Only a few indicators are mentioned here: an average tree produces 100kg/year of O_2, equal to the requirement of two persons (CVG PROFORCA, 2012). Carbon storage values per year for *Pinus caribaea* in Venezuela from several sources are tabulated in Vilanova (2015) and range from 53 (Bonduki and Swisher, 1995) to 59Mg·ha^{-1}/year (Schroeder, 1992).

Taking an average value of 56Mg·ha^{-1}/year of C gives an estimated value of 205.3Mg·ha^{-1}/year of CO_2 .Then, for the whole plantation of 550000ha the amount of CO_2 sequestered is estimated of the order of 113×10^{6}Mg/year.

Plantations have favored biodiversity. The forest has become an ecological niche that contributes to the proliferation of savanna animal species such as partridge, the plains pigeon, donkeys and deer. A recent study by Maderas del Orinoco SA (CVG PROFORCA, 2012) quantified 44 species of mammals, 38 species of birds (34 of them not previously observed in the region) and 22 species of reptiles; there have been in the area significant improvements in water and air quality, with a decrease of atmospheric dust. It has also improved 'morichal' ecosystems. The presence of plantations decreases soil erosion, enhances the infiltration of water into the soil and improves the physicochemical properties of the ground.

Propagation capacity of Caribbean pine in Venezuela

The company Maderas del Orinoco SA was established in 2012. It absorbs projects of Caribbean pine forest in southern Monagas and Anzoategui states, *Eucalyptus urophylla* in southern Anzoátegui, Caribbean pine in Bolivar, Teak in Barinas, Acacia and Saladillo in Apure, which were managed by the company CVG-PROFORCA since 1988. The new company has personnel with forty years of experience in the development, management, protection and use of forest plantations. Therefore, it is able to promote forest projects in geographical areas similar to the conditions prevailing in forest Venezuelan plantations.

Seed production

There are two seed orchards to produce genetically improved seeds. One is located in Santa Cruz de Bucaral, Falcon state, and the other in San Antonio de Maturin, Monagas state. They have an available area of 194ha showing a sustainable seed production of about 2000kg/year. These orchards are involved in technological adaptation processes, research, development and innovation aimed at achieving greater efficiency in the extraction and seed production processes, so as to increase seed production levels and their quality. It is expected that they achieve an increase in yields from 10kg/day to some 50kg/day in order to supply 100% of current requirements and to ensure supply for the establishment of 40000ha/year from 2013. The Caribbean pine seed produced by the Maderas del Orinoco SA, is recognized internationally as one of the best in terms of quality and purity.

Seedling production

Since the year 2000 the company CVG PROFORCA has been developing a series of changes in technology designed to improve and optimize the production of seedlings in nurseries. The production system of bare root seedlings (planted gardens) that had unsatisfactory levels of seedling survival in savannas was changed to covered root systems (containers under controlled conditions). The benefits of this technology change have led to increased survival of seedlings in the savannas from 80% (under the bare root system) to 98%. This implies an increase in timber production at end of turn or harvest (15 years) of 24% and a cost reduction in the establishment of plantations due to decreased consumption of seeds and agricultural inputs fertilizers, herbicides and insecticides (CVG - PROFORCA, 2003).

Discussion and Conclusions

In this work we review the properties of Caribbean pine (*Pinus caribaea* var. *hondurensis*) showing that it has advantageous characteristics in relation to massive reforestation programs. We show how the Caribbean pine plantations are an effective instrument for the generation of considerable welfare to society. The plantations in Venezuela are a mechanism of storing the energy of the sun which we estimate at a yearly rate of 1710MW. This calculated value has a very considerable uncertainty range due to the uncertainty in the variables that go into the calculation. A source of uncertainty is the MAI index reported by the various authors for the Caribbean pine, which ranges widely from a low $2m^3 \cdot ha^{-1}$/year to $20m^3 \cdot ha^{-1}$/year. The wood density also has a high uncertainty as there is the question of whether to use 'basic density', 'air-dried density' or 'tree wood density', values which range from 480-$980kg \cdot m^{-3}$ (Molina Peñaloza, 2006). Additionally, heating values applicable to Caribbean pine have been estimated in the middle of a range of 15 to $20MJ \cdot kg^{-1}$. The plantations convert sun energy into a number of useful products that provide raw materials and beneficial conditions at the site of the plantations. These include the direct sequestering of considerable amounts of atmospheric greenhouse gas (CO_2), estimated at 113×10^6Mg/year and the release of about 82×10^6Mg/year of O_2. This results in the transformation of CO_2 into useful hydrocarbon products which are basic for human industry and welfare. The pine plantations transform areas which were semi-arid unused lands with oligotrophic sandy soils of low fertility, and create superior ecosystems where the ground, air, water and original animal population show clear indices of improvement. The unusual ability of *P. caribaea* for adaptation to a wide variety of terrains and its fast growth may be ideally suited for its use as a sun energy collector in reforestation programs for tropical and semitropical lands in regions of Africa, the Middle East and Asia. In these regions it could transform large semi deserted and unproductive areas, offset the effects of deforestation, reduce the pressure on the natural forests and help to decrease the net anthropogenic greenhouse gases that influence global climate change. The pool of knowledge, experienced personnel and facilities existing in Venezuela are an asset that could help an aggressive internationally supported program of reforestation with Caribbean pine.

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