Local innovation processes in Agroenergy directed at the mitigation and adaptation to climate change in Cuba

J. Suárez[1], G. Martín[1], L. Cepero, D. Blanco, J. Sotolongo[2], Valentina Savran[3], E. del Río[4] and J. L. Rivero [5]

[1]*Estación Experimental "Indio Hatuey", Universidad de Matanzas, C.P. 44280, Matanzas, Cuba*
[2]*LABIOFAM, Código Postal 95400, Guantánamo, Cuba*
[3]*Dirección de Planificación Física, Cabaiguán, Sancti Spíritus, Cuba*
[4]*Estación de Pastos y Forrajes, Apdo. 2255. Zona Postal 1. C.P. 60100. Sancti Spíritus, Cuba*
[5]*Estación de Pastos y Forrajes, Las Tunas, Cuba*
Email: jesus.suarez@indio.atenas.inf.cu

Since 2009 the International Project BIOMAS-CUBA is being executed. This is focused on biomass use as renewable energy source, on contributing to improve living conditions and attaining the coexistence between mitigation and adaptation to climate change, feeding security and energetic sustainability in rural areas. BIOMAS-CUBA covers the production and utilization of biodiesel and biogas, biomass gasification and the production of bioproducts. The project is directed at the integrated production of foods and energy in the context of agroenergetic farms of agro-ecological basis, with the purpose of participating in local development. It promotes a local agricultural innovation model, with large involvement of producers and impact studies. Its phase 1 was executed in 87 scenarios of five Cuban provinces making possible the sowing of 109 ha of *Jatropha curcas* L. associated to cultures, the installation of a plant of biodiesel production (105 600 liters/year) and two biomass gasifiers for generating electricity, the construction of 69 biodigestors and the installation of 52 plants for the production of the IHplus bioproduct of wide spectrum of agricultural use –in nine provinces-, with 3.4 benefit/cost, included the investment. If phase 1 was centered on the promotion of agroenergetic farms, the II (2012-2015) is directed at the formulation and implementation of local strategies of integrated production of foods and energy in six municipalities, accompanying the governments and other actors, as well as to attain greater incidence in national, regional and local policies, associated with food security, renewable energies and environment.

Key words: *agroenergy, climate change, food security, energy*

Introduction

At global level there is the challenge of how to make agroenergy, food security and protection of the environment coexist in the presence of climate changes, environmental degradation, food crisis and the "biofuel vs. food" contradiction which is consequence of a senseless policy for obtaining biofuels in large extensions of food monocultures, what morally merits rejection (Suárez and Martín 2010). Nonetheless, biofuels are also promoted as an ecological alternative to fossil fuels, due to their gas reduction capacity of greenhouse effect and by promoting the development of rural communities. This is potentiated in integrated agricultural systems where biofuels and foods can be produced with the application of the biorefinery that makes possible to turn the biomass into multiple products, whose total aggregate value could be higher than that generated by fossil fuels (Suárez *et al*. 2011).

With this aim contributes the BIOMAS-CUBA international project, headed by the Experimental Station "Indio Hatuey" (EEIH) and financed by the Switzerland Agency for Cooperation and Development (COSUDE), whose main results of phase 1 are shown in this paper that contributes to the solution of important challenges for humanity: food insecurity, energy sustainability and environmental protection.

BIOMAS-CUBA has generated key results in the development of technologies and for the promotion of innovation. It stands out for the evaluation of non-edible oleaginous plants, with potential for producing biodiesel and the conception of an appropriate technology for Cuba, allowing the integrated production of foods and biodiesel from *Jatropha curcas*. It also includes the evaluation of Jatropha oil as biolubricant and the improvement of the diesel lubricity, biogas production and biofertilizers from biodigestor effluents; biomass gasification to generate electricity, the evaluation of the integrated systems for food and energy production in Cuba and the economic, social and environmental impact produced. These results, applied in six Cuban provinces, are directed at improving the living quality through the integrated production of foods and energy in harmony with the environment.

BIOMAS-CUBA experiment. Evaluation of a non-edible oleaginous plant germoplasm with potential for biodiesel and its co-product production. The morphological and productive variability of *Jatropha curcas* collections (25 origins), *Ricimus communis* (5) and *Aleuritis trisperma* (10) collected in Cuba were characterized. These varieties have been introduced and established in germoplasm banks of three Cuban provinces for their evaluation in nurseries and under field conditions (Machado *et al*. 2012), for determining their potentialities for biofuel production.

In *J. curcas* collections in Cuba were identified accessions capable of attaining similar seed yields to

those of the introduced ones as with those called San Miguel and SSCE-10. However, Cabo Verde was the only one achieving a production potential per unit area according to the ranges that must be expected for the first year. Fruit characteristics and oil content of SSCE-10 origin were very similar to those of Cabo Verde, although this latter produced double of the oil (estimated) per area unit. These constitute the first materials identified as promising types.

Conception of the appropriate technology for the integrated production of foods and biodiesel. In Guantánamo, the easternmost province of Cuba, since 2009 was initiated the promotion of *J. curcas* for producing biodiesel. Between 2009 and 2011, 109 ha of *J. curcas* were sown associated with cultures in Paraguay Farm and in peasant farms of this province, as well as in EEIH (Matanzas) and in the Pasture Stations of Sancti Spíritus and Las Tunas (Sotolongo *et al*. 2012). However, Guantánamo is the territory holding the majority of the area sown (98 ha). *J. curcas* was prioritized due to the favorable results of the germoplasm evaluation.

Similarly, in the EEIH and in Guantánamo were evaluated eight combinations of sowing distances. From these two frames outstand: 2.5 x 4 m (1 000 trees/ha) appropriate for mechanized systems with 72 % of land occupation for producing foods and 28 % for energy and 2.5 x 3 m (l 333 trees/ha) for farming techniques using animal draft and 64 and 36 % occupation, respectively. In these frames were evaluated the performance of 21 intercropped agricultural cultures with *J. curcas* (outstanding the yields of bean, soybean, peanut, maize, yucca, sorghum and rice) under risk conditions of survival and medium fertilization with biofertilizers from the development of an agronomic management technology of the association, which is still under validation (Sotolongo *et al*. 2012).

In addition, *J. curcas* nurseries were made up with the application of the biofertilizers ECOMIC and FitoMass, prepared from myccorrhizas. This generated an infrastructure for producing in one year up to 80 000 seedlings, with two nurseries, in Guantánamo.

Benefit and oil extraction of Jatropha curcas seeds. Biodiesel production. From the physical and chemical characterization of the oil produced in Cuba and the tests of biodiesel production at small scale, conducted at the recognized laboratory Green Tec (Federal University of Rio de Janeiro) directed by Dr. Donato Randa, were conceived the raw material requirements, the benefice processes, extraction, filtrate, ungumming and neutralization. Furthermore, the biodiesel plant, the first in Cuba, was designed. This was installed in Paraguay Farm, with a mixture of Chinese and Costa Rican technologies and a production capacity of 400 L of biodiesel/day in an eight hour shift (105 600 L per year).

Positive environmental impacts have been generated (Suárez *et al*. 2012) as reforestation of 109 ha with *J. curcas* associated with food cultures. From these lands, 55 % are located in non-usable lands for other agricultural productions –with salinity and poor fertility- in areas of high fragility, with environmental damages and in one of the main Cuban hydrographic basins. Herein are included 112 ha of fruit trees and neem. It has been valued, between 2009 and 2011, a sequestration of 1 567 t of carbon dioxide (CO_2) –important gas of greenhouse effect (GGE) - by the plantations of *J. curcas* (it captures 6 kg of CO_2/year-tree).

Under Cuban conditions, the integrated production of biodiesel and foods has been demonstrated from the conception of an appropriate agroindustrial technology, still under validation, including from the agronomical management technology of the association of *J. curcas* with cultures until the production of biodiesel.

Evaluation of the J. curcas oil as biolubricant and for improving the diesel. In order of substituting oils by biolubricants, the performance of the oil friction of *J. curcas* was assessed regarding a mineral oil, representing the first study of this oil in the field of Tribology. *J. curcas* oil showed good stability to oxidation, an aspect of great interest in plant oils since this is one of their weak points and a coefficient of friction lower than that of mineral oil.

Concerning the utilization of this oil for improving the lubricity of the diesel, a fuel of low sulfur content that emits less pollutant gases, but generates greater wearing away in the motor injection systems. It was demonstrated that the pure plant oil of *J. curcas* can be used as quality additive, at 1 and 5 % to improve diesel lubricity, without modifying other properties of the fuel (Rodríguez *et al*. 2012a and 2012b).

Production of biogas and biofertilizers from anaerobic effluents of biodigestors. Within the project it has been designed and built 67 biodigestors. From them, nine are tubular of polyethylene, an anaerobic pool covered with 300 m^3 of a polyethylene geomembrane of high density (technology for great volumes of residuals that solves the limitations of the uncovered anaerobic pools, emitters of methane and other unpleasant smells). The remaining 57 are of fixed dome (Chinese model) with a total digestion capacity of 1 665 m^3 (Cepero *et al*. 2012a) and generate annual productions of 200 020 m^3 of biogas (equivalent to 754 oil barrels, 110 USD/barrel), that are used for cooking human and animal food, in the generation of electricity and in brick firing, as of 867 t of biofertilizers (equivalent to 115.6 tons of complete NPK fertilizer, 650 USD/t), used for fertility improvement of 1 830 ha of soil).

To this contributed the development of a program supported in LabVIEW 7.1 and its manual for designing biodigestors and their pools of secondary and tertiary treatment when necessary in function of the decrease of the Biochemical Demand for Oxygen of the effluent. These conditions facilitate optimum designs, with greater efficiency and lower material expenses. BIOMAS-CUBA allowed eliminating the

pollution generated by bovine and pig feces through biodigestors in 65 productive scenarios. This creates a positive environmental effect that is increased with the utilization of its effluents as biofertilizers, for the improvement of 1 830 ha of agricultural soils. Likewise, 52 plants of bioproduct production were installed from the effluents of biodigestors and other residuals, enriched with native microorganisms that are employed in animal and plant health, nutrition of cultures, elimination of bad smells in livestock production facilities, bioremedying of contaminated pools with organic residuals, as in bioceramics filters (Blanco *et al*. 2012).

Gasificacion of lignocellulose biomass for electricity generation. In view that biomass gasification is much more efficient that its traditional combustion as firewood or carbon, the technology selected, from technical and economical criteria was of fixed bed and with downdraft flow, with four phases within the gasifier (drying, pyrolisis, oxidation and reduction). This technology produces less tar than that of updraft flow, though is more appropriate for gas use in motors. As supplier was chosen the Indian enterprise Ankur Scientific Energy Technologies, one of the world leaders in low capacity gasifiers (lower than 100 kW of potency), to which two gasifiers were contracted with their generators with capacity of 20 and 40 k W potency (ANKUR 2011). They were installed at the Experimental Station "Indio Hatuey", in Matanzas and in the sawmill "El Brujo" at Gran Piedra-Baconao zone, Santiago de Cuba province. These facilities operate with branches and trunks of a woody thorny invader, as *Dichrostachys cinerea* (marabou) and with residuals from the prunings of livestock agroforest systems, as well as with wood wastes (pelleted sawdust and barks), respectively (Cepero *et al*. 2012b). The first gasifier generates "in island" for the livestock production areas of the Station while the second produces for the sawmill electricity during the day and at night is connected to the national electric system.

Evaluation of the integrated systems for the production of foods and energy in Cuba. For identifying and evaluating system typologies for the production of foods and energy, it was assumed as analytical basis the relationship between diversity, productivity and efficiency of the agroecological production. Monitoring was realized to 25 productive systems (farms) from the 53 participating in the BIOMAS-CUBA project (Funes *et al*. 2012).

The following indicators were assessed: 1) richness of species through the Margalef index (MI); 2) diversity of production by the Shannon index (H); 3) number of persons fed by the energy system (Pe); 4) number of persons fed by the protein system (Pp); 5) land use index (LUI) combined with the analysis of the polycultures employed; 6) annual energy balance (EB) and 7) energetic cost of the protein production (ECP).

The indicators of biodiversity (MI + H), productivity (Pe + Pp) and efficiency (LUI + EB + ECP) were added up for obtaining respective values of biodiversity index (DIV), productivity index (PROD) and energy efficiency index (EE). Later, the best performance of each index was adjusted among all the farms.

Also, it was validated the feasibility of using three farms evaluated as prototypes energetically sustainable for the production of foods and energy, from poor outside inputs, high recycling rates and livestock-agriculture integration, as objectives for attaining food security in a sustainable way. The typologies are the followings: BIOMAS IA (strong food and energy integration), BIOMAS IB (in the process of increasing the integration) and BIOMAS IC (initial stages).

Evaluation of the generated impact. Socio-economic and environmental studies have been carried out from a program of monitoring and evaluation, directed at evaluating the impact of the integrated production of foods and energy in 87 productive scenarios of fifteen municipalities during its first phase.

The economic and financial analysis realized in its Phase 1 (2009-2011), but with perspectives until 2014, revealed a 3.4 benefit/cost relationship including the investment made by the Switzerland cooperation and the Cuban counterparts. Also, it was calculated a net current value (NCV) higher than 34 millions Cuban pesos and an internal rate of return of the investment (IRR) of 7.4 %, with the recovery of the investment at the beginning of 2011. This confers to the project an adequate efficiency. Moreover, higher net profitability to 48.2 millions Cuban pesoswas calculated between 2009 and 2014 (Suárez *et al*. 2012). Increase in food production of plant and animal origin (3 196 t of vegetables, fruits, milks, meats and eggs in 2009-2011) was created in which the project influenced directly. According to evaluations at local market prices, the production was increased from 1.6 to 20.6 millions Cuban pesos and were notably diversified the productive items. Additionally, production of foods, tree plantules, biogas and biofertilizers between 2009 and 2011 attained 22 987 843 Cuban pesos.

In the improvements attained in the living quality, can be highlighted the creation of 108 direct jobs, with a monthly average salary higher to the average salary of the provinces involved. From these 14 % are occupied by women on equal terms. In addition it was demonstrated improvement of the living standard of 1 823 persons directly through the increase of jobs, incomes, access to equipments and productive inputs, better working conditions and availability of cooking service with gas. This represents increase in the purchasing power and living standard of peasant women that decide to better themselves by starting to work for acquiring economic independency.

Environmental impact. Between 2009 and 2011 (Suárez *et al*. 2012) a positive environmental impact has been generated, associated with the reforestation,

with more than 135 000 trees and CO_2 sequestration. Also, it was demonstrated biodiesel production with a favorable energetic productivity of the agroindustrial system of 1/5 as well as the substitution of fossil fuel and the decrease of the CO_2 and SO_2. Additionally, it was eliminated the pollution created by bovine and pig feces, the production of biofertilizers for improving soils and the gasification of woody biomass that besides producing electricity, allows to use pollutant residuals and eliminate potential fire focuses, as are wastes from sawmills and from the pruning of agroforestry systems with a conversion efficiency much more higher than the traditional biomass combustion.

References

Blanco, D., Cepero, L., Donis, F., González, O., García. Y., Martín, G., Suárez, J., Ojeda, F., Catalá, R., Medina, R., Díaz, M., Fonte, L., Ramírez, I., Sánchez, S. & Miranda, T. 2012. Hplus®, un bioproducto de amplio uso agropecuario basado en microorganismos nativos. In: Suárez, J. & Martín, G. (Eds.). La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey". Matanzas, Cuba. p. 150-180

Cepero, L., Savran, V., Blanco, D., Díaz, M.R., Suárez, J. & Palacios, A. 2012. Producción de biogás y de bioabonos a partir de efluentes de biodigestores. In: Suárez, J. & Martín, G. (Eds.) La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey". Matanzas, Cuba. p.131-142

Cepero, L., Recio, A.A., Palacios, A., Iglesias, Y. & Suárez, J. 2012. Gasificación de biomasa para la producción de electricidad. En: J. Suárez & G. Martín (Eds.) La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey". Matanzas, Cuba. p. 143-149

Funes, F.R., Martín, G., Suárez, J., Blanco, D., Reyes, F., Cepero, L., Rivero, J.L., Rodríguez, E., Savran, V., Valle, Y., Cala, M., Vigil, M., Sotolongo, J.A., Boillat, S. & Sánchez, J.E. 2012. Evaluación de sistemas integrados para la producción de alimentos y energía en Cuba. In: Suárez, J. & Martín, G. (Eds.) La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey". Matanzas, Cuba. p. 181-195

Machado, R., Sotolongo, J.A. & Rodríguez, E. 2012. Caracterización de colecciones de oleaginosas útiles para la producción de biocombustible en bancos de germoplasma. En: Suárez, J. & Martín, G. (Eds.) La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey", Matanzas, Cuba. p. 41-69

Rodríguez, C., Lafargue, F., Sotolongo, J. A., Rodríguez, A. & Chitue de Assuncao, J. 2012a. Aceite vegetal de *Jatropha curcas*como posible biolubricante. In: Suárez, J. & Martín, G. (Eds.) La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey". Matanzas, Cuba. p. 113-121

Rodríguez, C., Lafargue, F., Sotolongo, J. A., Rodríguez, A. & Chitue de Assuncao, J. 2012b. Aceite de *Jatropha curcas*como mejorador de la lubricidad del combustible diesel. In: Suárez, J. & Martín, G.J. (Eds.) La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey". Matanzas, Cuba. p. 122-130

Sotolongo, J. A., Suárez, J., Martín, G., Cala, Marlenis; Vigil, María; Toral, Odalys; Reyes, F. & Santana, H. 2012. Producción integrada de biodiesel y alimentos: la concepción de una tecnología agroindustrial apropiada para Cuba. In: Suárez, J. & Martín, G. (Eds.) La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey". Matanzas, Cuba. p. 100-112

Suárez, J. & Martín, G. 2010. Producción de agroenergía a partir de biomasa en sistemas agroforestales integrados: una alternativa para lograr la seguridad alimentaria y la protección ambiental. Pastos y Forrajes 33 (3): 1-19

Suárez, J., Martin, G., Sotolongo, J.A., Rodríguez, E., Savran, V., Cepero, L., Funes, F., Rivero, J.L., Blanco, D., Machado, R., Martín, C. & García, A. 2011a. Experiencias del proyecto BIOMAS-CUBA. Alternativas energéticas a partir de la biomasa en el medio rural cubano. Pastos y Forrajes 34 (4): 473-496

Suárez, J., Martin, G., Sotolongo, J.A., Cepero, L. & Hernández, R. 2012. Impacto de la producción integrada de alimentos y de energía. Contribución a la seguridad alimentaria, ambiental y energética. In: Suárez, J. & Martín, G. (Eds.) La biomasa como fuente renovable de energía en el medio rural: La experiencia del proyecto BIOMAS-CUBA. Estación Experimental "Indio Hatuey". Matanzas, Cuba. p. 196-207

Received: September 2013