# Feasibility Study for the Production of Ethanol in Central American and Caribbean Countries

**IADB - Inter-American Development Bank**

**Product 2 – Final Report of Module I**

**Rio de Janeiro, June 14, 2008**

BID - Banco Interamericano de Desenvolvimento

FUNDAÇÃO GETULIO VARGAS
FGV PROJETOS

# Technical Data

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| **Project:** | **Feasibility Study for the Production of Ethanol in Central American and Caribbean Countries: Haiti.** |
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| **Term:** | **Six Months** |
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# Summary

Technical Data ....................................................................................................2
Summary ....................................................................................................3
Executive Summary ....................................................................................................7
1. General Aspects ....................................................................................................13
1.1 Current use of the land ....................................................................................................14
1.2 Agricultural Inputs Used in Haiti ....................................................................................................15
1.3 Agricultural Crops ....................................................................................................17
1.4 The Sugarcane Production Panorama ....................................................................................................20
1.5 Destination of Sugarcane Production ....................................................................................................22
1.6 Socioeconomic Analysis ....................................................................................................23
1.7 Economy ....................................................................................................25
1.8 Gross National Income ....................................................................................................26
1.9 Economically Active Population ....................................................................................................26
1.10 Labor ....................................................................................................28
1.11 Emigration ....................................................................................................30
1.12 Income ....................................................................................................31
1.13 Services Sector ....................................................................................................31
1.14 Inflation ....................................................................................................32
1.15 International Economic Relations ....................................................................................................32
1.16 Importations ....................................................................................................32
1.17 Exports ....................................................................................................33
1.18 Trade Balance ....................................................................................................33
1.19 Foreign Investments ....................................................................................................33
2. Land Capability for Production of Biofuels ....................................................................................................34
2.1 Data research and collection ....................................................................................................35
2.1.1 Land properties ....................................................................................................35
2.1.2 Soil Potential ....................................................................................................35
2.1.3 Slope ....................................................................................................36
2.1.4 Land use, protection areas and non agricultural areas ....................................................................................................38
2.1.5 Areas vulnerable to Inundation ....................................................................................................39
2.1.6 Data processing ....................................................................................................40
3. Land Capability for biofuel crops in the Republic of Haiti ....................................................................................................43

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3.1 Sugarcane: Manual harvest ..... 43
3.2 Sugarcane: Mechanical harvest. ..... 47
3.3 Sunflower ..... 51
3.4 Eucalyptus ..... 55
3.5 Jatropha ..... 59
3.6 Elephant grass ..... 63
3.7 Final remarks ..... 67
4. Agroclimatic Zoning for Biofuels Production ..... 68
4.1 Elaboration of Climate Maps ..... 69
4.2 Procedures and Criteria for Agroclimatic Zoning ..... 70
4.2.1 Sugarcane ..... 70
4.2.2 Sunflower ..... 71
4.2.3 Eucalyptus ..... 72
4.2.4 Jatropha ..... 73
4.2.5 Elephant Grass ..... 74
4.3 Climatic Characterization of Haiti ..... 75
4.4 Agroclimatic Crop Zoning ..... 81
4.4.1 Sugarcane ..... 81
4.4.2 Sunflower ..... 85
4.4.3 Eucalyptus ..... 88
4.4.4 Jatropha ..... 90
4.4.5 Elephant Grass ..... 93
4.5 Considerations on agroclimatic zoning ..... 96
5. Land suitability ..... 97
5.1 Land Suitability for biofuel crops ..... 98
5.1.1 Sugarcane ..... 99
5.1.2 Sunflower ..... 101
5.1.3 Eucalyptus ..... 103
5.1.4 Jatropha ..... 106
5.1.5 Elephant grass ..... 108
5.1.6 Final Remarks ..... 109
6. Identification and Analysis of the Energy Matrix ..... 110
6.1 Consumption of petroleum derivatives ..... 113
6.2 Consumption of energy per sector ..... 116

6.3 Consumption of Energy in the Residential Sector ....118
6.4 Consumption of Energy in the Industrial Sector ....121
6.5 Consumption of Energy in the Transformation Sector ....123
6.6 Consumption of Energy in the Transport Sector ....126
6.7 Potential for the use of biofuels ....128
6.8 Electricity ....132
7. Analysis of the Infrastructure ....133
7.1 Transport ....134
7.1.1 Roads ....134
7.2 Railways ....138
7.3 Waterways ....139
7.4 Ports and Maritime Transport ....139
7.5 Air transport ....143
7.6 Biofuel Storage Capacity ....143
7.7 Current Vehicle Fleet Situation and Prospective ....144
8. Survey of Available Technologies ....145
8.1 Sugarcane varieties ....146
8.1.1 Varieties currently cultivated in Haiti ....146
8.1.2 Development of sugarcane varieties ....147
8.1.3 Planting ....149
8.1.4 Semi-Mechanized Planting ....149
8.1.5 Mechanized planting ....150
8.1.6 Localized application of agricultural inputs ....152
8.1.7 Irrigation ....152
8.1.8 Use of GPS in Agriculture ....155
8.1.9 Monitoring of the Harvest ....156
8.1.10 Mechanized harvest ....156
9. Additional Reasons for the Development of a Biofuel Chain ....159
9.1 Environmental Benefits ....159
9.1.1 Reduction of Greenhouse Effect Gas Emissions ....159
9.1.2 Reduction of Pressure on Native Forests ....161
9.2 Benefits connected to Health ....163
9.3 The possibilities for the Generation of Income and Employment in Rural Areas ....164
9.4 Substitution of Petroleum Products ....165

9.4.1 Electricity Co-generation ..... 166
9.4.1.1 Environmental Benefits ..... 167
9.4.1.2 Economic Benefits for the Community ..... 167
9.4.1.3 Economic Benefits for Companies ..... 167
9.4.1.4 The use of bagasse in Co-generation ..... 168
10. Concluding remarks ..... 168
11. Bibliographic References ..... 170

# Executive Summary

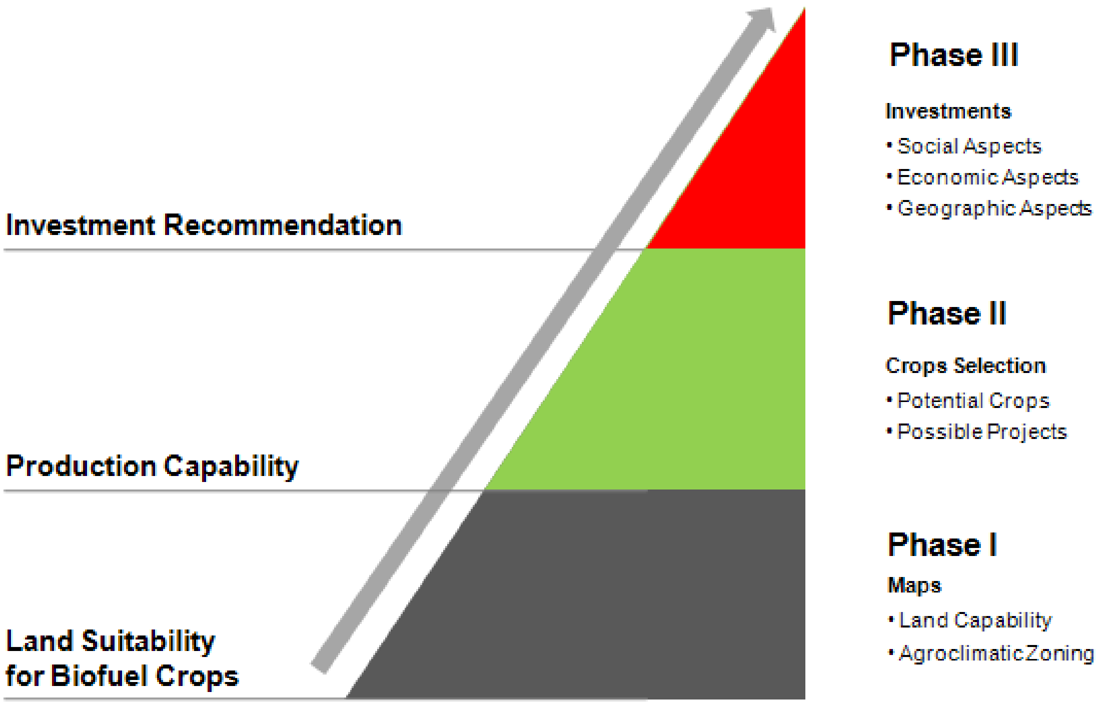
This study has the objective of defining the feasibility for the production of ethanol and other biofuels in Haiti considering factors related to agricultural suitability, logistical aspects, infrastructure, existing sugar mills, the energy matrix and socioeconomic data.

The need for the development of renewable energy sources is widely recognized because of the evidence of global warming and depletion of non-renewable fuel sources. This phenomenon is due to the massive release of toxic gases resulting mainly from the intensive use of fossil fuels. According to specialists, the content of $CO_2$ in the atmosphere and the effects of climatic changes can already be perceived in different parts of the planet.

In addition to the environmental concerns, the economic need, particularly for developing countries, to diversify their energy matrix is of extreme importance in order to reduce their dependence on petroleum and its byproducts. Therefore, the search for alternative energy sources has awakened world attention to the production of agricultural feedstocks, especially those that present agricultural and financial feasibility for the sustainable production of ethanol, biodiesel and biomass as presented in this project. This current scenario is of special importance to Haiti, given the danger it now faces of completely depleting its biomass reserves by unsustainable exploitation and its dependence on foreign fossil fuels of non-renewable origin.

In view of these questions, this Project is divided into two modules. The first module, corresponding to this document, presents a pre-feasibility analysis, determined by the discerning combination of different variables related to the agricultural suitability for the production of biofuels and the existing regional infrastructure. The second module, to be presented in the Final Report of this Project, analyzes the production capability and provides recommendations on investments in biofuel projects, using the information generated in Module I. Figure 1 presents a diagram of the ongoing work.

**Figure 1**
**The ongoing work.**




The method proposed for determining the agricultural suitability is presented succinctly in. The locations suited for biofuel production feedstock cultivation are determined based on the survey of land capability and of the agroclimatic characteristics of **Haiti**. The method proposed is important in order to define, with greater certainty, the regions where the best investments can be made.

The variables considered for the definition of agricultural suitability in **Haiti** were:

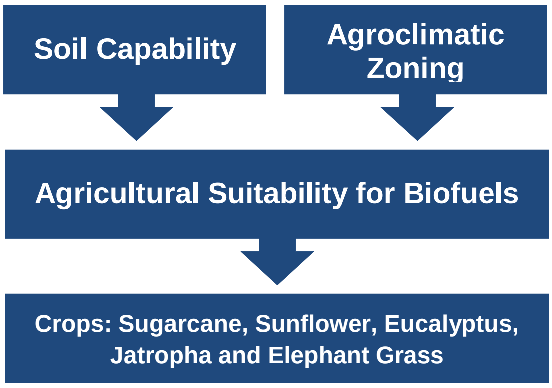
Land capability, observing:

- Soil potential;
- Slopes;
- Land use;
- Protected areas;
- Areas subject to inundation or inundated areas.

Agroclimatic Zoning, observing:

- Annual temperature and maps of annual average temperature;
- Temperature of the coldest month;
- Total annual rainfall, water deficit and surplus;
- Potential and effective evapotranspiration;
- Humidity index.

**Figure 2**
**Methodology for definition of agricultural suitability for the production of biofuels.**

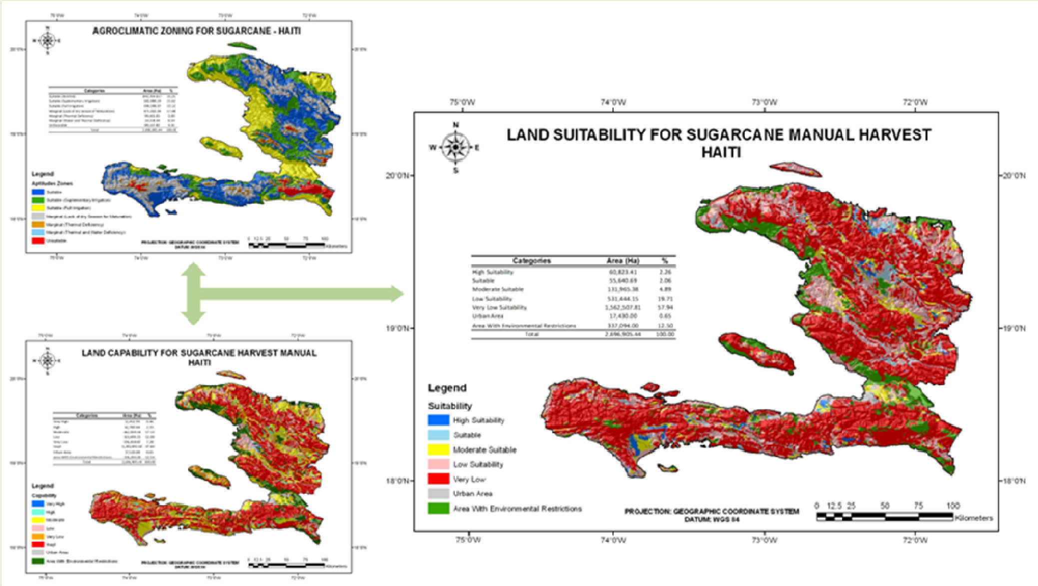



Agricultural suitability of the land, or agricultural suitability, was defined based on the results of the combination of land capability and agroclimatic zoning. Expert knowledge, along with the requirements of each crop considered, were the bases for defining the categories of suitability in accordance with the combination of land capability and agroclimatic zoning categories. The maps resulting from these surveys are presented throughout this report.

Figure 3[1] illustrates the process of combining the data on land capability and agroclimatic zoning in Haiti.

[1] This Layout aims to illustrate the combination of the land capability and climate, resulting in the land suitability map for manually harvested sugarcane. These maps are presented in better resolution in the attachment to this Report.

**Figure 3**
**Combination of land capability and climate maps to obtain a land suitability map.**




Example: Land suitability for manually harvested sugarcane in **Haiti.**

The large volume of data obtained was necessary because the soil, relief and agroclimatic characteristics have a direct influence on agricultural potential. Certain regions have highly adequate natural attributes, requiring little human intervention to be productive. Other less suitable regions may be economically feasible but would require various anthropic corrections and interventions. Finally, certain areas are inadequate due to natural particularities or because they are urban or environmentally protected areas.

It is important to observe that the agricultural suitability of a region varies in accordance with the crop being considered. In general terms, different vegetal species have different requirements for fulfilling their maximum potential. Therefore, each region within a specific locality presents a different potential for agricultural exploitation, defined by the inherent variability of the production environments. The advantage of considering different crops in a single study lies in allowing an effective comparison of the agricultural and financial sustainability of each crop in different locations.

Land suitability in Haiti was defined for the following vegetal species intended for the production of biofuels using sugarcane, sunflower, eucalyptus, jatropha and elephant grass. In general lines, the results obtained for each crop were:

**Sunflower** (*Helianthus annuus*)

- Approximately 79% of the area of Haiti presented a very low suitability and only up to 0.77% of the area was found to be highly suitable or suitable for sunflower. On the other hand, 2% of the area is suitable for use with varieties of sunflower adapted to the local conditions or with the application of technology to overcome the restrictions. In that case, of course, further financial viability studies should be done in order to evaluate the cost/benefit relation of the necessary measures.

**Sugarcane** (*Saccharum officinarum*)

- Approximately 78% of the area of Haiti was found to be little suitable or unsuitable and only about 9% of the area was considered to be moderately suitable, suitable or highly suitable for sugarcane in general. Nevertheless, a greater area must be considered little suitable or unsuitable if mechanical harvest is to be adopted, as slope may pose as restriction in this case.

**Eucalyptus** (*Eucalyptus spp.*)

- Given the large number of different eucalyptus species, for the purpose of suitability analysis, this crop was subdivided into four groups of species adaptable to different climate conditions.
- Group 1 was found to be suitable or highly suitable for a greater area (3.2%) than any other group. Approximately 11% of Haiti's area was classified as moderately suitable for eucalyptus species from group 1 and the sum of areas considered moderately suitable for all the other groups summed up to another 11% of the country's total area.

**Elephant grass** (*Pennisetum purpureum*)

- Approximately 66.6% of the area of Haiti was considered unsuitable and 19.2% was considered moderately or little suitable for elephant grass, due especially to the low soil potential conditions. On the other hand, about 1.42% (38,395 ha) of the area of Haiti was classified as suitable or highly suitable for elephant grass.

**Jatropha** (*Jatropha curcas*)

- Approximately 70% of the area of Haiti was considered to be unsuitable or little suitable for jatropha, mainly because of soil conditions, as climate in most parts of the country are nearly ideal for this plant native from Central America and the Caribbean. Only about 5% of the area could be classified as suitable or very suitable, while about 12% may be considered as moderately suitable for jatropha.

Based on a survey of the agroclimatic suitability of each region, it is possible to perform the pre-analysis of the operational capability in Haiti. Focus should be put, therefore, on the adequacy of the land for the production of biofuel production feedstock, which will allow a more precise estimation of agricultural productivities, production costs, investments necessary and planned financial results.

In addition to the agricultural analyses, data was collected on the existing infrastructure in Haiti. Based on this data, the main logistical modalities and the positions of ports were mapped. The analysis of the energy matrix showed that most of the country's energy requirements are met consuming the domestic biomass reserves in the form of fuelwood or charcoal. Petroleum products are imported to be used, especially, in the industry, services and transportation sectors.

Haiti is a traditional grower of sugarcane for the manufacturing of sugar and liquor, but production as well as productivity have fallen dramatically in the last 20 years. Investments in agricultural technology are necessary in order to enable economically advantageous yields. The development of varieties adapted to local conditions as well as the implementation of soil management techniques should be adopted for eventual ethanol production projects to be competitive.

The information contained in this report, combined with the agricultural suitability analysis, enables the preparation of Module II, which will define the best regions for project installation, as well as the investment recommendations and the analyses of financial-economic feasibility.

# 1. General Aspects

Presenting a total surface of 27,750 km², Haiti has 65% of its territory comprised of mountains. In spite of this, the country benefits from favorable climatic conditions: 70% of the territory has annual rainfall greater than 1200 mm[2].

The country presents a large variability and heterogeneity as to agricultural crops: various ecosystems can be found in the same locality, which the local farmers seek to explore and overcome any eventual soil-climatic[3] difficulties.

Subsistence agriculture is the norm, both in the rural areas and the urban areas, and does not meet the needs of the population. The principal sources of income from agriculture are: sugarcane, coffee, rice, sorghums, corn, beans, manioc and fruits[4].

In the last decades, the Haitian agricultural sector has shown a constant decline[5], a result of the combination of a deficient infrastructure, low investment in human capital, and limitations as to

[2] Bellande, 2005.
[3] Werbrouk, P. et Damais, G., 2005.
[4] Haitiwebs, 2008.
[5] World Bank, 2001. Haiti at a Glance.

access to credit, absence of research and development and a badly defined farming structure. During the decade of the 80s, this drop was 0.1% per year, and, in the decade of the 90s, sharpened to (3.3% per year) as a result of the constant crises that shook the country

## 1.1 Current use of the land

For the agronomic standards, 63% of Haitian lands are considered arable, however, only 28% can be plowed and only 11.5% are used with permanent crops (Table 1).

**Table 1**
**Current land use in Haiti.**

| Areas | | Year-2005 km² | Year-2005 % |
|---|---|---|---|
| | Arable | 7,800 | 28.11 |
| **Agricultural** | Permanent Crops | 3,200 | 11.53 |
| | Pastures | 4,900 | 17.66 |
| **Forest** | | 1,050 | 3.78 |
| **Other** | | 10,800 | 38.92 |
| **Total** | | 27,750 | 100 |

Source: FAO, 2008.

Due to the diversity of ecological conditions, a vast range of species is cultivated in Haitian territory. Sorghums are found in the more arid zones through to fruits characteristic of temperate zones (strawberries), tubers and fructiferous species of tropical zones.

The combination of the relief characteristics of a region and its climatic classification result in agro ecological zones. In this manner different combinations of agricultural cultures may be found in the Haitian territory, in accord with each ecosystem[6]:

- In the dry and semi-arid zones there are associations of cultures like sorghum, corn, peas, as well as fructiferous species like mango trees;
- In the plains and plateau regions, with a predominance of wet and semi-wet climates, corn, sorghum, potatoes, manioc, sugarcane, mango and banana arte cultivated;
- In the irrigated plains cereals are cultivated, especially rice, corn and sorghums, and bananas are also produced;

[6] Bellande, 2005.

- In the mountain and wet climate regions there are associations of corn, beans, sweet potatoes. Citrus, coffee, banana, cocoa beans and yam are also produced.

## 1.2 Agricultural Inputs Used in Haiti

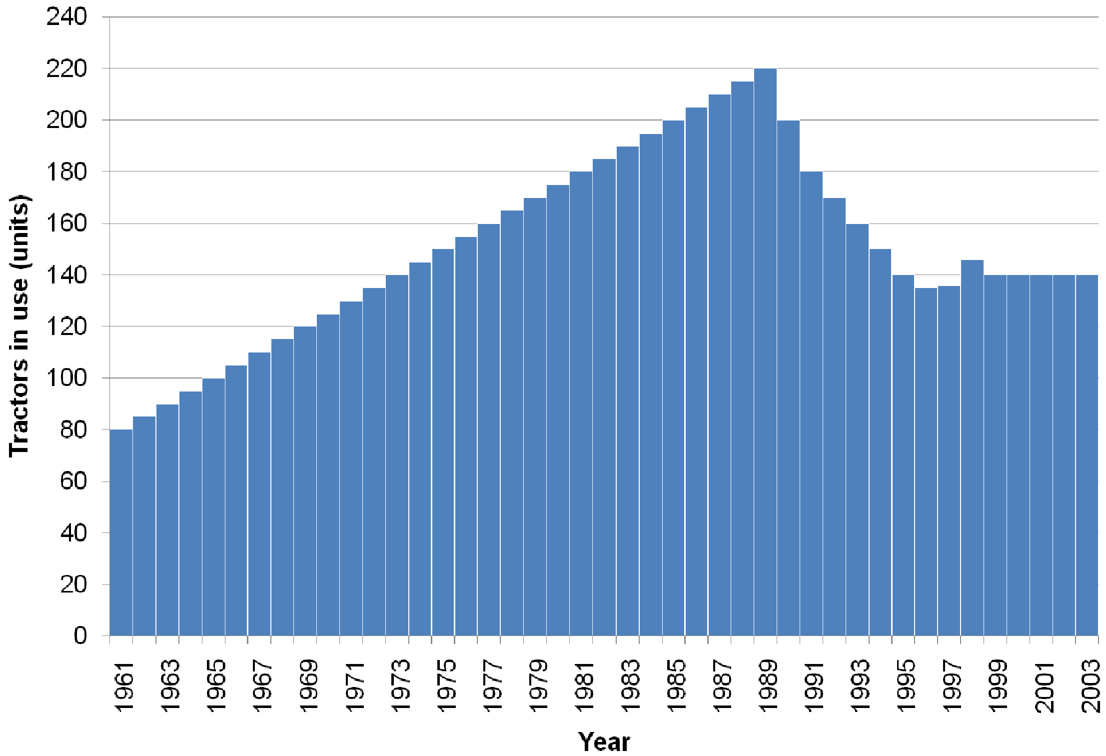
The majority of the Haitian farmers have only primitive agricultural tools, such as the hoe and pickaxe. Only 5% of rural families have vehicles drawn by animals[7].

In the Artibonite department, one third of the rural families make use of some kind of fertilizer and/or pesticides, which represents less than 5% of rural Haitian families. In the districts of Grand'Anse and North-West, the rural producers do not use any kind of fertilizers or pesticides[8].

Surveys on the number of tractors in use in Haiti, done by FAO (2008) for the period from 1961 to 2003 (Figure 4), show that the number of tractors in use in Haiti increased at a constant rate of 5 units per year from 1961 to 1989, when it reached a total of 220 units.  From 1990 to 1995, the number of tractors fell to 135 units and, from 1999 to 2003, this number remained constant at the mark of 140 units.

[7] Identification de Creneaux Potentiels dans les Filieres Rurales Haitianes, 2006.
[8] Idem.

**Figure 4**
**Number of tractors in use in Haiti during the period from 1961 to 2003.**




Source: FAO, 2008.

The consumption of fertilizers by Haitian rural producers is low and only large producers make use of them. The country does not produce any kind of fertilizer compound. Table 2 shows the quantities imported between 1998 and 2002. In this period, there was an increase in importation of all types of fertilizers. In absolute values, the nitrogenous compounds were the type of fertilizer that was most imported (7,670 tons in 2002), whilst the phosphate fertilizers were those that showed the largest relative increase, jumping from 1,640 tons, in 1998, to 2,560 tons, in 2000.

**Table 2**
**Quantity of fertilizers used in Haiti during the period 1998-2002.**

| Fertilizers (t) | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|
| **Nitrogenous** | 6,965 | 5,113 | 8,854 | 7,663 | 7,670 |
| **Phosphate** | 1,640 | 2,113 | 2,659 | 2,558 | 2,560 |
| **Potash** | 2,777 | 1,849 | 2,916 | 3,703 | 3,700 |

Source: FAO, 2008.

## 1.3 Agricultural Crops

Although the farming activity in Haiti is marked by subsistence agriculture, the country has also a small export agricultural sector. Agriculture, as well as forestry and fishery are responsible for approximately 28% of the Gross National Product of the country .

Table 3 shows the values, in tons, of the production of the principal agricultural crops in Haiti, in the period from 1965 to 2004. Sugarcane, characterized by being a large source of income for the country, showed peaks in production for many years. The production of sugarcane kept levels of around 2.8 million tons, in the middle of the 1970s. After this period, the cost of production in Haiti exceeded the world cost of production, and production of sugarcane entered into decline.

Coffee, introduced into Haiti by the French during the colonial period, became one of the principal products of the country. The production of coffee maintained high stable levels during the 1980s, however, as occurred with other agricultural activities in Haiti, suffered drops in production. The production, of 39,000 tons, in 1975, reached the level of 29,000 tons, in 1995. High taxes associated to a fall in prices in previous years probably contributed to the decline in production.

Other agricultural crops such as rice, manioc and banana had an increase in their yields during the period analyzed. These products, however, are typical of subsistence agriculture, and do not significantly contribute to the collection of taxes or exportations.

Crops such as cocoa and sisal performed, in other periods, an essential role in the Haitian economy. Cocoa, in the middle of the 1980s, covered around 10 thousand hectares, yielding about 4 thousand tons per year. Sisal, raw material for the manufacture of cloth, was used a lot in the middle of the 20th century, supplying fibers for markets like the Dominican Republic and Puerto Rico[9].

**Table 3**
**Agricultural Production in Haiti.**

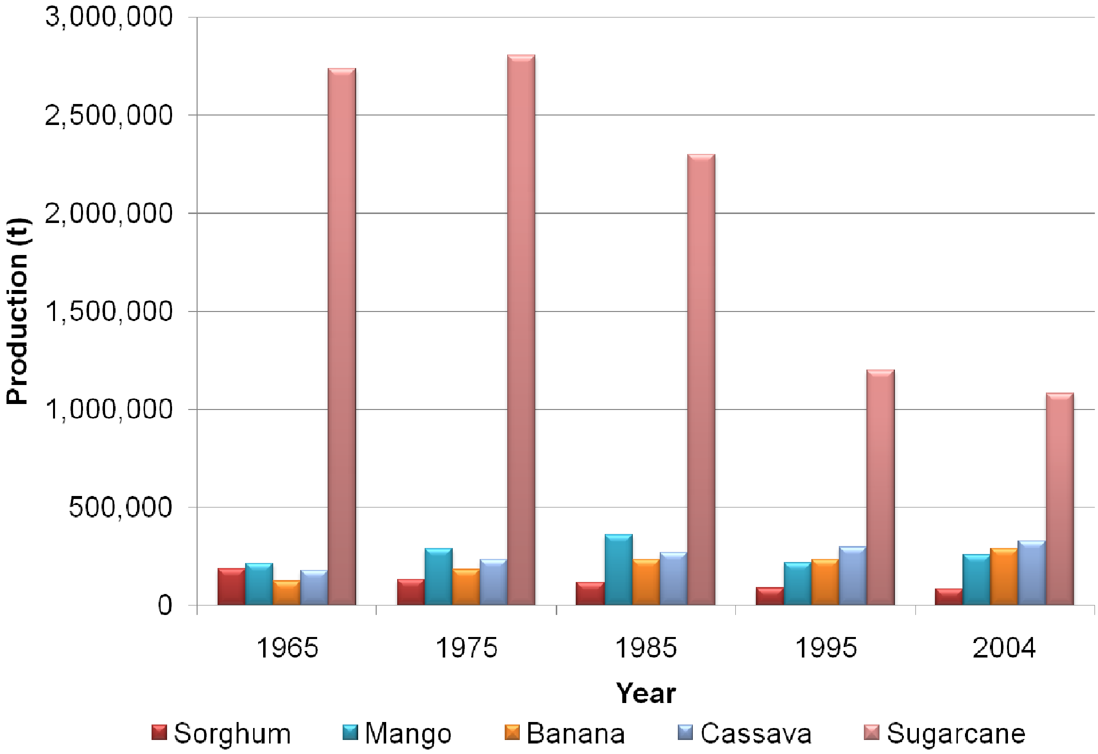
| Crop | Production (t) | | | | |
|---|---|---|---|---|---|
| | 1965 | 1975 | 1985 | 1995 | 2004 |
| **Coffee** | 36,720 | 39,000 | 36,900 | 29,000 | 28,000 |
| **Sorghum** | 187,000 | 135,000 | 119,165 | 90,000 | 85,000 |
| **Rice** | 72,000 | 107,500 | 129,195 | 100,000 | 102,000 |
| **Maize** | 234,000 | 180,000 | 196,295 | 220,000 | 180,000 |
| **Mango** | 215,000 | 290,000 | 363,000 | 220,000 | 260,000 |
| **Banana** | 125,000 | 185,000 | 235,000 | 235,000 | 290,000 |
| **Cassava** | 180,000 | 235,000 | 270,000 | 300,000 | 330,000 |
| **Sugarcane** | 2,738,000 | 2,802,000 | 2,300,000 | 1,200,000 | 1,080,000 |

Source: FAO, 2008.

Figure 5 shows that, in the decades of the 60s and 70s, sugarcane was the principal agricultural product of Haiti. However, the drop in prices on the market, the undercapitalization of farmers and strong international competition made that production aimed at cane crop fall drastically as from the 1990s. At the same time, there was a decrease in the production of sorghum and a small increase in the production of fruits (bananas and mango — in the last two decades) and roots (manioc).

[9] Library of Congress, 2006.

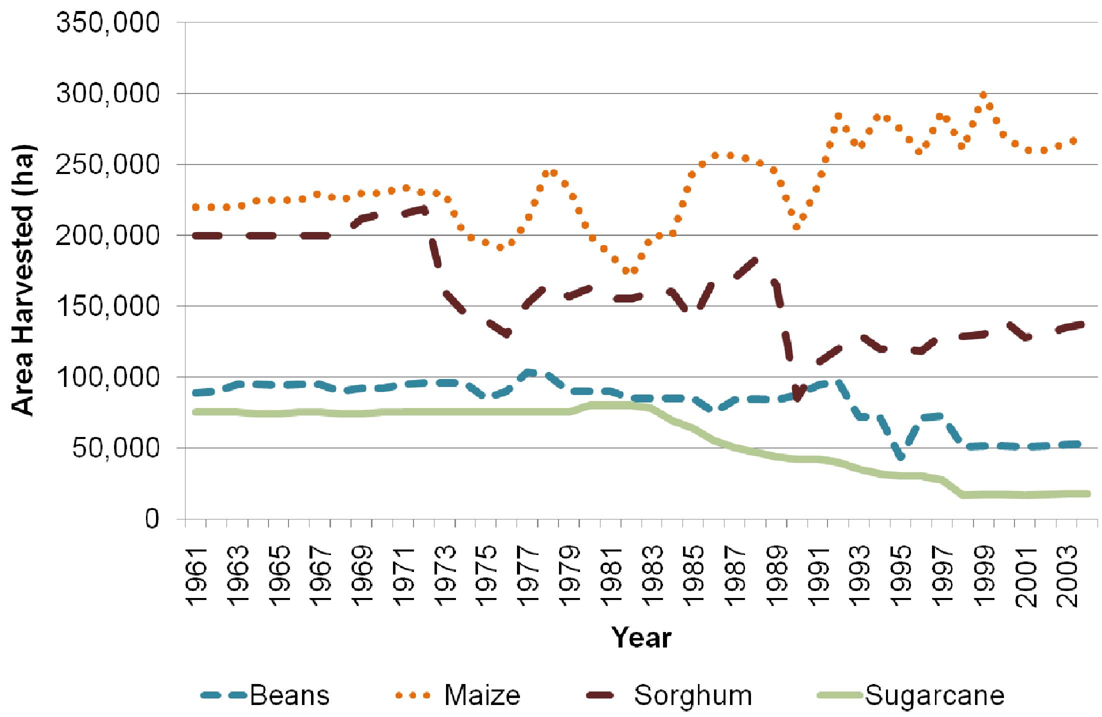
**Figure 5**
**Haitian agricultural production**




Source: FAO, 2008.

The instability and the decline of the agricultural sector in Haiti can be seen in Figure 6, which represents, in hectares, the area harvested by some of the principal agricultural crops in the country, between the years 1961 and 2004. Sugarcane, sorghum and beans crops suffered a drop and variations in their harvested areas, notably sorghum, whose harvested area, during the decade of the 1960s, was approximately 200 thousand hectares annually and, in 2004, did not exceed 150 thousand hectares. Amongst the cultures analyzed by FAO, only maize showed an absolute increase in area harvested annually, that, in spite of the oscillations throughout the period, had 20 thousand more hectares planted in 2004 than in 1961.

**Figure 6**
**Area harvested of some agricultural cultures in Haiti between 1961 and 2004.**

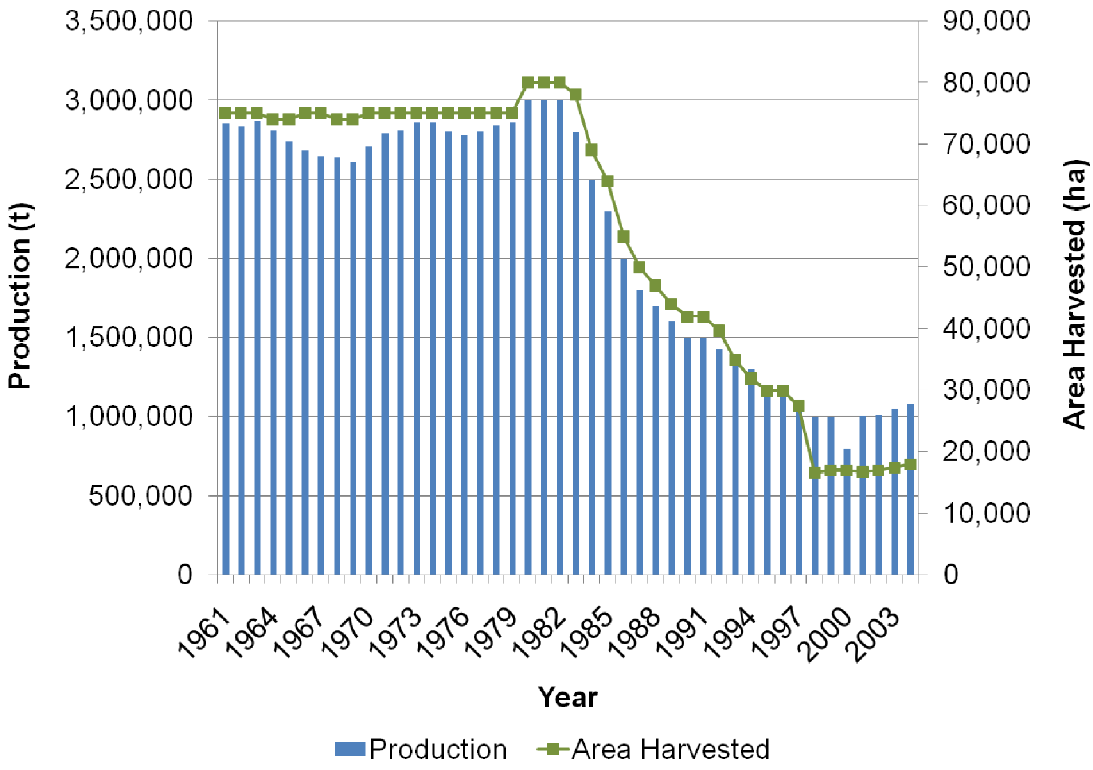



Source: FAO, 2008.

## 1.4 The Sugarcane Production Panorama

The evolution of sugarcane production, with annual comparison of production and areas harvested, is shown in Figure 7. Both the production of sugarcane and the area harvested annually have been stable during the decades of 1960, 1970 and the middle of the 1980s, amounting to 3 million tons and 80 thousand hectares respectively. As noted before, changes in the sugar market, combined to structural problems, made the production of sugarcane crash. In a few years, there was a fall greater than 100% in production and the area planted, without any signs of recovery up to today. During the decade of the 1980s, 4 companies closed temporarily and only the oldest, HASCO (Haitian American Sugar Company), maintains large areas for sugarcane production.

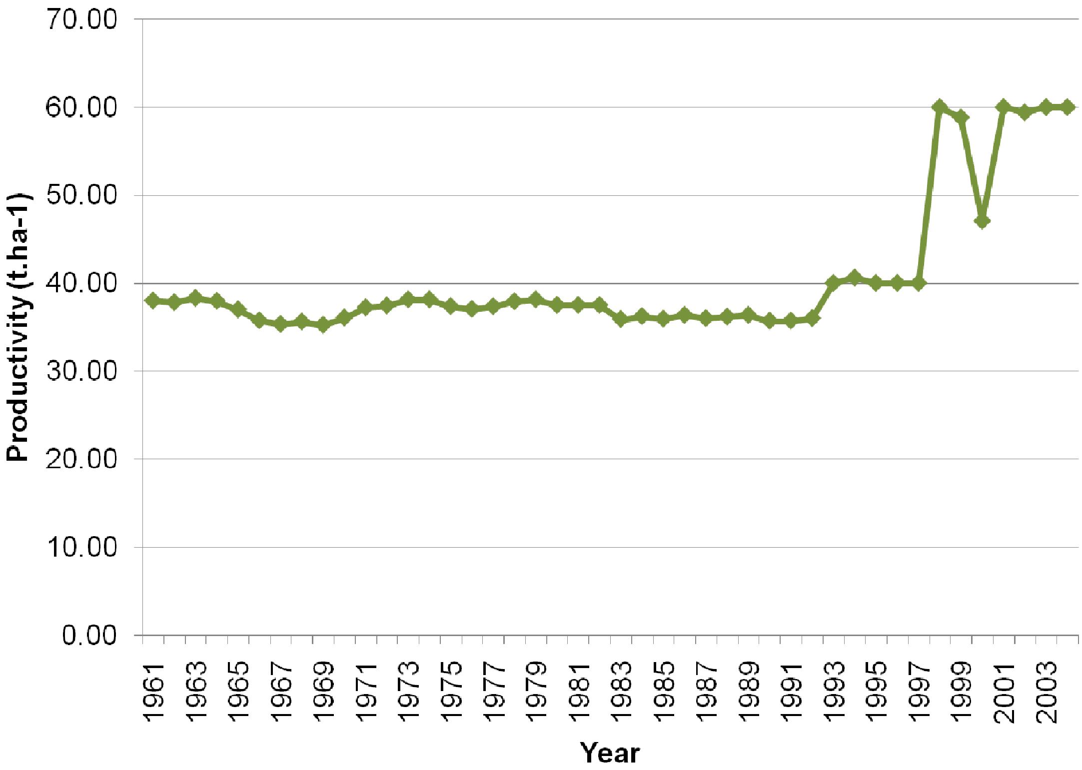
**Figure 7**
**Production of sugarcane × Area harvested.**




Source: FAO, 2008.

The productivity (ratio between production and harvested area) of the Haitian cane fields (Figure 7) oscillated a little under 40 tons per hectare until 1998, a yield currently considered low. As from 1999, the graph in Figure 8 shows that the nominal productivity increased to around 60 tons per hectare. This fact may be confused with a consequence of use of better technology or an increase in investments in the sector. But the reality is that the production and the area harvested also fell dramatically and the apparent increase in productivity shows only that the less efficient farmers abandoned the cane activity.

**Figure 8**
**Productivity of Haitian cane fields.**




Source: FAO, 2008.

## 1.5 Destination of Sugarcane Production[10]

A great part of sugarcane produced in the different regions of Haiti is sold to companies located in the surroundings of the cultivated area. The other part is processed locally by the farmers themselves, in small mills powered by animal traction or small motors.

In Haiti, sugarcane is destined to the production of:

- *Clairin*, white rum distilled from cane;
- Syrup (*sirop*), an intermediate product in the production of *clairin or* alcohol;
- *Rapadou*, a type of sugar produced in artisan factories; and
- Rum.

---

[10] Pierre, 2005.

## 1.6 Socioeconomic Analysis

With around 8.7 million inhabitants, Haiti is the poorest country in the Western Hemisphere and its population density is one of the highest in the Caribbean region. The development of this country has been very tortuous, connected to the political instability and the structural and institutional weaknesses[11].

In 2001, 49% of Haitian families lived in conditions of absolute poverty. A large part of this population is found in rural areas (3.06 million people), principally in the Northwest and Northeast regions of the country. Fifty eight percent of the households that occupy the rural area survive on less than US$ 1 a day and do not manage to provide the basic food needs for their families.

Social indicators like the literacy rate, life expectancy, infant mortality and infant malnutrition also show the seriousness of poverty in this country. Around 4 in every 10 people do not know how to read or write; 20% of children suffer from malnutrition; half the population does not have health care and more than 80% do not have access to drinking water.

Another aggravating factor is in income distribution. In terms of income, there has been no reduction of poverty in latter decades. As well as this, the gap between rich and poor and amongst the regions is still large, like the West and Northwest regions.

According to estimative made by the CIA[12], the population of Haiti is estimated at around 8.9 million inhabitants (95% blacks and 5% whites and mulatos), with an annual growth rate of approximately 2.5%. Haiti is the second most densely populated country in the Western Hemisphere, with more than 280 inhabitants per square kilometer. Close to 1.5 million Haitians live in the capital Port-au-Prince and its surroundings. On the other hand, only 4 Haitians cities have a population greater than 100 thousand inhabitants and the greater part of the population lives in small cities and villages[13].

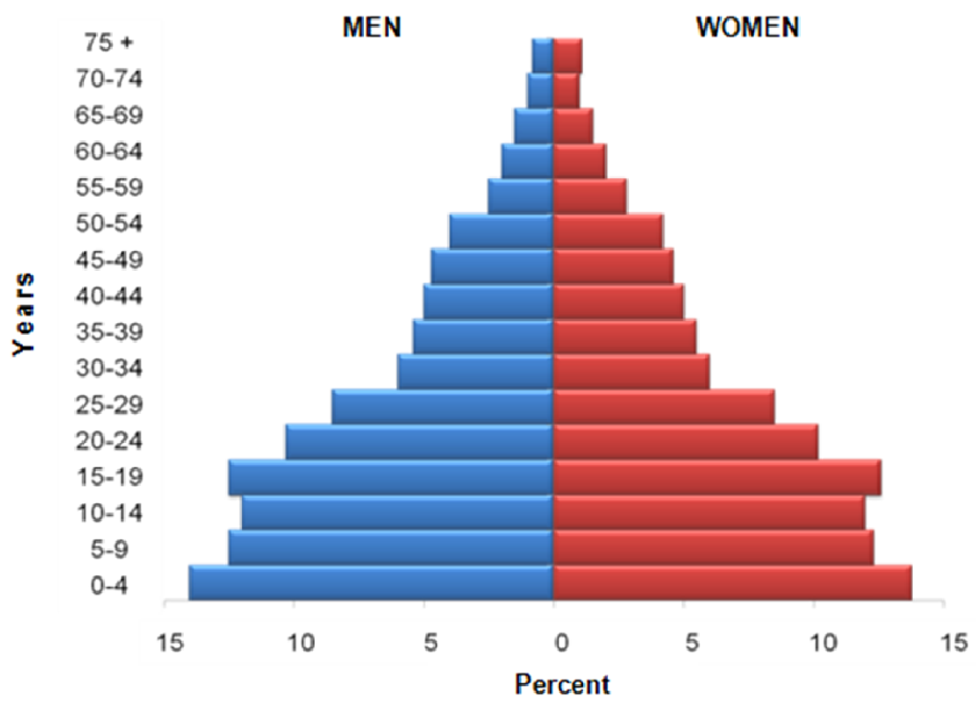
[11] Verner, 2008.
[12] Central Intelligence Agency –"The World Factbook".
[13] Library of Congress, 2006.

This high population growth rate is due especially to the high birth rate, since the net migration rate of Haiti is -0.94. The net migration rate shows the number of people, within a group of one thousand individuals, who leave the country during a period of one year. Emigration is generalized due to the political-economic conditions in later years and thousands of Haitians have tried to reach the Unites States coast in boats.

The birth and mortality rates are 35.87 births and 10.4 deaths for each one thousand individuals, respectively. The infant mortality rate is 62.83 for every thousand births and the fertility rate is 4.86 individuals per woman (CIA 2008).

The population distribution in Haiti by age groups (Figure 9) is distributed in the following manner: 42.1% of Haitians have between 0 and 14 years; 54.4 %, between 15 and 64; and 3.5% have more than 65 years of age. The life expectancy of the population is 57.03 years, 55.35 years for men and 58.75 years for women. The average age of the population is 18.4 years.

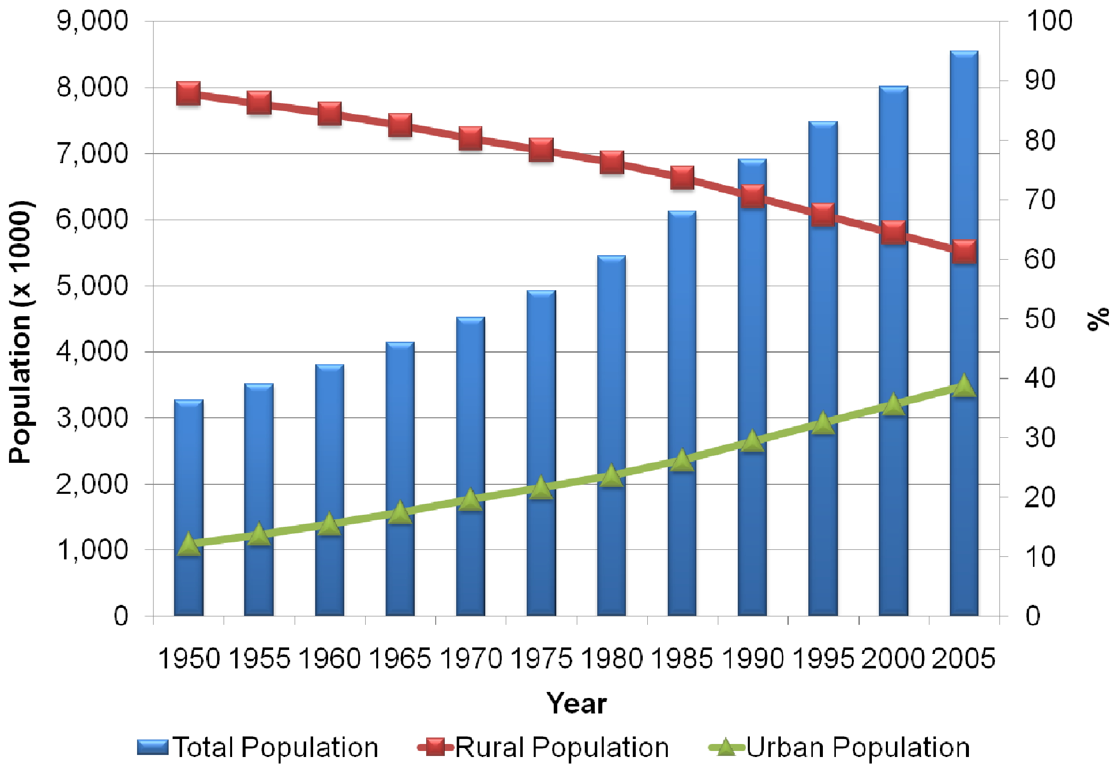
**Figure 9**
**Haitian Population distribution by age groups.**




Source: “Haiti at a glance”, 2006.

Like other countries in the Caribbean region, Haiti is experiencing fast urban growth. The urban population growth rate is 3.65%, against 0.90% in the rural zones. The population of Port-au-Prince increases 5% per year and 40% of Haitians live in urban conglomerates, including slums in coastal alluvial plains such as Cité Soleil in Port-au-Prince, Roboteau, in Gonaïves, and la Faucette in Cap-Haïtien.  Figure 10 shows the population growth process of Haiti, throughout fifty five years, the rapid growth of the urban population and the reduction of rural participation in the calculated period.

**Figure 10**
**Total population and percentage participation of the urban and rural populations in Haiti.**




Source: Prepared by FGV based on FAO data, 2008.

## 1.7 Economy

The economy of Haiti is the least developed in the Western Hemisphere. The economic growth potential is low, taking into account the political instability, lack of infrastructure and problems of an environmental nature. Income is badly distributed and poverty is generalized, a situation directly connected to the long period of economic stagnation. Currently, employment opportunities are extremely limited. Furthermore, the rate of inflation is the highest among all the Caribbean countries.

## 1.8 Gross National Income

The Gross National Income (GNI), previously denominated Gross National Product consists of the sum of the value added by all the resident producers, plus any product from taxes, fewer subsidies. Also not included in this sum are the net incomes from primary incomes (employees' remuneration and income assets) coming from outside the national territory. Table 4 shows the variation of the GNI in three different years. The gross national income decreased rapidly, in the period from 2000 to 2005, with a small recovery in the following year.

**Table 4**
**Gross National Income.**

| Year | 2000 | 2005 | 2006 |
|---|---|---|---|
| GNI (US$ – billions) | 4.0 | 3.9 | 4.0 |

Source: World Bank, 2008.

The division of Gross National Income by the population estimate yields the GNI *per capita*, shown on Table 5. A sharp decrease can be observed in the period between 2000 and 2005, with a slight recovery in the following year.

**Table 5**
**Gross National Income *per capita*.**

| Year | 2000 | 2005 | 2006 |
|---|---|---|---|
| GNI *per capita* (US$) | 470.00 | 420.00 | 430.00 |

Source: World Bank, 2008.

The frequent crises through which the country has passed have ruined investments and one of the few sources of income for the country, currently, are the remissions of money from Haitians who live overseas (around US$ 650 million, in 2002).

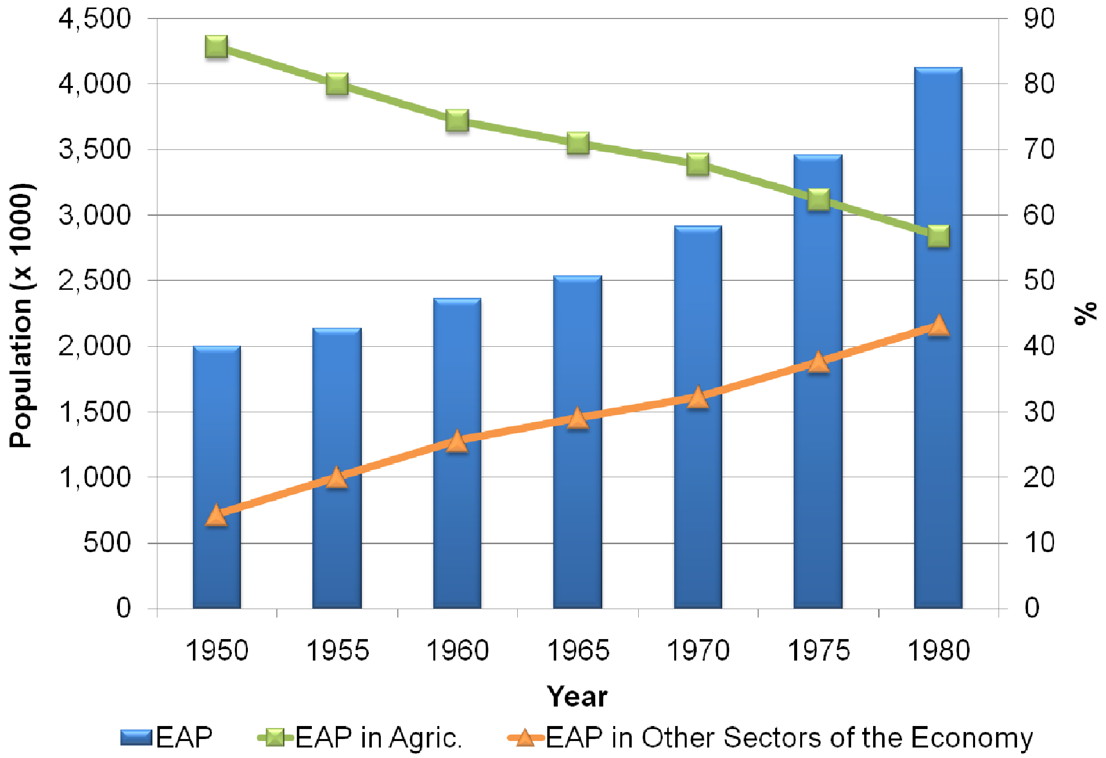
## 1.9 Economically Active Population

The Economically Active Population (EAP) of a country is composed of all those individuals who, according to the national law, are old enough to work and are employed or seeking employment.

The individuals in the same age group that give up seeking employment are called the Economically Inactive Population (EIP).

Figure 11 shows the behavior of the Economically Active Population in Haiti, as well as the dynamics of their composition, represented by the evolution of the Economically Active Populations in agricultural and non agricultural activities.

**Figure 11**
**Comparative analysis between the growth of the Economically Active Population and the behavior of its composition**

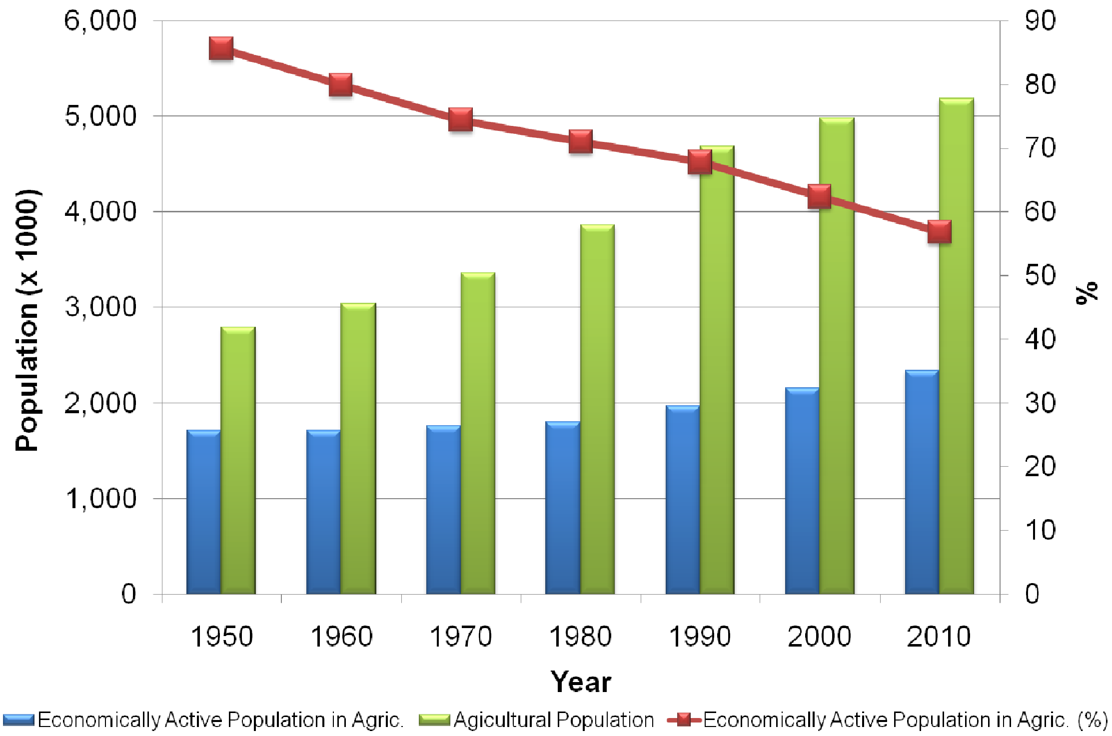



Source: Prepared by FGV based on FAO data, 2008.

Concurrently with the tendency for urbanization seen in Haiti, there is an increase in the Economically Active Population in sectors of the economy not connected to agriculture, since the rural population migrates to urban zones.

In Figure 12, can be seen the growth of the agricultural population. However, the economically active population in this sector has remained constant, and its percentage participation in the composition of the agricultural population has reduced considerably. This fact can be explained by the high rates of birth found in the country, combined with the elevated rates of urbanization observed in latter years.

**Figure 12**
**Comparative analysis between the growth of the agricultural population, the economically active population in agriculture and their contribution to the percentage composition.**




Source: Prepared by FGV based on FAO data, 2008.

This migration of people with an agricultural vocation to the urban areas results on employment offers characterized by low specialization and low remuneration and, as a consequence, in impoverished communities, pressure on the infrastructure and the other public services.

## 1.10 Labor

The greater part of economically active labor is in sub-employment or unemployed. It is estimated that almost two thirds of the almost 4 million workers in the country do not have a stable occupation. Many Haitians live off subsistence agriculture and prefer not to leave in search of employment in the urban zones. The work force distribution in Haiti is shown in Table 6. Note the current labor concentration in agriculture, in spite of the intense migration from the countryside to the city.

**Table 6**
**Labor distribution by occupation in various economic sectors of Haiti.**

| Sector of the Economy | Labor (%)[14] |
|---|---|
| Agriculture | 66 |
| Industry | 9 |
| Services | 25 |

Source: CIA - The Word Fact Book, 2008

The high population growth in the last few decades caused the arousal of an elastic offer of unskilled work. As a result, with the exception of employment for highly qualified people, the salary levels are low.

Port-au-Prince, in spite of the scarcity of work, attracts many people from rural areas. This migration lead to an explosion in the civil construction sector, however the majority of the population adhered to the informal work sector.

There is little employment in the formal sector. Ninety five percent of employment in the formal economy that exists in Haiti is situated in Port-au-Prince. About half of the workers in this sector are public servants, who work in the areas of education, health and justice. Other formal employment is connected to state companies, in areas like telephony and electricity, the police force, and inspection services. The rest of the economically active population employed in the formal sector is connected to the private sector, principally in factories, banks, commerce and transport. Since 1995, the private insurance sector has had an increase in the offer of employment, reflecting the worries with an increase in criminality.

In the agricultural sector, the labor activities are restricted to the cultivation of some subsistence crops, the rural workers being charged with performing simple operations like grass cutting, planting, irrigation, harvesting, searching for drinking water and managing pastures for the cattle.

The minimum age for employment is legally fixed at 15 years, with the exception of domestic services. Child labor in Haiti is common on family agricultural properties and in the informal sector. Children are also involved in sales services in urban areas. In general, due to the high rate of unemployment and the intense competition for employment vacancies, child labor is common in

[14] Estimativas de 1995.

the industrial and commercial[15] sectors. A report published by the International Confederation of Free Trade Unions noted the existence of Haitian child labor citizens in the transport of sugarcane harvests in the Dominican Republic[16].

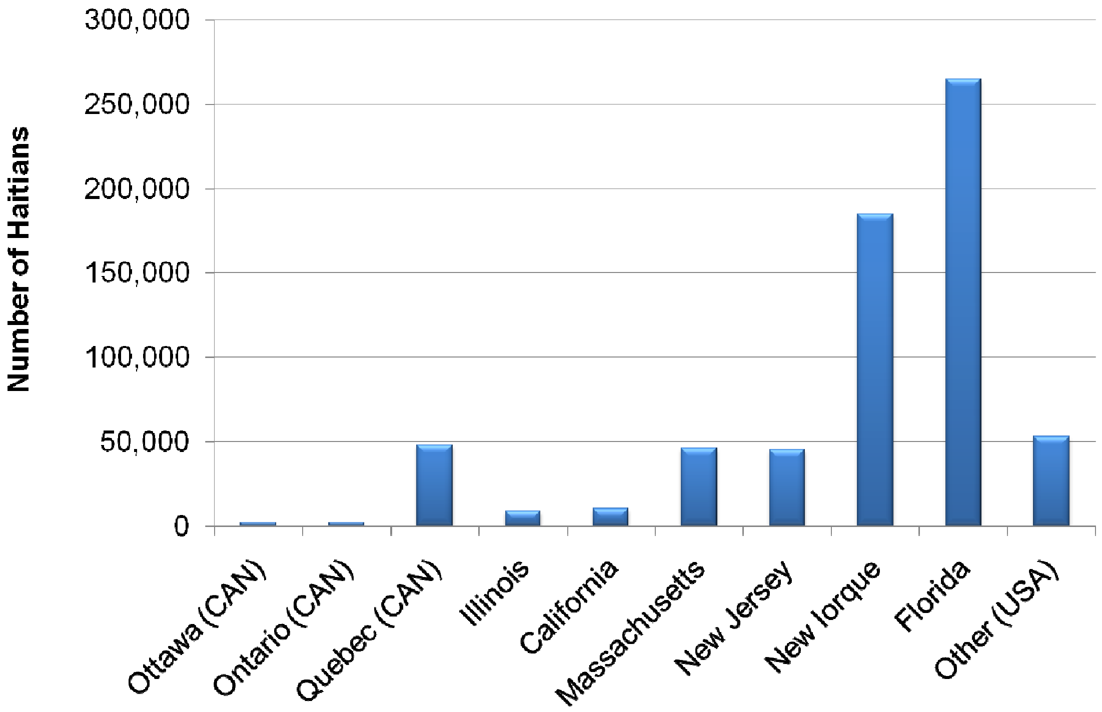
There is legal protection for Haitian employees in the formal sector. The workers have the right to association and collective negotiations. At the same time, the Labor Code protects the workers unions from complaints by the employers. In 2002, there were 9 principal workers federations, representing 5% of the total work force. The unions are independent of the government and political parties. However, to obtain legal recognition, they need to be formally registratered. Strikes are allowed, however the adhesion to them is low and collective negotiation does not happen.

## 1.11 Emigration

As well as the issue of high rate of unemployment and under employment, the lack of labor qualification represents a huge obstacle to the expansion of Haitian economy. In later years, there has been a drain of qualified labor overseas, in search of better salary opportunities. Annually, thousands of Haitian cross the frontier to work in industries of the Dominican Republic. Others go to North America, to countries like the United States (New York and Florida) and Canada (Figure 13).

[15] Country Reports on Human Rights Practices, 2006.
[16] International Confederation of Free Trade Unions, 2002.

**Figure 13**
**Haitians present in the states of Canada and the United States.**




Source: Verner, 2008.

## 1.12 Income

After having recorded an average annual growth of around 2.3% in real terms, during the decade of the 1970s, income *per capita* suffered a drop of 2.4% on average per year, during the decade of the 1980s and, in the 1990s, the drop accelerated, remaining on average 2.6 per year (Folha de São Paulo, 2006).

## 1.13 Services Sector

The Haitian services sector was responsible for the generation of approximately 50% of the gross national income of the country in 2004. This sector also employs 25% of the work force. According to statistics from the World Bank, the services sector was the only part of the Haitian economy that remained stable during the whole turbulent decade of the 1990s and the first years of the current decade.

## 1.14 Inflation

Purchasing power in Haiti fell markedly throughout the last two decades. The rise in the price of fuel and the small internal demand, combined with the recurrent political instability, has produced uncontrollable inflation in these last years. In the year of 1994[17], the rate of inflation reached 40%. With a rigorous policy and international aid, the rate of inflation remained under control. However the exchange rate devaluation pushed inflation once more to 40% in 2003. In 2004, the rate of inflation stayed around 22%. In the present, rise in inflation rate is sharper and sharper, causing violent protests throughout the country.

## 1.15 International Economic Relations

In the current economic scenario, the role of the Republic of Haiti has been mainly that of receiving international financial aid. The United States has been the principal donor, performing an important role in the attempt to promote development of the country.

Haiti takes part in some international economic organizations; it is a member of the International Coffee Organization; Latin American Economic System[18]; and Caribbean Community. It is also a signatory to the *Cotonou* Convention – an economic community that seeks to encourage commerce between African countries, the Caribbean and the Pacific[19].

## 1.16 Importations

Haitian importations, in the majority (35%), come from the United States. The sum of the import totaled a value estimated at US$ 1.5 billion for 2005, and US$ 1.84 billion for 2007. Other significant suppliers to Haiti were the Dutch Antilles, Malaysia and Colombia. The most relevant products imported were: food, fuel (including petroleum), machinery in general and manufactured products.

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[17] Library of Congress, 2006.
[18] SELA – Latin American Economic System.
[19] Library of Congress, 2006.

## 1.17 Exports

In 2005, Haitian exports summed a total of US$ 391 million and in 2007, an estimated value of US$ 554.8 million, and more than 80% of the export revenue came from the United States. Other large partners in export were the Dominican Republic and Canada. The chief Haitian export products are: coffee, cocoa beans and mango.

**Figure 14**
**Sale of mangoes in Port-au-Prince.**

Source: FGV, 2008.

## 1.18 Trade Balance

As a consequence of the high level of dependency on imports, the trade balance of Haiti remained negative. A large part of this deficit is compensated for by business transfers received, including international aid.

## 1.19 Foreign Investments

Investments coming from other countries, in the last 20 years, were scarce. The aid for incentive to development and loans has been the only constant source of external capital. So as to encourage foreign investment, in 2004, provisional government of Haiti approved tax exemptions for foreign companies that invested in Haiti for a period of 3 years [20].

## 2. Land Capability for Production of Biofuels

Analysis of land capability combines a study of land (properties) with the study of land-use and determines whether the compound requirements of land-use are adequately met by the compounded properties of the land. The comparison of relevant land-use requirements with the associated land characteristics or land qualities is the essence of land-use systems. The outcome of this matching procedure forms the basis for assessing the capability of the land for the defined use. Land capability expresses the inherent capacity of a land unit to support a defined land-use for a long period of time without deterioration. Most established methods for land capability assessment are qualitative. Experts determine which land-use requirements are relevant to the functioning of a particular system, the adequacy of the corresponding land qualities, and the overall land capability. Different experts may hold different views. Conventional methods are therefore prone to be subjective. Yet, they are widely applied because reliance on expert knowledge is often the only option if primary information and analytical means are limited.

Biofuel producing crops require different land capabilities for successful production. The evaluation of these capabilities in different countries is important for regional planning and to evaluate the potentialities for biofuel production. With the objective of evaluating the potentiality for biofuel production in the Republic of Haiti, the land capability for five crops was evaluated. The evaluated biofuel producing crops for this country are: sugarcane, eucalyptus, elephant grass, sunflower and Jatropha curcas.

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[20] Library of Congress, 2006.

## 2.1 Data research and collection [21]

### 2.1.1 Land properties

Selection of relevant land-use requirements is the starting point of any analysis of land capability. To be able to select these requirements there was a necessity of knowing what type of land information existed, as well as its quality. An intense search for this information was performed initially. Data related to soil potential, land use, inundation vulnerability, etc, was found in a georeferenced format that enabled this data to be processed in geographic information systems. Unfortunately not all of this cartographic information was accompanied by a databank that provided quantifiable information of each cartographic unit. This lack of quantifiable information led to a more qualitative analysis based on expert knowledge of the land properties and land-use requirements.

Based on the available data, the selected land-use requirements for this project were: soil potential, slope, land use, protected areas (environment, tourism, urban areas, beach and dumpsites), and inundated areas.

### 2.1.2 Soil Potential

A soil potential map for Haiti was provided by the Forester Ecologist Joel Timyan[22]. The map is in a digital format which enables one to process them in a GIS system. The soil potential data attached to this map was quite complete for this country.

The soil potential map of Haiti is based on the USDA potential soils classification system (Figure 15). In this study eight soil potential classes were defined for the land surface of Haiti. These classes were defined according to their potential for agriculture and were based on the following maps: slope, soil properties, lithology, and geomorphology. These eight classes are ranked from 1 to 8. Classes 1 to 3 are the most suitable for agriculture with no or few restrictions for agricultural

[21] The figures that appear from this section during the report can be viewed with better resolution in the Annexes to this document.

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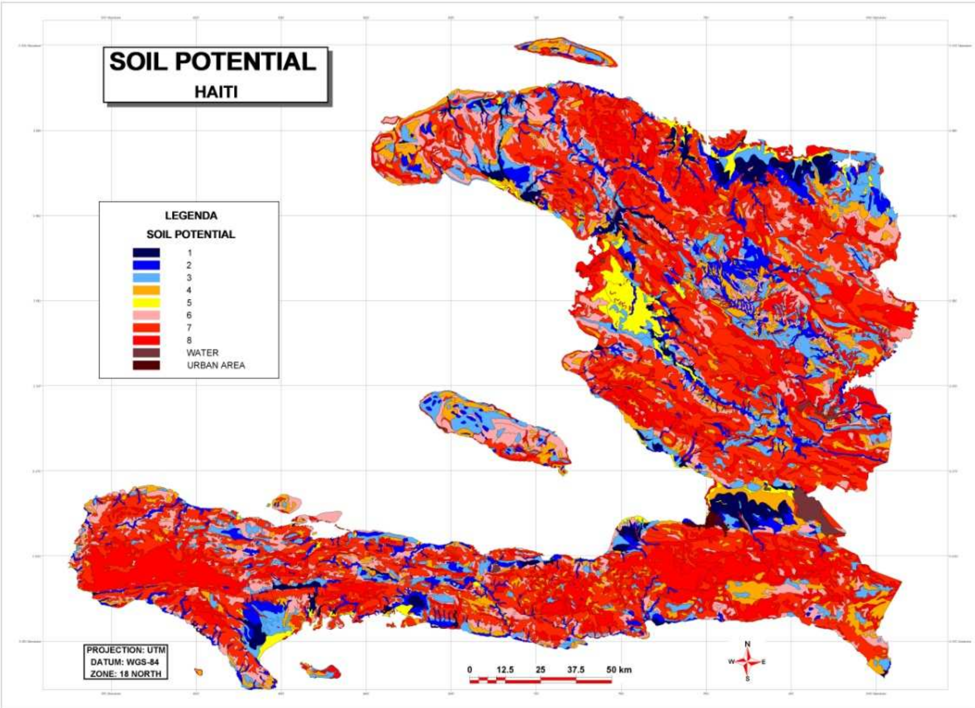
production. Classes 4 to 6 present higher restrictions for agricultural production and conservation practices have to be used for cultivation of these areas. Classes 7 and 8 are areas that do not present capabilities for agricultural production and areas that are to be left uncultivated and protected against degradation.

**Figure 15**
**Soil potential map of the Republic of Haiti.**




## 2.1.3 Slope

The slope and landscape shading maps for country were calculated based on the digital elevation models (DEM) obtained from the site http://seamless.usgs.gov/. After downloading the DEMs, filters were applied using a GIS for elimination of noise and amelioration of the quality of information obtained (Raster spatial filtering, Class: Noise reduction filter, Type: median). Six slope classes were calculated based on the DEMs of Haiti: 0-3%, 3-6%, 6-12%, 12-20%, 20-40% and >40%. The slope classes extracted from the raster map were calculated by using the following geoformula:

if (*SLOPE_Value* >= 0 and *SLOPE_Value* <=3) *value* = 1 else

if (*SLOPE_Value* > 3 and *SLOPE_Value* <=6) *value* = 2 else

if (*SLOPE_Value* > 6 and *SLOPE_Value* <=12) *value* = 3 else

if (*SLOPE_Value* >12 and *SLOPE_Value* <=20) *value* = 4 else

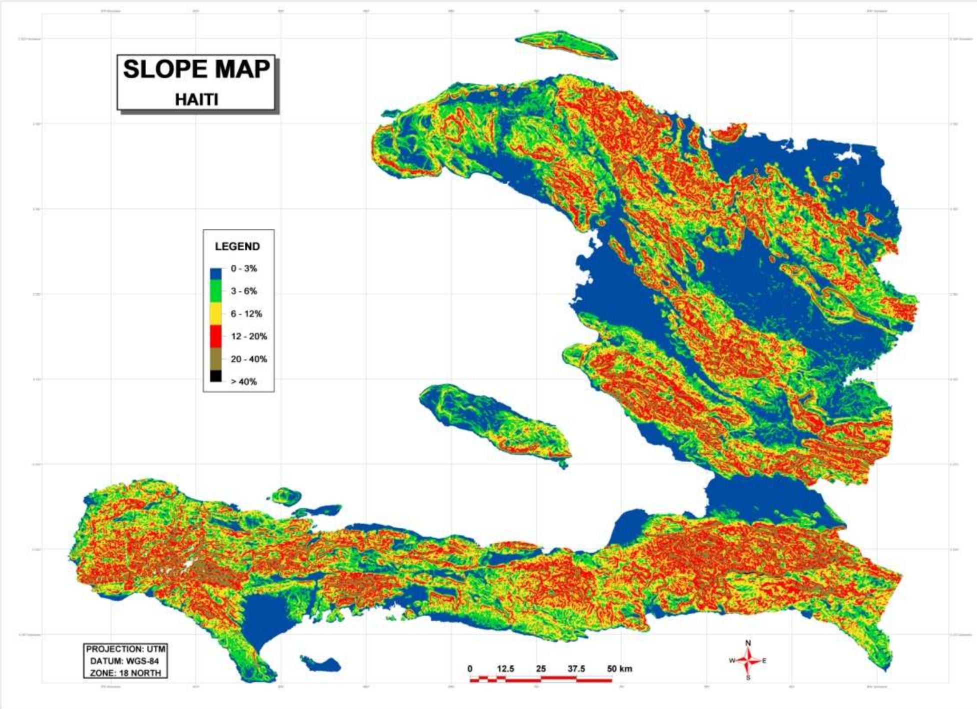
if (*SLOPE_Value* >20 and *SLOPE_Value* <=40) *value* = 5 else

if (*SLOPE_Value* >40) *value* = 6

The detail of the slope classes was chosen based on the topography of the terrain of country and on the chosen land uses for biofuel production.

For the republic of Haiti three different levels of detail of slope calculations were performed. This was done in order to determine which of the levels of detail better fitted the soil potential map of this country. The results of this fitting process showed that the level of detail 2 better fitted the soil data for matching in the GIS (Figure 16).

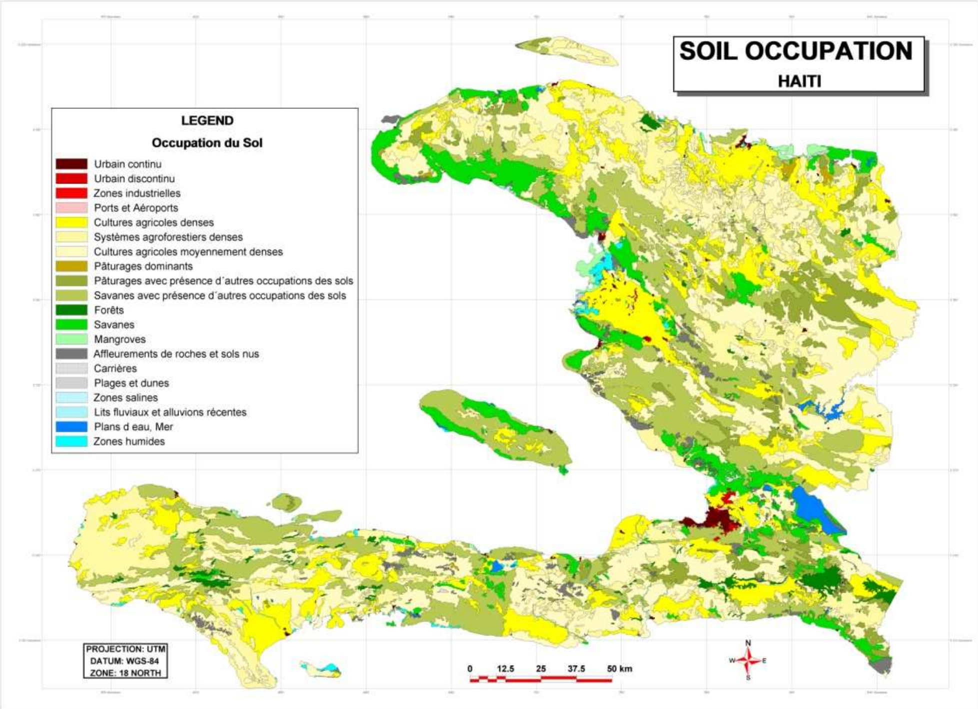
**Figure 16**
**Slope map for the republic of Haiti.**




## 2.1.4 Land use, protection areas and non agricultural areas

Agricultural land use or soil occupation was considered for the definition of the land capability classes in Haiti as will be explained in the next section. Figure 17 illustrates all the soil occupation activities or land uses in Haiti as well as the environmentally protected areas (forests, savannas, beaches, mangroves, etc.) and non agricultural areas (urban areas, humid zones, salty areas, rock outcrops, etc.). The environmental protected areas were not considered for land capability. These areas include protected native forest areas or any other ecosystems that have been defined as protected. Other areas excluded from land capability analysis were beaches, dump sites, ponds, ports, quarries, sand mining, scrubs, tourist developments and urban areas.

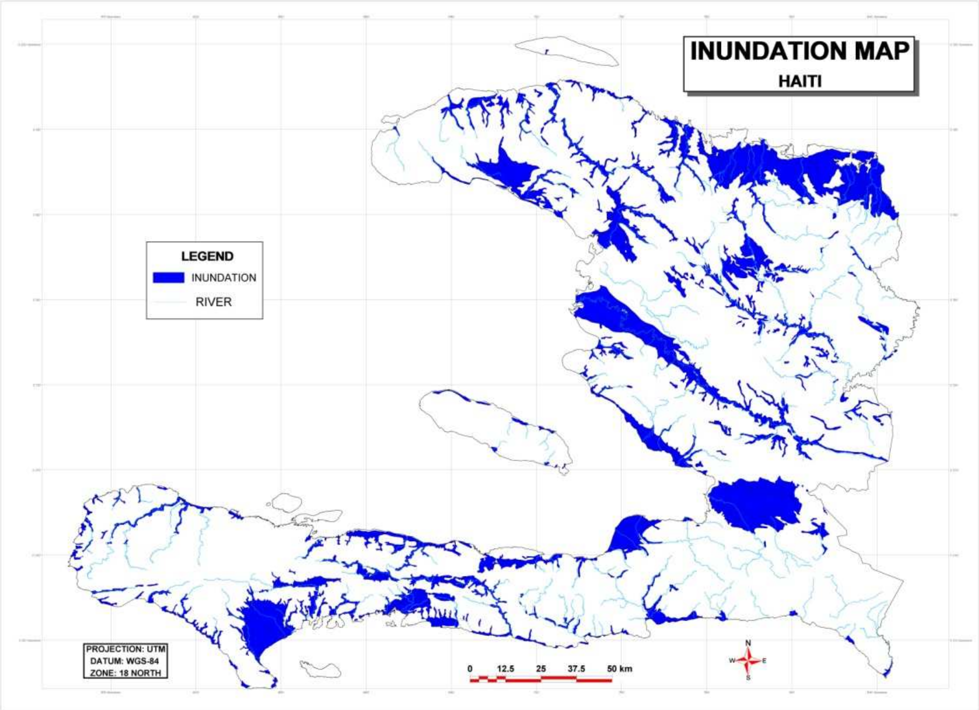
**Figure 17**
**Soil occupation of the republic of Haiti.**




## 2.1.5 Areas Vulnerable to Inundation

A map with the areas vulnerable to inundation was supplied to us by Joel Timyan from the Environmental Vulnerability in Haiti study produced by USAID (United States Agency for International Development). We used this map for penalizing areas that present inundation vulnerability and consequently were classified with a lower capability class for the crops evaluated in this project. Figure 18 illustrates the inundation vulnerable areas for Haiti.

**Figure 18**
**Inundation vulnerable areas for the republic of Haiti.**




## 2.1.6 Data processing

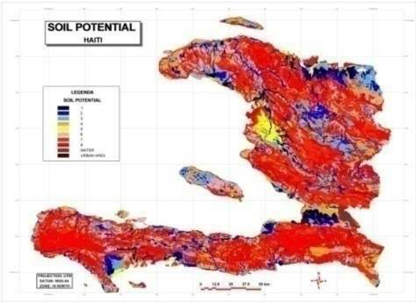
After searching and collecting all the information listed above, this information was prepared for matching and generating the Land Capability maps for each crop. This data preparation consisted in correcting the georeference of all the maps, adequation of the information for each specific crop according to its characteristics and elimination of any outliers and erroneous data found in the databases.

Using Boolean logic, the information of the soil potential was crossed with the soil occupation map. The agricultural soil uses were extracted from the soil occupation map of Haiti. Six agricultural use zones were extracted: dense agricultural zones, agroforestry zones, medium dense agricultural zones, pastures, mixed pastures, and savannas with other land uses. For interpretation of these zones we considered that the higher input intense zones (dense agricultural zones and agroforestry zones) would occupy areas with better soils and landscape conditions. The lower the input intensity of the soil use (medium dense agricultural zones, pastures, mixed pastures, and savannas with other land uses) the lower the quality of the soil and landscape conditions. Finally, the result of matching between soil potential and agricultural use zones was crossed with the environment protection areas and inundation zones map producing the Land Capability map for each biofuel crop.

Figure 19 illustrates the map matching for generating the Land Capability maps of Haiti. More detailed description of these class definitions will be given in forthcoming sections.

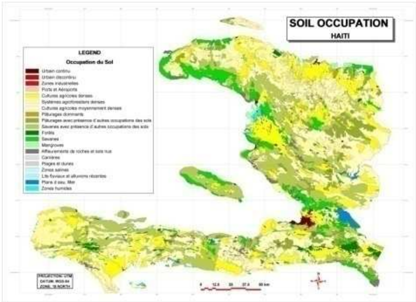
**Figure 19 - Data matching for the definition of the Land Capability of the Republic of Haiti.**

Soil Potential map




+

Soil Occupation map

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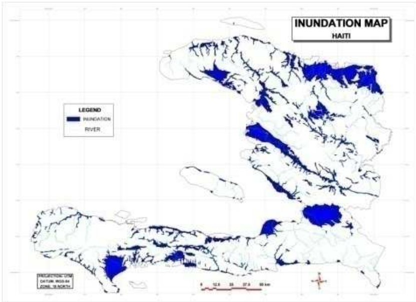
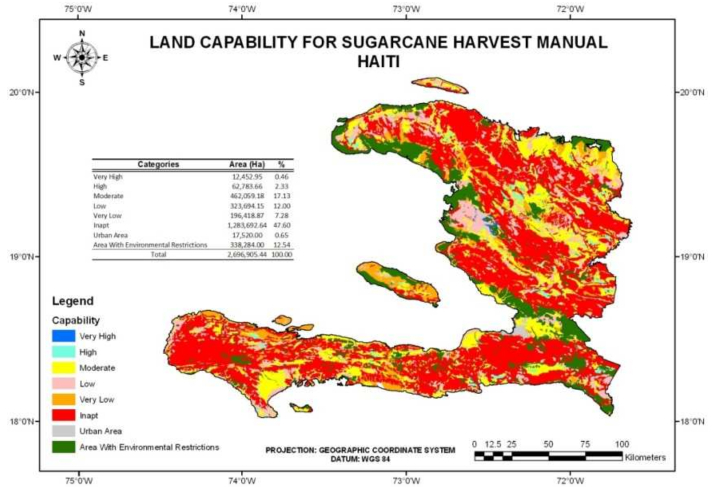
Inundation Vulnerability



# 3. Land Capability for biofuel crops in the Republic of Haiti

In this section we will present the results of the data matching explained in the previous section that defined the land capability classes. As explained before land capability was defined for each of the evaluated biofuel crops (sugarcane, sunflower, elephant grass, eucalyptus and jatropha).

The five biofuel producing crops cited above were analyzed. Sugarcane, however, was subdivided into manually harvested and mechanically harvested sugarcane. This was done to help future decision making concerning what type of sugarcane harvesting system is going to be eventually implemented in this country. The choice would be between a labor intensive system with environmental restrictions, if the sugarcane is burnt previous to harvest (manual harvest), or a highly technological system with low labor demand, which is environmentally friendly (mechanical harvest).

## 3.1 Sugarcane: Manual harvest

Table 7 presents the land capability classification key for manually harvested sugarcane (*Saccharum officinarum*). In this case as sugarcane will be harvested manually the restriction of slope disappears and more areas can be included if this type of harvest is sought for. The slope limit for manual harvest was extended to 20%. This means more restrictive soil potential classes were included as viable for manually harvested sugarcane. As for the rest of the soil and land attributes, the same can be said for annual crops.

**Table 7**
**Land capability definition for sugarcane manually harvested (ZAD = dense agricultural zones, ZAF = agroforestry zones, ZAMD = medium dense agricultural zones, PD = pastures dominating, PAOS = pastures with other land uses, SAOS = savannas with other land uses).**

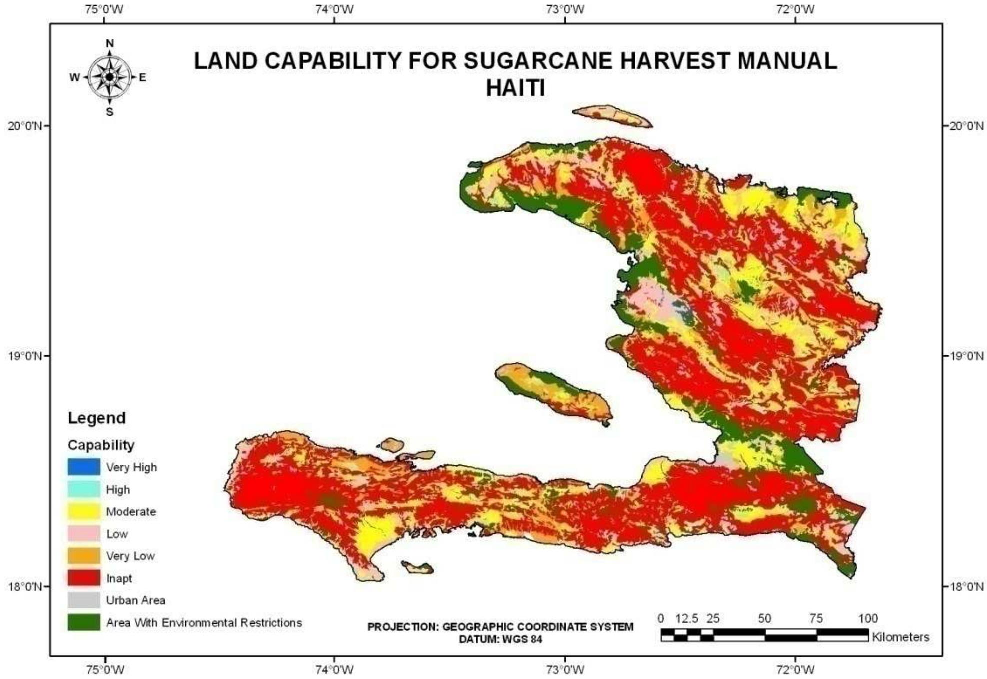
| Soil potential classes | Agricultural | Soil Inundation | Land |
|---|---|---|---|
| 1 | ZAD | no | very high |
| 1 | ZAF | no | high |
| 1 | ZAMD | no | high |
| 1 | PD | no | low |
| 1 | PAOS | no | low |
| 1 | SAOS | no | very low |
| 1 | ZAD | yes | high |
| 1 | ZAF | yes | moderate |
| 1 | ZAMD | yes | moderate |
| 1 | PD | yes | very low |
| 1 | PAOS | yes | very low |
| 1 | SAOS | yes | very low |

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 2 | ZAD | no | high |
| 2 | ZAF | no | moderate |
| 2 | ZAMD | no | moderate |
| 2 | PD | no | low |
| 2 | PAOS | no | low |
| 2 | SAOS | no | very low |
| 2 | ZAD | yes | moderate |
| 2 | ZAF | yes | low |
| 2 | ZAMD | yes | low |
| 2 | PD | yes | very low |
| 2 | PAOS | yes | very low |
| 2 | SAOS | yes | very low |
| 3 | ZAD | no | moderate |
| 3 | ZAF | no | low |
| 3 | ZAMD | no | low |
| 3 | PD | no | very low |
| 3 | PAOS | no | very low |
| 3 | SAOS | no | very low |
| 3 | ZAD | yes | low |
| 3 | ZAF | yes | very low |
| 3 | ZAMD | yes | very low |
| 3 | PD | yes | very low |
| 3 | PAOS | yes | very low |
| 3 | SAOS | yes | very low |
| 4 | ZAD | no | |
| 4 | ZAF | no | very low |
| 4 | ZAMD | no | very low |
| 4 | PD | no | very low |
| 4 | PAOS | no | very low |
| 4 | SAOS | no | very low |
| 4 | ZAD | yes | very low |
| 4 | ZAF | yes | very low |
| 4 | ZAMD | yes | very low |
| 4 | PD | yes | very low |
| 4 | PAOS | yes | very low |
| 4 | SAOS | yes | very low |
| 5 | ZAD | no | moderate |
| 5 | ZAF | no | low |
| 5 | ZAMD | no | low |
| 5 | PD | no | low |
| 5 | PAOS | no | low |
| 5 | SAOS | no | very low |
| 5 | ZAD | yes | low |
| 5 | ZAF | yes | very low |
| 5 | ZAMD | yes | very low |
| 5 | PD | yes | very low |
| 5 | PAOS | yes | very low |
| 5 | SAOS | yes | very low |
| 6 | ZAD | no | very low |
| 6 | ZAF | no | very low |
| 6 | ZAMD | no | very low |
| 6 | PD | no | very low |
| 6 | PAOS | no | very low |
| 6 | SAOS | no | very low |
| 6 | ZAD | yes | very low |
| 6 | ZAF | yes | very low |
| 6 | ZAMD | yes | very low |
| 6 | PD | yes | very low |
| 6 | PAOS | yes | very low |
| 6 | SAOS | yes | very low |
| 7 | ZAD | no | inapt |

| Soil potential classes | Agricultural | Soil | Inundation | Land |
|---|---|---|---|---|
| 7 | ZAF | | no | inapt |
| 7 | ZAMD | | no | inapt |
| 7 | PD | | no | inapt |
| 7 | PAOS | | no | inapt |
| 7 | SAOS | | no | inapt |
| 7 | ZAD | | yes | inapt |
| 7 | ZAF | | yes | inapt |
| 7 | ZAMD | | yes | inapt |
| 7 | PD | | yes | inapt |
| 7 | PAOS | | yes | inapt |
| 7 | SAOS | | yes | inapt |
| | | | | |
| 8 | ZAD | | no | inapt |
| 8 | ZAF | | no | inapt |
| 8 | ZAMD | | no | inapt |
| 8 | PD | | no | inapt |
| 8 | PAOS | | no | inapt |
| 8 | SAOS | | no | inapt |
| 8 | ZAD | | yes | inapt |
| 8 | ZAF | | yes | inapt |
| 8 | ZAMD | | yes | inapt |
| 8 | PD | | yes | inapt |
| 8 | PAOS | | yes | inapt |
| 8 | SAOS | | yes | inapt |

Analyzing Figure 20 and Table 8 we can observe an increase in area of the very high, high and moderate capability classes when compared to sunflower. These classes represent 15.17% of the agricultural area of Haiti and they can be used with good to reasonable potential for sugarcane manually harvested. This represents about 409,287 ha of which 164,845 ha have a very high and high land capability and 244,442 ha have a moderate land capability. Restrictions in the moderate capability classes can be overcome with good land management and use of modern and appropriate agronomic technology. Around 24.01% of the agricultural areas were classified as low or very low for manually harvested sugarcane. Although these classes represent high restrictions, mainly regarding slope or stoniness, they are areas which, with some investment, could be included in the sugarcane productive areas. Probably more rustic varieties of sugarcane with lower productivities could be planted in these areas taking care especially of the erosion problem which can be important in these areas with higher slopes. The main investments should be in soil conservation practices to avoid soil erosion problems.

**Figure 20**
**Land capability map for sugarcane manually harvested.**
**Without landscape (top) and with landscape (bottom).**



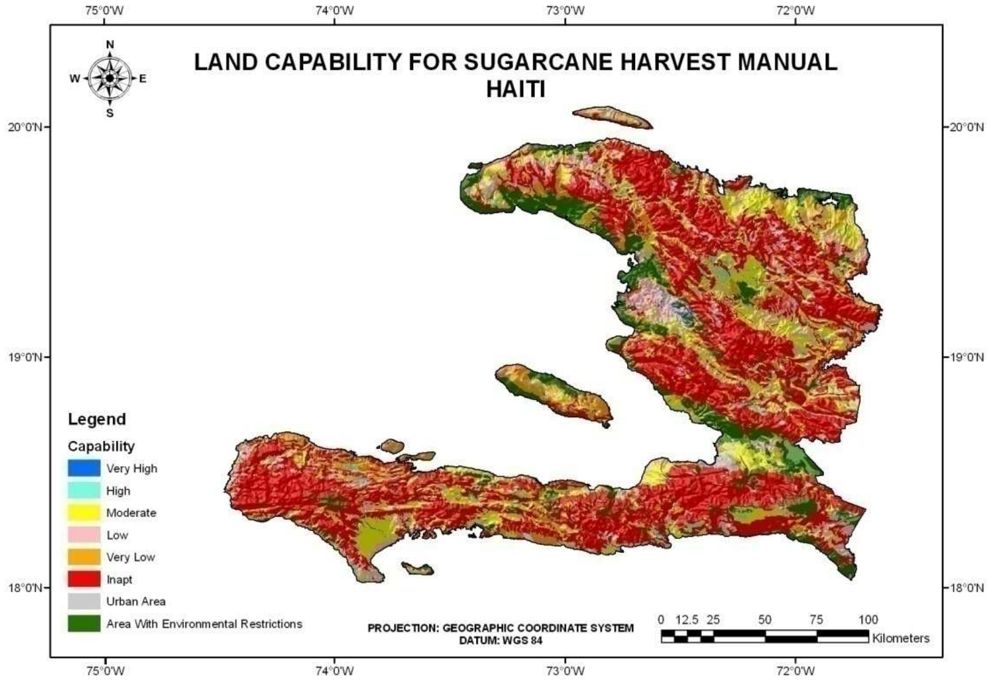



**Table 8**
**Area quantification for sugarcane manually harvested**

| Categories | Area (ha) | % |
|---|---|---|
| Very High | 12,452.95 | 0.46 |
| High | 62,783.66 | 2.33 |
| Moderate | 462,059.18 | 17.13 |
| Low | 323,694.15 | 12.00 |
| Very Low | 196,418.87 | 7.28 |
| Inapt | 1,283,692.64 | 47.60 |
| Urban Area | 17,520.00 | 0.65 |
| Area With Environmental Restrictions | 338,284.00 | 12.54 |
| Total | 2,696,905.44 | 100.00 |

## 3.2 Sugarcane: Mechanical harvest.

Table 9 presents the decision key that defines the land capability for sugarcane mechanically harvested. Mechanical harvesting presents a limitation in slope degree up to which it can work without problems of rolling over. This slope limit is normally fixed at 12%. Soil potential classes above 4 normally restrict mechanized agriculture due to limitations in slope or other restrictions as stoniness or waterlogged areas. These were the main land and soil attributes that penalized this land use when compared to manually harvested sugarcane.

**Table 9**
**Land capability definition for sugarcane mechanically harvested (ZAD = dense agricultural zones, ZAF = agroforestry zones, ZAMD = medium dense agricultural zones, PD = pastures dominating, PAOS = pastures with other land uses, SAOS = savannas with other land uses).**

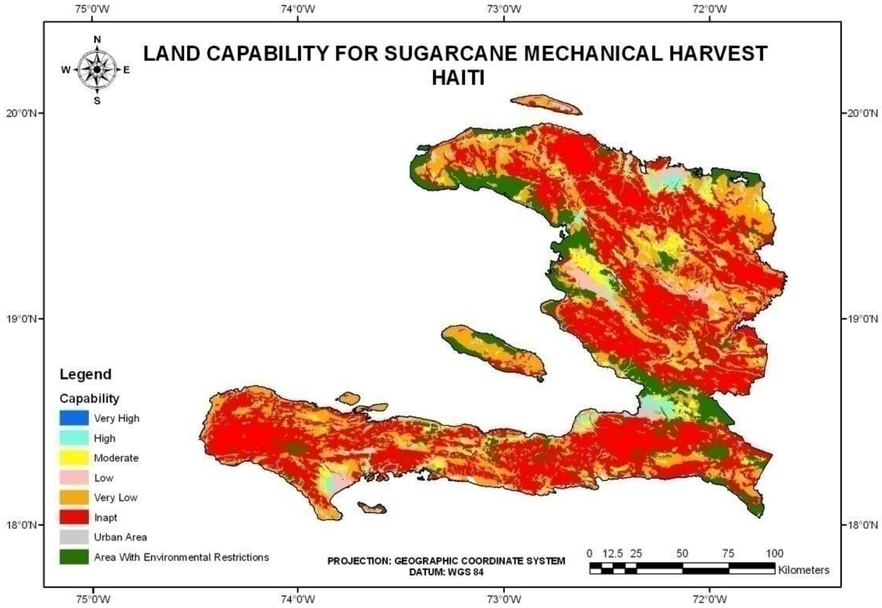
| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 1 | ZAD | no | very high |
| 1 | ZAF | no | high |
| 1 | ZAMD | no | high |
| 1 | PD | no | low |
| 1 | PAOS | no | low |
| 1 | SAOS | no | very low |
| 1 | ZAD | yes | high |
| 1 | ZAF | yes | moderate |
| 1 | ZAMD | yes | moderate |
| 1 | PD | yes | very low |
| 1 | PAOS | yes | very low |
| 1 | SAOS | yes | very low |
| 2 | ZAD | no | very high |
| 2 | ZAF | no | high |
| 2 | ZAMD | no | high |
| 2 | PD | no | low |
| 2 | PAOS | no | low |
| 2 | SAOS | no | very low |
| 2 | ZAD | yes | high |
| 2 | ZAF | yes | moderate |
| 2 | ZAMD | yes | moderate |
| 2 | PD | yes | very low |

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 2 | PAOS | yes | very low |
| 2 | SAOS | yes | very low |
| | | | |
| 3 | ZAD | no | high |
| 3 | ZAF | no | moderate |
| 3 | ZAMD | no | moderate |
| 3 | PD | no | low |
| 3 | PAOS | no | low |
| 3 | SAOS | no | very low |
| 3 | ZAD | yes | moderate |
| 3 | ZAF | yes | low |
| 3 | ZAMD | yes | low |
| 3 | PD | yes | very low |
| 3 | PAOS | yes | very low |
| 3 | SAOS | yes | very low |
| 4 | ZAD | no | |
| 4 | ZAF | no | moderate |
| 4 | ZAMD | no | low |
| 4 | PD | no | low |
| 4 | PAOS | no | low |
| 4 | SAOS | no | low |
| 4 | ZAD | yes | very low |
| 4 | ZAF | yes | low |
| 4 | ZAMD | yes | very low |
| 4 | PD | yes | very low |
| 4 | PAOS | yes | very low |
| 4 | SAOS | yes | very low |
| | | | |
| 5 | ZAD | no | moderate |
| 5 | ZAF | no | low |
| 5 | ZAMD | no | low |
| 5 | PD | no | low |
| 5 | PAOS | no | low |
| 5 | SAOS | no | very low |
| 5 | ZAD | yes | low |
| 5 | ZAF | yes | very low |
| 5 | ZAMD | yes | very low |
| 5 | PD | yes | very low |
| 5 | PAOS | yes | very low |
| 5 | SAOS | yes | very low |
| | | | |
| 6 | ZAD | no | low |
| 6 | ZAF | no | low |
| 6 | ZAMD | no | low |
| 6 | PD | no | low |
| 6 | PAOS | no | low |
| 6 | SAOS | no | very low |
| 6 | ZAD | yes | low |
| 6 | ZAF | yes | very low |
| 6 | ZAMD | yes | very low |
| 6 | PD | yes | very low |
| 6 | PAOS | yes | very low |
| 6 | SAOS | yes | very low |
| | | | |
| 7 | ZAD | no | inapt |
| 7 | ZAF | no | inapt |
| 7 | ZAMD | no | inapt |
| 7 | PD | no | inapt |
| 7 | PAOS | no | inapt |
| 7 | SAOS | no | inapt |
| 7 | ZAD | yes | inapt |
| 7 | ZAF | yes | inapt |
| 7 | ZAMD | yes | inapt |
| 7 | PD | yes | inapt |
| | | | |
| 7 | PAOS | yes | inapt |

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 7 | SAOS | yes | inapt |
| | | | |
| 8 | ZAD | no | inapt |
| 8 | ZAF | no | inapt |
| 8 | ZAMD | no | inapt |
| 8 | PD | no | inapt |
| 8 | PAOS | no | inapt |
| 8 | SAOS | no | inapt |
| 8 | ZAD | yes | inapt |
| 8 | ZAF | yes | inapt |
| 8 | ZAMD | yes | inapt |
| 8 | PD | yes | inapt |
| 8 | PAOS | yes | inapt |
| 8 | SAOS | yes | inapt |

and Table 10 illustrate the distribution of the land capability classes for mechanically harvested sugarcane in Haiti. This map shows that 2% of the area of Haiti, approximately 53,622 ha, presents very few restrictions for this crop; 5.55%, moderate capability and the rest would have low to very low capability presenting serious land restrictions that could affect sugarcane productivity. 31.65 % or 853,045 ha of the agricultural lands in Haiti are areas with low and very low capabilities. These lands would need certain amount of investments to overcome the restrictions the land presents. Depending on the limitation, the high cost of the technological investment for the amelioration of these areas could eliminate part of them for the production of this crop. If the limitation is stoniness or slope, the option of manual harvesting can be adopted for overcoming this limitation (see previous section). Areas considered inapt for mechanically harvested sugarcane in Haiti represent 47.61% of the lands or 1,283,467 ha.

**Figure 21**
**Land capability map for sugarcane mechanically harvested.**
**Without landscape (top) and with landscape (bottom).**



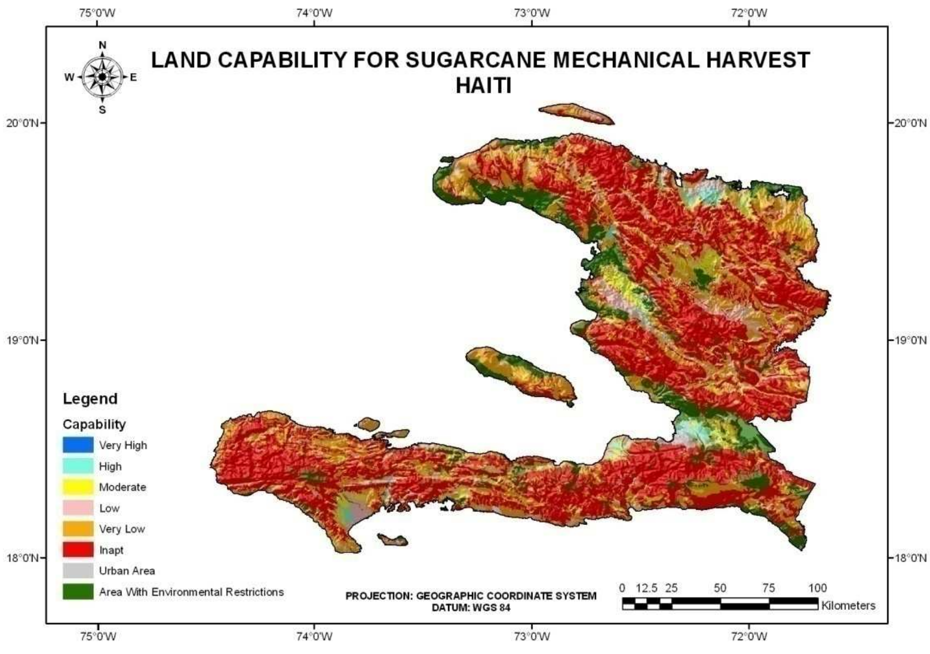



**Table 10**
**Area quantification for sugarcane mechanically harvested.**

| Categories | Area (ha) | % |
|---|---|---|
| Very High | 2,434.11 | 0.09 |
| High | 51,636.83 | 1.91 |
| Moderate | 149,844.35 | 5.56 |
| Low | 204,196.32 | 7.57 |
| Very Low | 649,297.03 | 2.08 |
| Inapt | 1,283,692.81 | 4.60 |
| Urban Area | 17,520.00 | 0.65 |
| Area With Environmental Restrictions | 338,284.00 | 12.54 |
| Total | 2,696,905.44 | 100.00 |

## 3.3 Sunflower

Table 11 presents the results of the land capability classes for sunflower (*Helianthus annuus*). The main factors limiting land capability for this crop were the predominance of low soil potential classes in Haiti. These low soil potential classes are mainly due to high slopes and low soil fertility. Crops that need to be mechanically planted or harvested cannot occupy terrains with slopes higher that 12%, which is the slope threshold within which a machine can work without danger of rolling over. Slope also increases soil erosion problems. Soil fertility affects plant nutrition.

**Table 11**
**Land capability definition for sunflower (ZAD = dense agricultural zones, ZAF = agroforestry zones, ZAMD = medium dense agricultural zones, PD = pastures dominating, PAOS = pastures with other land uses, SAOS = savannas with other land uses).**

| Soil potential classes | Agricultural Soil Use | Inundation | Land Capability |
|---|---|---|---|
| 1 | ZAD | no | very high |
| 1 | ZAF | no | high |
| 1 | ZAMD | no | high |
| 1 | PD | no | low |
| 1 | PAOS | no | low |
| 1 | SAOS | no | very low |
| 1 | ZAD | yes | high |
| 1 | ZAF | yes | moderate |
| 1 | ZAMD | yes | moderate |
| 1 | PD | yes | very low |
| 1 | PAOS | yes | very low |
| 1 | SAOS | yes | very low |
| | | | |
| 2 | ZAD | no | high |
| 2 | ZAF | no | moderate |
| 2 | ZAMD | no | moderate |
| 2 | PD | no | low |
| 2 | PAOS | no | low |
| 2 | SAOS | no | very low |
| 2 | ZAD | yes | moderate |
| 2 | ZAF | yes | low |
| 2 | ZAMD | yes | low |
| | | | |
| 2 | PD | yes | very low |

| Soil potential classes | Agricultural Soil Use | Inundation | Land Capability |
|---|---|---|---|
| 2 | PAOS | yes | very low |
| 2 | SAOS | yes | very low |
| 3 | ZAD | no | moderate |
| 3 | ZAF | no | low |
| 3 | ZAMD | no | low |
| 3 | PD | no | very low |
| 3 | PAOS | no | very low |
| 3 | SAOS | no | very low |
| 3 | ZAD | yes | low |
| 3 | ZAF | yes | very low |
| 3 | ZAMD | yes | very low |
| 3 | PD | yes | very low |
| 3 | PAOS | yes | very low |
| 3 | SAOS | yes | very low |
| 4 | ZAD | no | very low |
| 4 | ZAF | no | very low |
| 4 | ZAMD | no | very low |
| 4 | PD | no | very low |
| 4 | PAOS | no | very low |
| 4 | SAOS | no | very low |
| 4 | ZAD | yes | very low |
| 4 | ZAF | yes | very low |
| 4 | ZAMD | yes | very low |
| 4 | PD | yes | very low |
| 4 | PAOS | yes | very low |
| 4 | SAOS | yes | very low |
| 5 | ZAD | no | low |
| 5 | ZAF | no | very low |
| 5 | ZAMD | no | very low |
| 5 | PD | no | very low |
| 5 | PAOS | no | very low |
| 5 | SAOS | no | very low |
| 5 | ZAD | yes | very low |
| 5 | ZAF | yes | very low |
| 5 | ZAMD | yes | very low |
| 5 | PD | yes | very low |
| 5 | PAOS | yes | very low |
| 5 | SAOS | yes | very low |
| 6 | ZAD | no | very low |
| 6 | ZAF | no | very low |
| 6 | ZAMD | no | very low |
| 6 | PD | no | very low |
| 6 | PAOS | no | very low |
| 6 | SAOS | no | very low |
| 6 | ZAD | yes | very low |
| 6 | ZAF | yes | very low |
| 6 | ZAMD | yes | very low |
| 6 | PD | yes | very low |
| 6 | PAOS | yes | very low |
| 6 | SAOS | yes | very low |
| 7 | ZAD | no | inapt |
| 7 | ZAF | no | inapt |
| 7 | ZAMD | no | inapt |
| 7 | PD | no | inapt |
| 7 | PAOS | no | inapt |
| 7 | SAOS | no | inapt |
| 7 | ZAD | yes | inapt |
| 7 | ZAF | yes | inapt |
| 7 | ZAMD | yes | inapt |
| 7 | PD | yes | inapt |

| Soil potential classes | Agricultural Soil Use | Inundation | Land Capability |
|---|---|---|---|
| 7 | PAOS | yes | inapt |
| 7 | SAOS | yes | inapt |
| | | | |
| 8 | ZAD | no | inapt |
| 8 | ZAF | no | inapt |
| 8 | ZAMD | no | inapt |
| 8 | PD | no | inapt |
| 8 | PAOS | no | inapt |
| 8 | SAOS | no | inapt |
| 8 | ZAD | yes | inapt |
| 8 | ZAF | yes | inapt |
| 8 | ZAMD | yes | inapt |
| 8 | PD | yes | inapt |
| 8 | PAOS | yes | inapt |
| 8 | SAOS | yes | inapt |

Figure 22, Figure 23 and Table 12 illustrate the distribution of the land capability classes for sunflower in Haiti. These maps show that only 2% of the area of the country, corresponding to approximately 54,070 ha, presents very few restrictions for this crop and 5% were classified as moderate capability. The rest of the land would have low to very low capability for these crops or would present serious land restrictions that could affect these crops productivities. Areas with low and very low capability, which occupy approximately 868,827 ha, would need certain amount of investments to overcome some restriction the land presents. Depending on the limitation, the cost of the technological investment for the amelioration of these areas could eliminate part of them for the production of these crops. Mainly due to very low soil potential and high slopes 47.6% of the area of Haiti (1,283,692 ha) is inapt for annual crops.

**Figure 22**
**Land capability map for sunflower without landscape.**

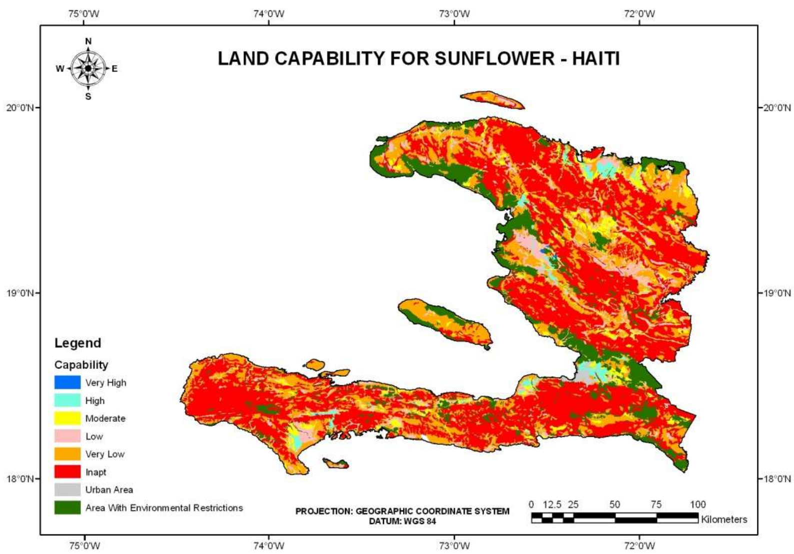


**Figure 23**
**Land capability map with landscape.**

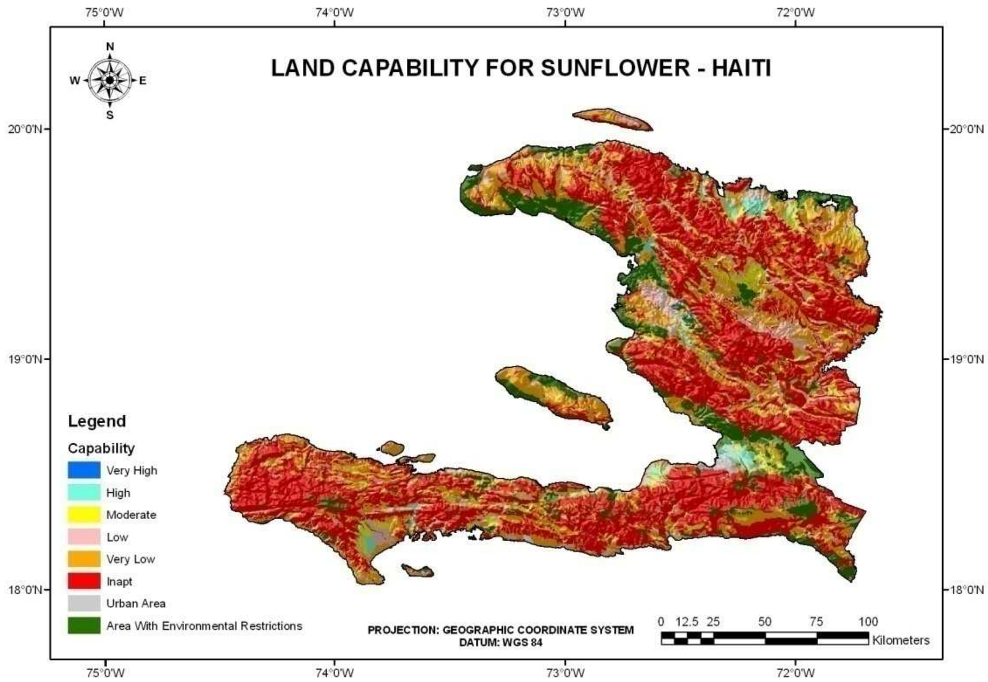



**Table 12**
**Area quantification for sunflower**

| Categories | Area (ha) | % |
|---|---|---|
| Very High | 2,433.95 | 0.09 |
| High | 51,636.66 | 1.91 |
| Moderate | 134,510.18 | 4.99 |
| Low | 191,248.15 | 7.09 |
| Very Low | 677,579.87 | 25.12 |
| Inapt | 1,283,692.64 | 47.60 |
| Urban Area | 17,520.00 | 0.65 |
| Area With Environmental Restrictions | 338,284.00 | 12.54 |
| Total | 2,696,905.44 | 100.00 |

## 3.4 Eucalyptus

Table 13 presents the land capability classification key for eucalyptus (*Eucalyptus spp.*). The main changes in this classification key are in the land capabilities of the more restrictive areas. As eucalyptus is normally planted in more marginal areas, especially more uneven areas, the level of restriction for these classes was brought down when compared to the more demanding crops. At the higher levels the classification was maintained similar to the sugarcane classification.

**Table 13**
**Land capability definition for eucalyptus (ZAD = dense agricultural zones, ZAF = agroforestry zones, ZAMD = medium dense agricultural zones, PD = pastures dominating, PAOS = pastures with other land uses, SAOS = savannas with other land uses).**

| Soil potential classes | Agricultural | Soil Inundation | Land |
|---|---|---|---|
| 1 | ZAD | no | very high |
| 1 | ZAF | no | high |
| 1 | ZAMD | no | high |
| 1 | PD | no | moderate |
| 1 | PAOS | no | moderate |
| 1 | SAOS | no | very low |
| 1 | ZAD | yes | high |
| 1 | ZAF | yes | moderate |
| 1 | ZAMD | yes | moderate |
| 1 | PD | yes | low |
| 1 | PAOS | yes | low |
| 1 | SAOS | yes | very low |
| 2 | ZAD | no | very high |
| 2 | ZAF | no | high |
| 2 | ZAMD | no | high |
| 2 | PD | no | moderate |
| 2 | PAOS | no | moderate |
| 2 | SAOS | no | very low |
| 2 | ZAD | yes | high |
| 2 | ZAF | yes | moderate |
| 2 | ZAMD | yes | moderate |
| 2 | PD | yes | low |
| 2 | PAOS | yes | low |
| 2 | SAOS | yes | very low |
| 3 | ZAD | no | high |
| 3 | ZAF | no | high |
| 3 | ZAMD | no | moderate |
| 3 | PD | no | moderate |
| 3 | PAOS | no | moderate |
| 3 | SAOS | no | very low |
| 3 | ZAD | yes | moderate |
| 3 | ZAF | yes | low |
| 3 | ZAMD | yes | low |
| 3 | PD | yes | low |
| 3 | PAOS | yes | low |
| 3 | SAOS | yes | very low |
| 4 | ZAD | no | moderate |
| 4 | ZAF | no | moderate |
| 4 | ZAMD | no | moderate |
| 4 | PD | no | moderate |
| 4 | PAOS | no | moderate |

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 4 | SAOS | no | very low |
| 4 | ZAD | yes | moderate |
| 4 | ZAF | yes | low |
| 4 | ZAMD | yes | low |
| 4 | PD | yes | low |
| 4 | PAOS | yes | low |
| 4 | SAOS | yes | very low |
| 5 | ZAD | no | moderate |
| 5 | ZAF | no | moderate |
| 5 | ZAMD | no | moderate |
| 5 | PD | no | moderate |
| 5 | PAOS | no | moderate |
| 5 | SAOS | no | very low |
| 5 | ZAD | yes | moderate |
| 5 | ZAF | yes | low |
| 5 | ZAMD | yes | low |
| 5 | PD | yes | low |
| 5 | PAOS | yes | low |
| 5 | SAOS | yes | very low |
| 6 | ZAD | no | moderate |
| 6 | ZAF | no | moderate |
| 6 | ZAMD | no | moderate |
| 6 | PD | no | moderate |
| 6 | PAOS | no | moderate |
| 6 | SAOS | no | very low |
| 6 | ZAD | yes | moderate |
| 6 | ZAF | yes | low |
| 6 | ZAMD | yes | low |
| 6 | PD | yes | low |
| 6 | PAOS | yes | low |
| 6 | SAOS | yes | very low |
| 7 | ZAD | no | inapt |
| 7 | ZAF | no | inapt |
| 7 | ZAMD | no | inapt |
| 7 | PD | no | inapt |
| 7 | PAOS | no | inapt |
| 7 | SAOS | no | inapt |
| 7 | ZAD | yes | inapt |
| 7 | ZAF | yes | inapt |
| 7 | ZAMD | yes | inapt |
| 7 | PD | yes | inapt |
| 7 | PAOS | yes | inapt |
| 7 | SAOS | yes | inapt |
| 8 | ZAD | no | inapt |
| 8 | ZAF | no | inapt |
| 8 | ZAMD | no | inapt |
| 8 | PD | no | inapt |
| 8 | PAOS | no | inapt |
| 8 | SAOS | no | inapt |
| 8 | ZAD | yes | inapt |
| 8 | ZAF | yes | inapt |
| 8 | ZAMD | yes | inapt |
| 8 | PD | yes | inapt |
| 8 | PAOS | yes | inapt |
| 8 | SAOS | yes | inapt |

A great increase in moderate capability areas can be seen in this map (Figure 24). These areas represent approximately 22.13% of the area of the country and a total of 596,615 ha. As

Eucalyptus is less restrictive in relation to land capability than other crops, larger areas could be classified into high and moderate land capability categories for this crop (Figure 24 and Table 14). This is important to know especially if the project envisions a multi-crop production for biofuels. In this case eucalyptus could be an alternative, in terms of land requirements, for a system in which more than one crop can be planted in a region. In more marginal areas where more sensible crops present low to very low capability, eucalyptus appears as an alternative which could be interesting from the socio-economical point of view.

**Figure 24**
**Land capability map for eucalyptus.**
**Without landscape (top) and with landscape (bottom).**

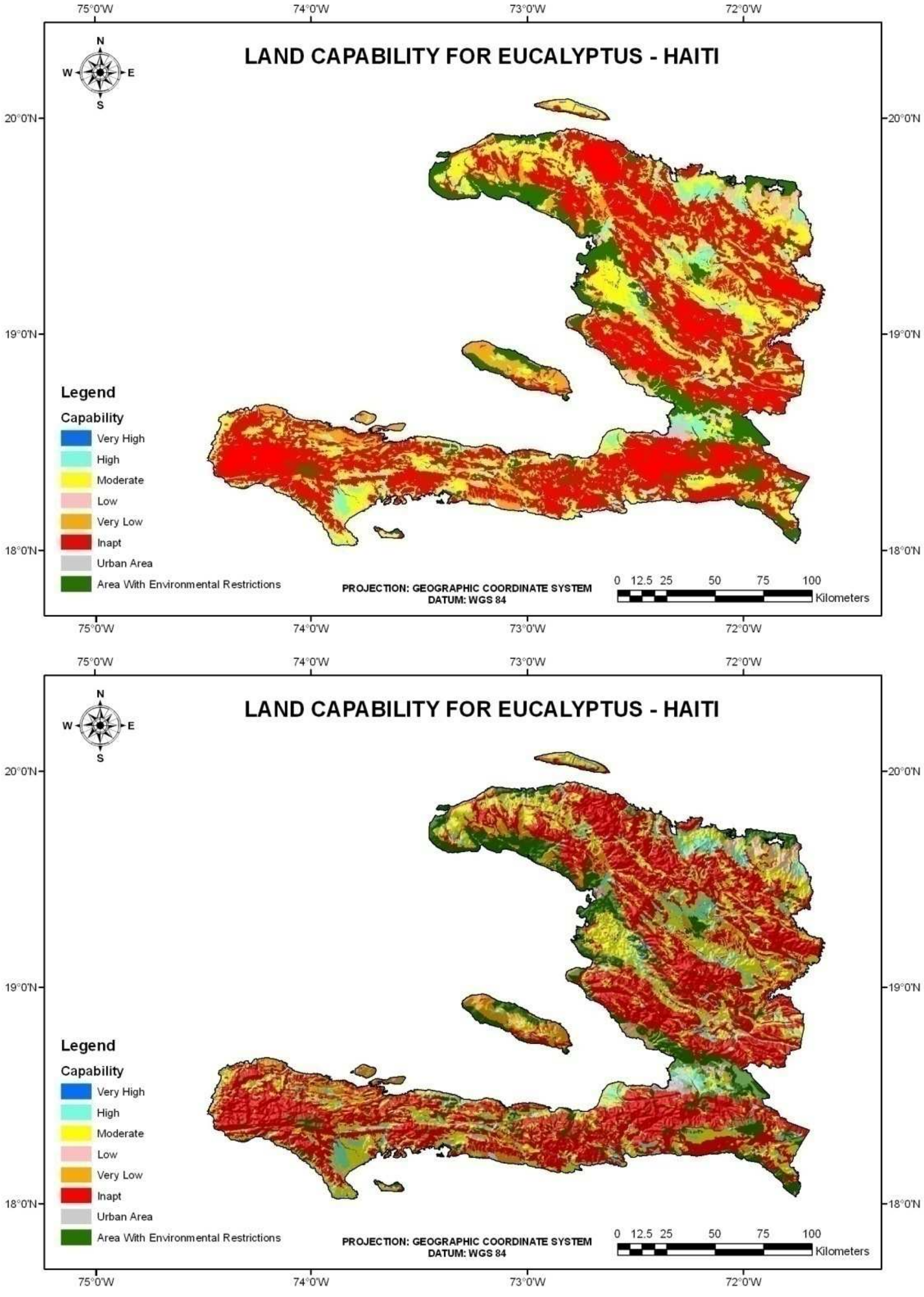


**Table 14**
**Area quantification for eucalyptus**

| Categories | Area (ha) | % |
|---|---|---|
| Very High | 12,452.95 | 0.46 |
| High | 179,009.66 | 6.64 |
| Moderate | 596,839.18 | 22.13 |
| Low | 73,705.15 | 2.73 |
| Very Low | 195,401.87 | 7.25 |
| Inapt | 1,283,692.64 | 47.60 |
| Urban Area | 17,520.00 | 0.65 |
| Area With Environmental Restrictions | 338,284.00 | 12.54 |
| Total | 2,696,905.44 | 100.00 |

## 3.5 Jatropha

Jatropha (*Jatropha curcas*) is a biofuel producing crop that requires little care for its survival and can grow in relatively marginal areas with poor physical and chemical soil attributes. It is a highly adaptable plant that presents a high ability to grow in low aptitude and dry regions. Although jatropha is a rustic plant and is adaptable to moderate and extreme land conditions, it does have some requirements regarding soil conditions, but when cultivated in good soils it will yield high productivities.

Table 15 presents the land capability classification key for jatropha. Due to the high adaptability of this crop, the more marginal areas were less penalized during the definition of the land capabilities. Areas that presented the highest restrictions were those classified as classes 4 to 8 in the soil potential classification.

**Table 15**
**Land capability definition for *Jatropha curcas* (ZAD = dense agricultural zones, ZAF = agroforestry zones, ZAMD = medium dense agricultural zones, PD = pastures dominating, PAOS = pastures with other land uses, SAOS = savannas with other land uses).**

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 1 | ZAD | no | very high |
| 1 | ZAF | no | high |
| 1 | ZAMD | no | high |
| 1 | PD | no | low |
| 1 | PAOS | no | low |
| 1 | SAOS | no | very low |
| 1 | ZAD | yes | high |
| 1 | ZAF | yes | moderate |
| 1 | ZAMD | yes | moderate |
| 1 | PD | yes | very low |
| 1 | PAOS | yes | very low |
| 1 | SAOS | yes | very low |

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 2 | ZAD | no | very high |
| 2 | ZAF | no | high |
| 2 | ZAMD | no | high |
| 2 | PD | no | low |
| 2 | PAOS | no | low |
| 2 | SAOS | no | very low |
| 2 | ZAD | yes | high |
| 2 | ZAF | yes | moderate |
| 2 | ZAMD | yes | moderate |
| 2 | PD | yes | very low |
| 2 | PAOS | yes | very low |
| 2 | SAOS | yes | very low |
| | | | |
| 3 | ZAD | no | high |
| 3 | ZAF | no | moderate |
| 3 | ZAMD | no | moderate |
| 3 | PD | no | low |
| 3 | PAOS | no | low |
| 3 | SAOS | no | very low |
| 3 | ZAD | yes | moderate |
| 3 | ZAF | yes | low |
| 3 | ZAMD | yes | low |
| 3 | PD | yes | very low |
| 3 | PAOS | yes | very low |
| 3 | SAOS | yes | very low |
| | | | |
| 4 | ZAD | no | |
| 4 | ZAF | no | moderate |
| 4 | ZAMD | no | low |
| 4 | PD | no | low |
| 4 | PAOS | no | low |
| 4 | SAOS | no | low |
| 4 | ZAD | yes | very low |
| 4 | ZAF | yes | low |
| 4 | ZAMD | yes | very low |
| 4 | PD | yes | very low |
| 4 | PAOS | yes | very low |
| 4 | SAOS | yes | very low |
| | | | |
| 5 | ZAD | no | moderate |
| 5 | ZAF | no | low |
| 5 | ZAMD | no | low |
| 5 | PD | no | low |
| 5 | PAOS | no | low |
| 5 | SAOS | no | very low |
| 5 | ZAD | yes | low |
| 5 | ZAF | yes | very low |
| 5 | ZAMD | yes | very low |
| 5 | PD | yes | very low |
| 5 | PAOS | yes | very low |
| 5 | SAOS | yes | very low |
| | | | |
| 6 | ZAD | no | low |
| 6 | ZAF | no | low |
| 6 | ZAMD | no | low |
| 6 | PD | no | low |
| 6 | PAOS | no | low |
| 6 | SAOS | no | very low |
| 6 | ZAD | yes | low |
| 6 | ZAF | yes | very low |
| 6 | ZAMD | yes | very low |
| 6 | PD | yes | very low |
| 6 | PAOS | yes | very low |
| 6 | SAOS | yes | very low |

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 7 | ZAD | no | inapt |
| 7 | ZAF | no | inapt |
| 7 | ZAMD | no | inapt |
| 7 | PD | no | inapt |
| 7 | PAOS | no | inapt |
| 7 | SAOS | no | inapt |
| 7 | ZAD | yes | inapt |
| 7 | ZAF | yes | inapt |
| 7 | ZAMD | yes | inapt |
| 7 | PD | yes | inapt |
| 7 | PAOS | yes | inapt |
| 7 | SAOS | yes | inapt |
| 8 | ZAD | no | inapt |
| 8 | ZAF | no | inapt |
| 8 | ZAMD | no | inapt |
| 8 | PD | no | inapt |
| 8 | PAOS | no | inapt |
| 8 | SAOS | no | inapt |
| 8 | ZAD | yes | inapt |
| 8 | ZAF | yes | inapt |
| 8 | ZAMD | yes | inapt |
| 8 | PD | yes | inapt |
| 8 | PAOS | yes | inapt |
| 8 | SAOS | yes | inapt |

Haiti presents 519,874 ha of land with very high, high and moderate land capabilities for jatropha. This represents around 19.28% of the total area of the country (Figure 25, and Table 16). The valleys among the mountain chains and the footslopes of the escarpments were included in these areas. The most limited areas for jatropha are those that, as cited above, presented the highest slopes or problems with highly restrictive soil potential attributes.

Jatropha is an alternative option for areas that present marginal land capabilities for other more sensible crops. If the approach of producing biofuels is a multi-crop approach, the use of jatropha in restricted areas, even if there is a loss in productivity, could be a suitable alternative to no land use. Socio-economical factors should be weighed when trying this approach, but jatropha is highly suitable for small property management or family agriculture.

**Figure 25**
**Land capability map for jatropha. Without landscape.**

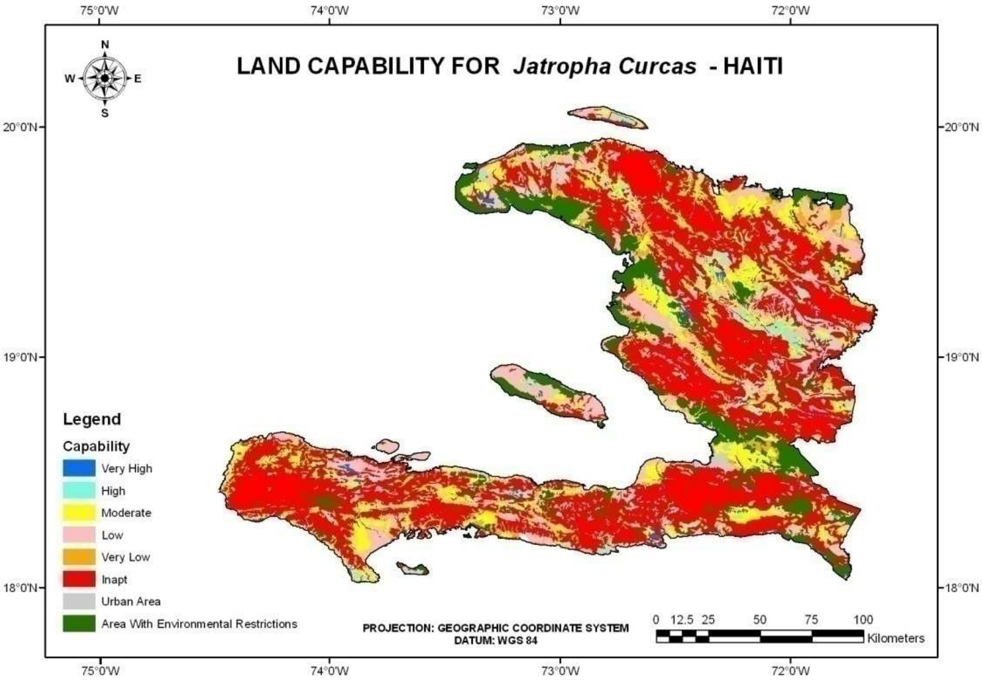



**Figure 26**
**Land capability map for jatropha. With landscape.**

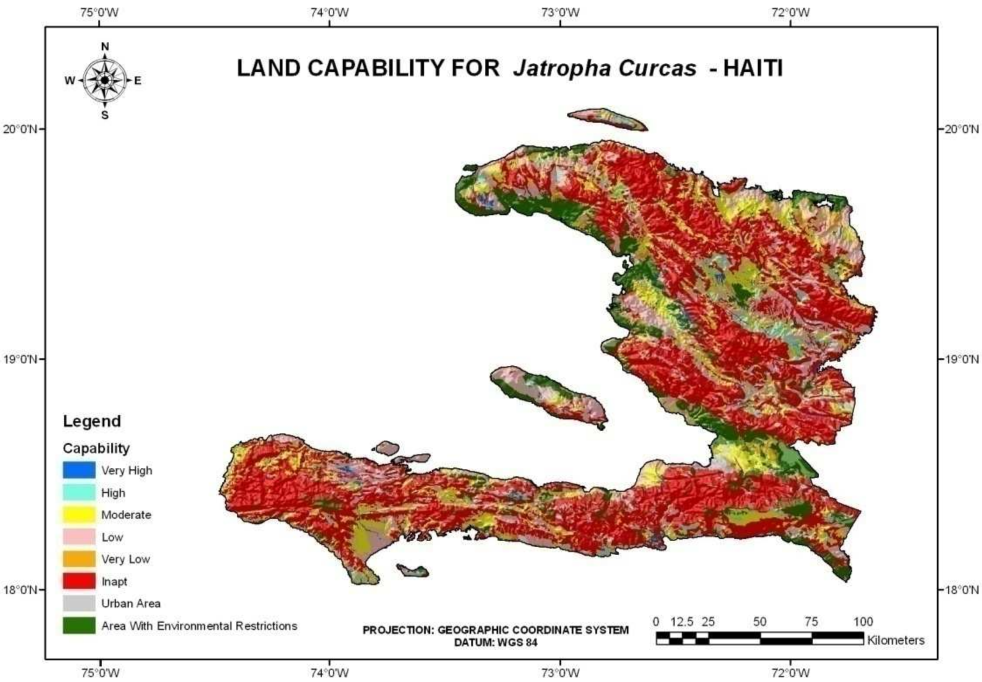


**Table 16**
**Area quantification for jatropha.**

| Categories | Area (Ha) | % |
|---|---|---|
| Very High | 45,576.78 | 1.69 |
| High | 101,022.49 | 3.75 |
| Moderate | 373,947.02 | 13.87 |
| Low | 472,452.98 | 17.52 |
| Very Low | 64,409.70 | 2.39 |
| Inapt | 1,283,692.47 | 47.60 |
| Urban Area | 17,520.00 | 0.65 |
| Area With Environmental Restrictions | 338,284.00 | 12.54 |
| Total | 2,696,905.44 | 100.00 |

## 3.6 Elephant grass

Elephant grass (*Pennisetum purpureum*) is a highly energetic plant that transforms solar energy into chemical. Although a little more restrictive than sugarcane in terms of soils requirements, the net energy balance of elephant grass for electricity generation is higher than sugarcane and corn. The use of elephant grass as biomass for generating electricity has a great potential in Haiti.

Table 17 presents the land capability classification key for elephant grass. Although elephant grass is similar to sugarcane, it presents higher restrictions in terms of soil potential. The highest restrictions it presents in terms of soil are bad drainage conditions or areas than are vulnerable to inundations.

**Table 17**
**Land capability definition for elephant grass (ZAD = dense agricultural zones, ZAF = agroforestry zones, ZAMD = medium dense agricultural zones, PD = pastures dominating, PAOS = pastures with other land uses, SAOS = savannas with other land uses).**

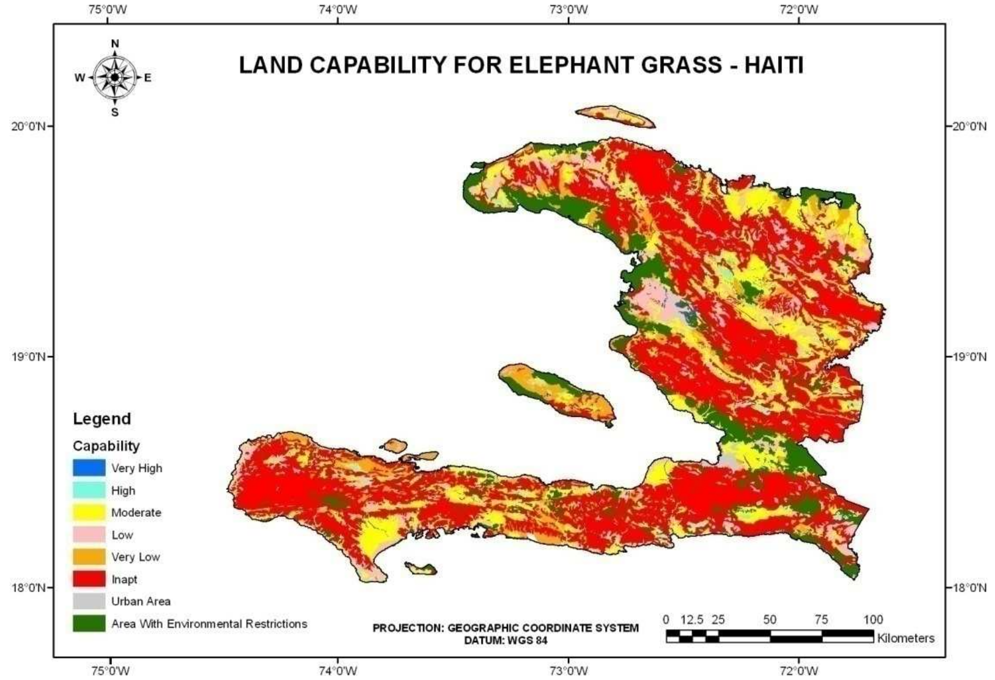
| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 1 | ZAD | no | very high |
| 1 | ZAF | no | high |
| 1 | ZAMD | no | high |
| 1 | PD | no | moderate |
| 1 | PAOS | no | moderate |
| 1 | SAOS | no | low |
| 1 | ZAD | yes | moderate |
| 1 | ZAF | yes | moderate |
| 1 | ZAMD | yes | moderate |
| 1 | PD | yes | very low |
| 1 | PAOS | yes | very low |
| 1 | SAOS | yes | very low |
| 2 | ZAD | no | very high |
| 2 | ZAF | no | high |
| 2 | ZAMD | no | high |

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 2 | PD | no | moderate |
| 2 | PAOS | no | moderate |
| 2 | SAOS | no | low |
| 2 | ZAD | yes | moderate |
| 2 | ZAF | yes | moderate |
| 2 | ZAMD | yes | moderate |
| 2 | PD | yes | very low |
| 2 | PAOS | yes | very low |
| 2 | SAOS | yes | very low |
| | | | |
| 3 | ZAD | no | high |
| 3 | ZAF | no | moderate |
| 3 | ZAMD | no | moderate |
| 3 | PD | no | low |
| 3 | PAOS | no | low |
| 3 | SAOS | no | very low |
| 3 | ZAD | yes | moderate |
| 3 | ZAF | yes | moderate |
| 3 | ZAMD | yes | moderate |
| 3 | PD | yes | very low |
| 3 | PAOS | yes | very low |
| 3 | SAOS | yes | very low |
| | | | |
| 4 | ZAD | no | moderate |
| 4 | ZAF | no | low |
| 4 | ZAMD | no | moderate |
| 4 | PD | no | low |
| 4 | PAOS | no | low |
| 4 | SAOS | no | very low |
| 4 | ZAD | yes | low |
| 4 | ZAF | yes | low |
| 4 | ZAMD | yes | low |
| 4 | PD | yes | very low |
| 4 | PAOS | yes | very low |
| 4 | SAOS | yes | very low |
| | | | |
| 5 | ZAD | no | low |
| 5 | ZAF | no | low |
| 5 | ZAMD | no | low |
| 5 | PD | no | low |
| 5 | PAOS | no | low |
| 5 | SAOS | no | very low |
| 5 | ZAD | yes | low |
| 5 | ZAF | yes | low |
| 5 | ZAMD | yes | low |
| 5 | PD | yes | very low |
| 5 | PAOS | yes | very low |
| 5 | SAOS | yes | very low |
| | | | |
| 6 | ZAD | no | moderate |
| 6 | ZAF | no | low |
| 6 | ZAMD | no | low |
| 6 | PD | no | low |
| 6 | PAOS | no | low |
| 6 | SAOS | no | very low |
| 6 | ZAD | yes | low |
| 6 | ZAF | yes | low |
| 6 | ZAMD | yes | low |
| 6 | PD | yes | very low |
| 6 | PAOS | yes | very low |
| 6 | SAOS | yes | very low |
| | | | |
| 7 | ZAD | no | inapt |
| 7 | ZAF | no | inapt |
| | | | |
| 7 | ZAMD | no | inapt |

| Soil potential classes | Agricultural Soil | Inundation | Land |
|---|---|---|---|
| 7 | PD | no | inapt |
| 7 | PAOS | no | inapt |
| 7 | SAOS | no | inapt |
| 7 | ZAD | yes | inapt |
| 7 | ZAF | yes | inapt |
| 7 | ZAMD | yes | inapt |
| 7 | PD | yes | inapt |
| 7 | PAOS | yes | inapt |
| 7 | SAOS | yes | inapt |
| | | | |
| 8 | ZAD | no | inapt |
| 8 | ZAF | no | inapt |
| 8 | ZAMD | no | inapt |
| 8 | PD | no | inapt |
| 8 | PAOS | no | inapt |
| 8 | SAOS | no | inapt |
| 8 | ZAD | yes | inapt |
| 8 | ZAF | yes | inapt |
| 8 | ZAMD | yes | inapt |
| 8 | PD | yes | inapt |
| 8 | PAOS | yes | inapt |
| 8 | SAOS | yes | inapt |

Most of the agriculturally apt areas of Haiti for elephant grass fall into the moderate land capability class (Figure 27 and Table 18). 17.13% of these areas present a moderate land capability for elephant grass representing a total of 461,835 ha. Very high and high capability classes represent 2.75% of the country and an area of 74,788 ha. Areas with low and very low capabilities are mainly distributed in areas with high slopes or that present restrictions to more demanding land uses. These areas can be used if soil management technologies are applied for erosion control and overcoming other deficiencies these soils may have.

**Figure 27**
**Land capability map for elephant grass.**
**Without landscape (top) and with landscape (bottom).**



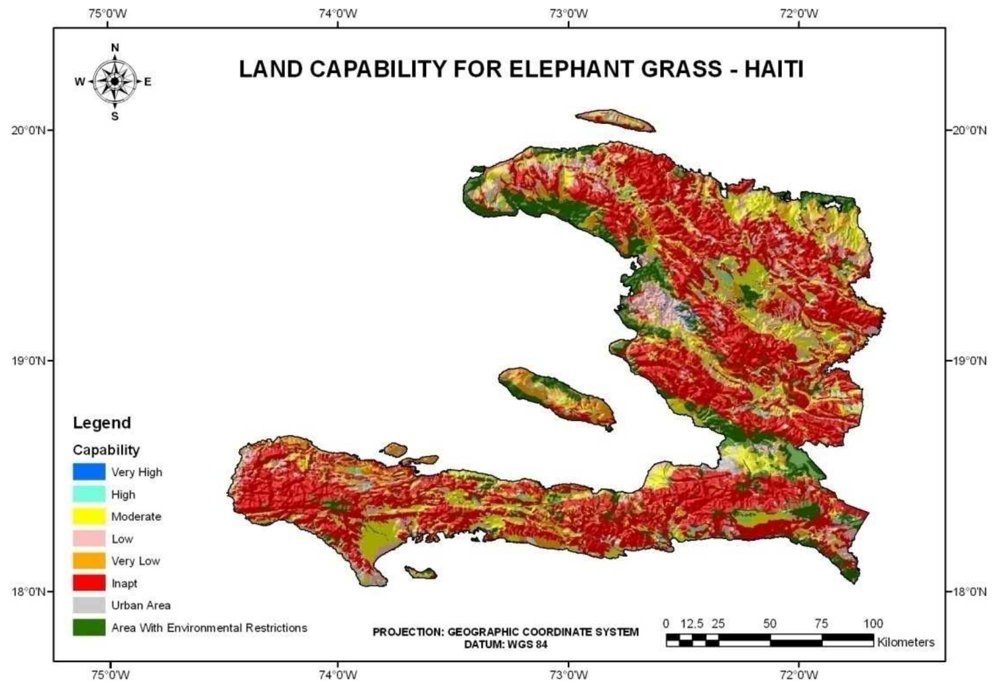



**Table 18**
**Area quantification for elephant grass**

| Categories | Area (Ha) | % |
|---|---|---|
| Very High | 12,457.95 | 0.46 |
| High | 62,788.66 | 2.33 |
| Moderate | 462,064.18 | 17.13 |
| Low | 323,699.15 | 12.00 |
| Very Low | 196,393.87 | 7.28 |
| Inapt | 1,283,697.64 | 47.60 |
| Urban Area | 17,520.00 | 0.65 |
| Area With Environmental Restrictions | 338,284.00 | 12.54 |
| Total | 2,696,905.44 | 100.00 |

## 3.7 Final remarks

Agriculturally apt areas in Haiti are restricted to valleys and the footslopes of the mountain ranges. Large areas of Haiti are inapt for all analyzed crops. Around 47% of the country is inapt for any of the crops analyzed. The main soil restrictions were those that define soil potential classes above class 4 which are mainly erosion problems, soil fertility, soil drainage and stoniness. Land use gives an excellent idea of the soil use potential and crossing this information with the soil potential gave an excellent idea of the capabilities of the soils for biofuel production. The lack of basic data made a more detailed analysis difficult but the information obtained through Mr. Joel Timyian was enough to make an evaluation of land capabilities possible for the five biofules crops analyzed in Haiti.

Very few areas in Haiti presented very high and high land capability classes. Most of the potential areas fell into the moderate class of land capability. This shows the great restrictions the Haitian soils present for the production of these crops. Large investments on soil management will have to be done in order to increase the productive areas without further soil degradation. Initially for pilot projects and to fulfill actual demands of biofuels the areas classified as very high, high and moderate would be enough, but if growth is sought then technological innovations will have to be implemented for using areas with higher capability restrictions.

# 4. Agroclimatic Zoning for Biofuels Production

Agriculture is highly sensitive to climatic conditions and the weather, which determine the adequate plant species or varieties, the agricultural system to be adopted and the practices necessary to manage a crop with a good performance. This being the case, agro-meteorological information, especially climatological, is essential for agricultural planning, which together with information on the soil, will define the potential of an area for a specific agricultural activity.

This chapter presents the results of the first phase of the Project Agroclimatic Zoning for Biofuel Crops in Haiti. Sugarcane was considered as the main crop for this study, aiming ethanol production. However, alternative crops were also studied in relation to their agroclimatic suitability for the country, considering their potential for biofuel production. The alternative crops were: sunflower; eucalyptus; elephant grass; and jatropha.

The agroclimatic zoning was based on climate information collected from different sources, mainly from FAOCLIM2 system, powered by FAO/UN. Rainfall data from the Centre National de Meteorologie D'Haiti were also considered. The climate data used for our analyses were evaluated and consisted accordingly to WMO (World Meteorological Organization) criteria. Average rainfall and mean air temperature were just considered when calculated with more than 10 years of data, since results from literature have shown that this period is long enough to have good results (Woltling et al., 2000; Marquinez et al., 2003). A total of 114 weather stations were selected for this study.

Monthly rainfall and mean air temperature were the main variables used in this project. With these two variables was possible to estimate the other parameters required for the agroclimatic zoning. Potential evapotranspiration (ETP) was estimated with Thornthwaite method, presented by Pereira et al. (2002). Rainfall and ETP were used to run the climatological water balance, accordingly to Thornthwaite and Mather (1955) model, which allowed estimating monthly actual evapotranspiration (ETR), water deficiency (WD) and water surplus (WS). For running the water balance, different soil water holding capacities (SWHC) were adopted for each studied crop, ranging from 125 mm to 200 mm, according to the information available in the literature. The climatological water balance made possible to characterize the regional climate, not only in terms of rainfall and temperature but also in terms of soil water availability, defining the wet and dry seasons, information that is essential for agricultural planning, mainly for agroclimatic zoning.

The climate requirements of each crop were obtained from previous studies presented in the literature, considering the main parameters that limit their development and production. The parameters required by the crops were: annual average temperature; temperature of the coldest month; annual total rainfall; annual total water deficiency; annual total water surplus; and humidity index (calculated with WD, WS and ETP data). The crossing of crop climate requirements and climatic data allowed determining the levels of suitability of each region for crop development and production. The climatic and agroclimatic zoning maps were obtained with a geographical information system (ARGIS 9.2), considering the relationship among climatic parameters and geographical coordinates, determined by multiple linear regressions (Rodriguez-Lado et al., 2007).

## 4.1 Elaboration of Climate Maps

Data from all bases were used to elaborate the climate maps of Haiti. The maps for climate characterization of the country was based on annual temperature and total rainfall as well as on the variables obtained from the climatological water balance, for a SWHC of 125 mm. Maps of annual average temperature, temperature of the coldest month, rainfall, ETP, ETR, WD, WS and Ih (humidity index) were elaborated.

Multiple regression analysis was used, combined with interpolation techniques, for modeling all the climatic parameters (Rodriguez-Lado et al., 2007). The mean values of the climatic variables were considered as dependent variables in the multiple regression analysis. As possible independent variables nominal altitude (Alt), latitude (Lat) and longitude (Long) of the weather stations were considered, as well as other climatic parameters. The adjusted regression model finally gives an expression in the form:

$$y = a + b_1(X_1) + b_2(X_2) + \cdots + b_n(X_n) + \varepsilon \quad (1)$$

Where: y is the estimated value of the dependent climatic variable; *a* is the intercept, *b* are multiple regression coefficients; X the significant independent variables and ε is the residual error of the estimation. For each model, the multiple coefficient of determination ($R^2$) was computed. The following models were obtained for Haiti:

$$Ta = 53.6 - 0.125*Lat + 0.339*Long - 0.00675*Alt \quad (R^2 = 0.89)$$

*Rain = -18275.7+ 30.12*Lat – 261.37*Long – 0.607* Alt* ($R^2 = 0.24$)

*ETP = 1434.4 – 35.42*Lat – 11.29*Long – 0.605* Alt* ($R^2 = 0.75$)

*ETR = -3178.5+20.88*Lat – 47.13*Long – 0.325*Alt + 0.39*Rain* ($R^2 = 0.64$)

*DEF = 3674.9 – 54.75*Lat + 22.43*Long – 0.249*Alt – 0.445*Rain* ($R^2 = 0.67$)

*EXC = 2775.9 – 26.32*Lat + 39.82*Long + 0.327*Alt + 0.59*Rain* ($R^2 = 0.83$)

*Ih = -117.7 – 1.43*Lat – 1.81*Long + 0.039*Alt – 0.0216*DEF + 0.08*EXC* ($R^2 = 0.98$)

These models were converted to climatic parameters maps using map algebra with a Geographic Information System (ArcGIS 9.2), processing the independent variables as map layers in raster format. Altitude raster layer, in meters, was obtained from digital elevation data (DEMs), provided by NASA Shuttle Radar Topographic Mission (SRTM), which has a resolution of 90 m. At each station the values of ε that expresses the difference between the observed and estimated values of each variable were also calculated. Maps of ε were added to the regression maps to diminish the errors of the regression model.

## 4.2 Procedures and Criteria for Agroclimatic Zoning

Based on the literature, different criteria were selected for crops evaluated in this study. These criteria are presented below, considering the requirements of each crop for high performance as well as for its development under stress conditions.

### 4.2.1 Sugarcane

The criteria adopted for delimiting the suitable zones for sugarcane were based on the agroclimatic zoning for this crop made by Camargo et al. (1974), which were also used by Alfonsi et al. (1987) and Barreto et al. (2006), for Brazilian conditions. The following variables were considered:

- **Annual average temperature (Ta)** – the limit of annual temperature considered for crop development and growth was 20ºC. Based on that, all the regions with Ta greater than 20°C were considered suitable for sugarcane. Regions with Ta between 18 and 20ºC were considered marginal by thermal restriction, whereas those with Ta below 18ºC were considered inapt by thermal deficiency.

- **Temperature of the coldest month (Tf)** – this temperature is an index to identify regions with frost risk during the winter. As sugarcane crop does not resist to frosts, Tf is normally considered for its agroclimatic zoning. So, regions with Tf below 14ºC were considered inapt for sugarcane production.

- **Water deficiency (WD)** – WD represents the amount of water that the soil-plant system was not able to consume throughout the year because of the shortage of water in soil during the dry season. Rainfed crops, mainly perennial ones like sugarcane, can resist to certain amount of WD during the growing season without reduce their yield. On the other hand, when WD becomes higher than crops can resist, irrigation becomes necessary. For this study, the limits of WD for sugarcane crop, for a SWHC = 125 mm, were: a) suitable for rainfed crop – with WD between 20 and 200 mm; b) suitable with supplementary irrigation or marginal as rainfed crop – with WD between 200 and 400 mm; c) suitable with full irrigation or inapt as rainfed crop – with WD above 400 mm; d) unsuitable, with lack of a dry season for maturation, when WD < 20 mm.

### 4.2.2 Sunflower

The criteria adopted for delimiting the suitable zones for sunflower were adapted from the agroclimatic zoning for this crop made by Camargo et al. (1974). The adapted criteria consider water surplus instead of water deficiency, since a minimum period with high soil water availability is required for obtaining economical yields. The following criteria were then considered:

- **Annual average temperature (Ta)** – the limit of annual average temperature considered for crop development and growth was 15ºC. Based on that, all the regions with Ta greater than 15$^{o}$C were considered suitable for sunflower. Regions with Ta between 10 and 15ºC were considered marginal by thermal restriction, whereas those with Ta below 10ºC were considered unsuitable by thermal deficiency.

- **Water surplus (WS)** – WS was used as an index to represent the length of the wet season for sunflower. For this crop, considering a SWHC = 125 mm, regions with annual

WS above 100 till 400 mm was considered suitable for rainfed crop. WS between 51 and 100 mm was classified as marginal, since the wet season is not long enough and water deficiency will occur during the growing season, damaging the crop. WS below 50 mm were considered unsuitable, for water deficiency, whereas WS above 400 mm was classified as unsuitable, with the excess of humidity increasing the risk of plant diseases and affecting negatively the maturation process.

### 4.2.3 Eucalyptus

The genus *Eucalyptus* comprises more than 700 species; however few of them, between 15 and 30, are suitable for commercial planting areas. Considering the huge diversity of eucalyptus species, this crop can be grown in different climate conditions, from tropical to temperate and from wet to dry climates. According to Angeli et al. (2007), eucalyptus species can be divided in 5 different groups based on the climate:

- **Group 1 – Humid and hot**
  - *E. camaldulensis, E. deglupta, E. robusta, E. tereticornis, E. urophylla*
- **Group 2 – Humidy and mild**
  - *E. botryoides, E. deanei, E. dunnii, E. globulus, E. grandis, E. maidenii, E. paniculata, E. pilularis, E. propinqua, E. resinifera, E. robusta, E. saligna, E. viminalis*
- **Group 3 – Sub-humid - Humid**
  - *E. citriodora, E. grandis, E. saligna, E. teriticornes, E. urophylla*
- **Group 4 – Sub-humid - Dry**
  - *E. camaldulensis, E. citriodora, E. cloeziana, E. maculata, E. pellita, E. pilularis, E. pyrocarpa, E. teriticornes, E. urophylla*
- **Group 5 – Semi-arid**
  - *E. brassiana, E. camaldulensis, E. crebra, E. exserta, E. tereticornes, E. tessalaris*

The definition of the climate types for each region of Haiti was made based on the Thornthwaite´s climate classification (Thornthwaite & Mather, 1995), according to Humidity Index (Ih), calculated with the Water Index (Iw) and Aridity Index (Ia), both obtained with the variables of the climatological water balance (WD and WS), for a SWHC = 200 mm, and potential evapotranspiration (ETP) (Pereira et al., 2002):

- Ih = Iw – 0.6 * Ia
- Iw = (WS / ETP) * 100
- Ia = (WD / ETP) * 100

ETP was also used to distinguish between hot and mild climates: regions with ETP greater or equal to 1.000 mm were considered hot and below this value mild.

Based on these parameters the following criteria were considered to climate classification:

- **Humid and hot** → Ih > 20 and ETP ≥ 1000
- **Humid and mild** → Ih > 20 and ETP < 1000
- **Sub-humid – Humid** → 0 < Ih ≤ 20
- **Sub-humid – Dry** → -20 ≤ Ih < 0
- **Semi-arid** → -40 ≤ Ih < -20
- **Arid** → Ih ≤ -40

For regions with arid climate, eucalyptus was considered inapt.

### 4.2.4 Jatropha

Jatropha is a drought-resistant perennial crop. It is easy to establish, grows relatively quickly and can keep on producing seeds for 40 to 50 years. It is still uncertain where the centre of origin is, but it is believed to be Mexico and Central America. It has been introduced to Africa and Asia and is now cultivated world-wide. This highly drought-resistant species is adapted to arid and semi-arid conditions. The current distribution shows that introduction has been most successful in the drier regions of the tropics with annual rainfall above 600 mm. With less rainfall than that production is affected drastically. It occurs mainly at lower altitudes (0–500 m) in areas with annual average temperatures between 18 and 28.5℃ but can grow at higher altitudes and tolerates slight frost (Saturnino et al., 2005). Based on this reference, the following criteria were adopted for jatropha agroclimatic zoning in Haiti:

- **Annual average temperature (Ta)** – the interval of annual temperature considered suitable for good jatropha development and growth was between 18 and 28.5ºC. Temperatures below or above this interval were considered marginal by thermal insufficiency.

- **Mean annual rainfall (R)** – considering that 600 mm of rainfall is the lower limit for jatropha production, it was established that regions with mean annual rainfall less than 600 mm were unfavorable for commercial production of rainfed crop. Regions with mean annual rainfall between 600 and 1,000 mm were considered marginal and regions with more than 1,000 mm suitable under rainfed conditions.

Even considering these references, there is little trustable information about the behavior of this crop in different climates and what is the actual effect of water deficiency on crop yield. The criteria adopted above for agroclimatic zoning of jatropha are just a preliminary approach, therefore they must be considered with caution.

### 4.2.5 Elephant Grass

Based on the fact that there are no criteria for elephant grass agroclimatic zoning and that its climatic requirements are very similar to sugarcane, we adopted in this study the same parameters used for sugarcane crop zoning with some adaptations, as follows:

- **Annual average temperature (Ta)** – the limit of annual temperature considered for crop development and growth was 20ºC. Based on that, all the regions with Ta greater than 20$^{o}$C were considered suitable for sugarcane. Regions with Ta between 18 and 20ºC were considered marginal by thermal restriction, whereas those with Ta below 18ºC were considered inapt by thermal deficiency.
- **Temperature of the coldest month (Tf)** – this temperature is an index to identify regions with frost risk during the winter. As sugarcane crop does not resist to frosts, Tf is normally considered for its agroclimatic zoning. So, regions with Tf below 14ºC were considered inapt for sugarcane production.
- **Water deficiency (WD)** – the limits of WD for elephant grass crop, for a SWHC =

125 mm, were: a) suitable for rainfed crop – with WD up to 200 mm; b) marginal as rainfed crop – with WD between 200 and 400 mm; c) usuitable as rainfed crop – with WD above 400 mm.

## 4.3 Climatic Characterization of Haiti

The climate characterization of Haiti will be presented in the following topics. To characterize the climate of the country, maps of annual average temperature (Ta), temperature of the coldest month (Tf), mean annual rainfall (R), potential evapotranspiration (ETP), actual evapotranspiration (ETR), water deficiency (WD), and water surplus (WS) are presented.

The climate of Haiti depends on season, terrain and location. The lowland areas of Haiti have a tropical climate. The annual average temperature along the coasts is always above 25℃ (Figure 28). Very little variation between summer and winter are observed. The temperatures of the coldest months are presented in, where it is possible to see that average temperature is greater than 20℃ in the majority of the country. The mountains are significantly cooler (between 15 and 20℃) and routinely experience frost during the winter months, in the highest points.

Potential evapotranspiration follows the same pattern of temperature, accumulating from less than 1,000 mm per year in the high mountains to more than 1,600 mm in the low land areas (Figure 30).

Most rainfall occurs between April and November, but there is variation among different regions. Heavier rainfall occurs in the southern peninsula and in the northern plains and mountains (Figure 31). Rainfall decreases from east to west across the northern peninsula. The eastern central region receives a moderate amount of precipitation, while the western coast from the northern peninsula to Port-au-Prince, the capital, is relatively dry. Hurricanes with torrential rain and destructive wind are a threat in the late summer and fall, making Haiti particularly susceptible to flooding, mainly because of large-scale deforestation. Without trees to slow or stop rainfall, the water runs over the sun-baked ground, filling low spots.

In function of the irregular rainfall distribution in the country throughout the year, the actual evapotranspiration is decrease in relation to ETP, and ranges from 600-800 mm in the dry areas and high mountains to around 1,200 mm in the wettest regions of the country (Figure 32). The variation in rainfall and ETR is also observed for the water balance variables. Annual water deficiency varies significantly (Figure 33). It ranges from 0 to 100 mm in the upper lands, where rainfall is heavier. On the other hand, in the dry low lands it can achieve more that 1,000 mm. The opposite is observed for water surplus (Figure 34), with higher values in the upper lands and smaller values in the dry valleys.

**Figure 28**
**Map of annual average air temperature for Haiti.**

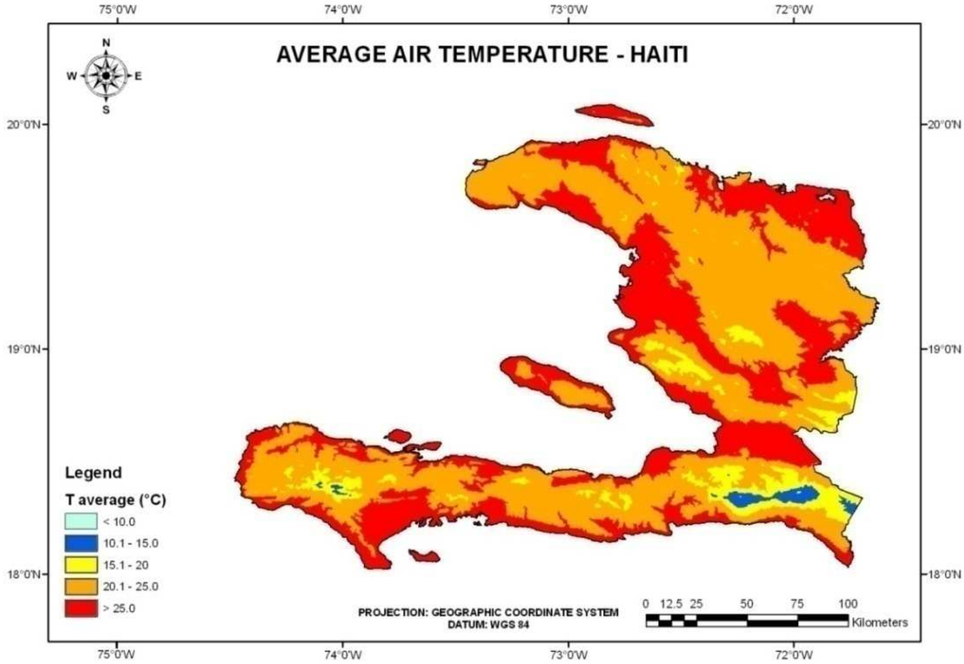



**Figure 29**
**Map of average temperature of the coldest month for Haiti.**

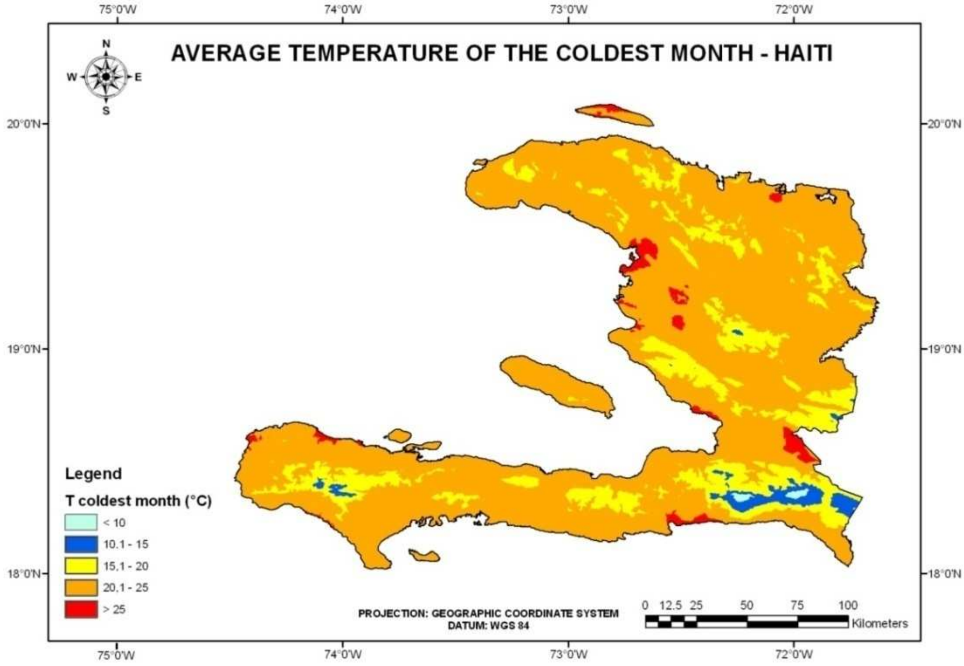


**Figure 30**
**Map of annual potential evapotranspiration for Haiti.**

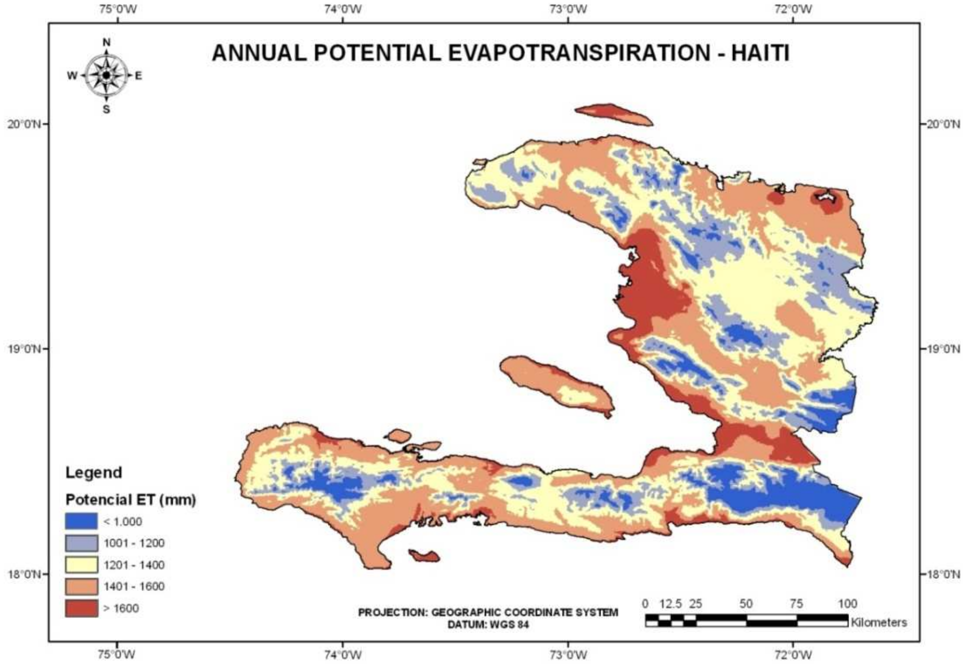



**Figure 31**
**Map of mean annual rainfall for Haiti.**

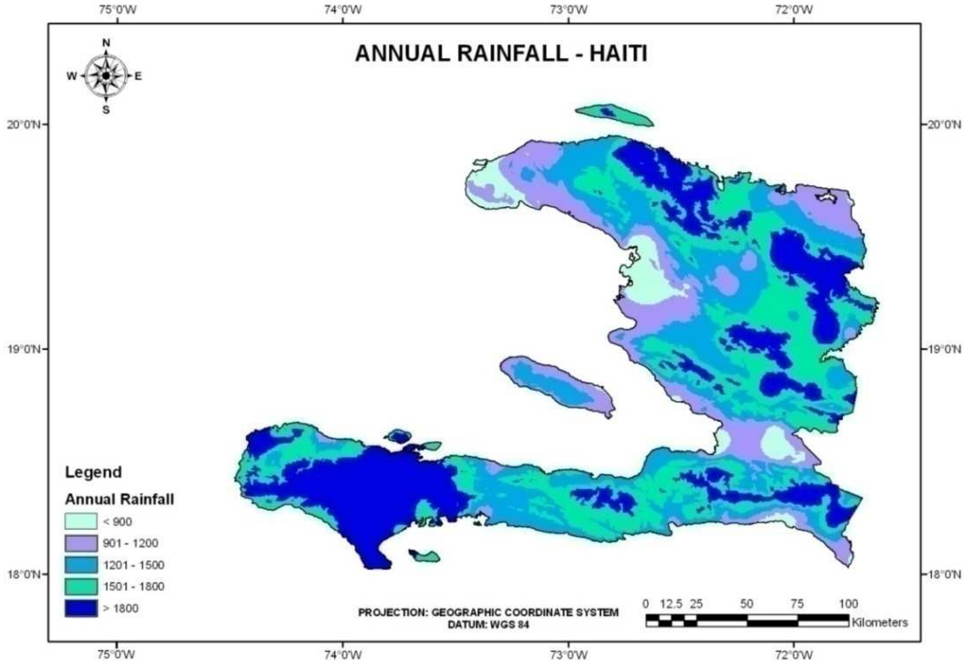


**Figure 32**
**Map of annual actual evapotranspiration for Haiti.**

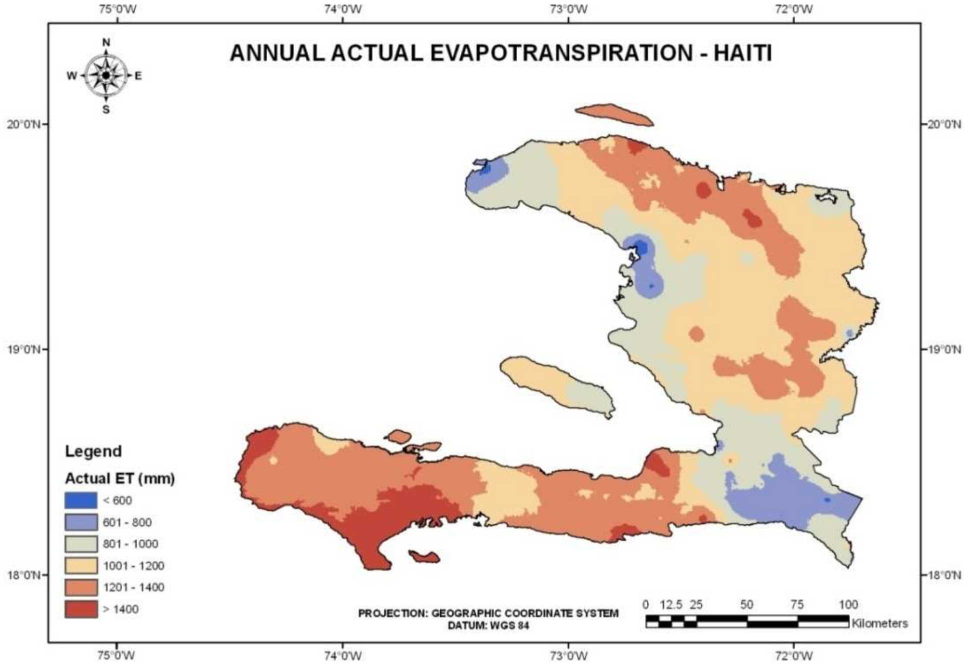



**Figure 33**
**Map of annual water deficiency, considering a soil water holding capacity of 125 mm, for Haiti.**

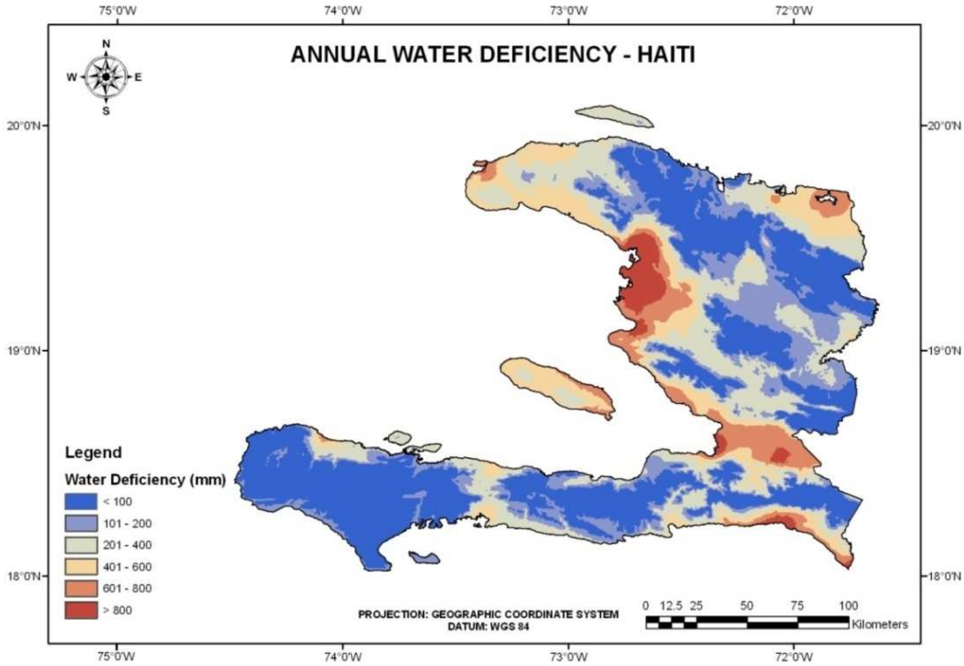
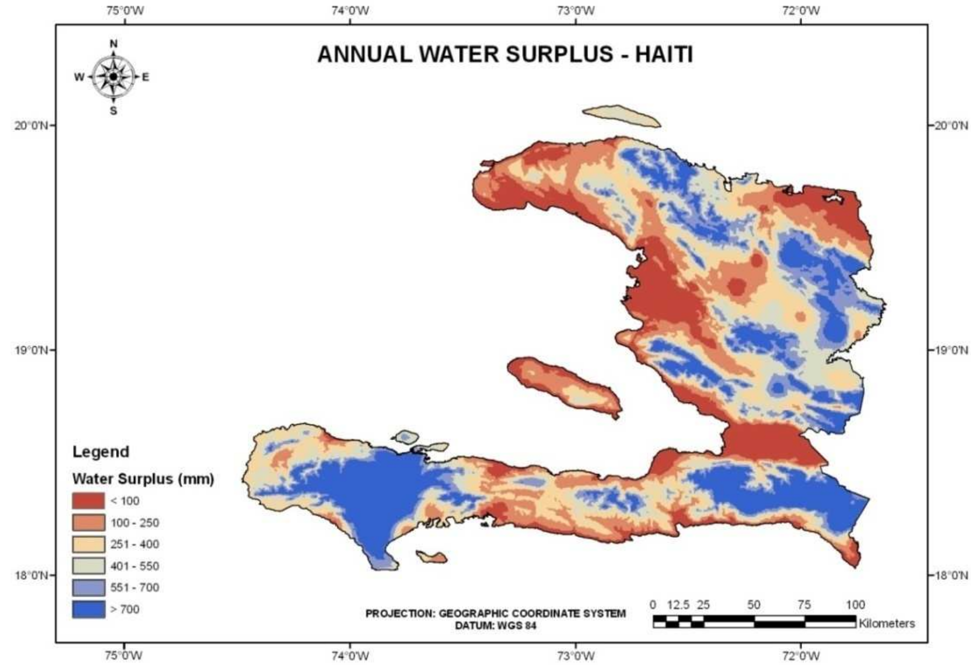


**Figure 34**
**Map of annual water surplus, considering a soil water holding capacity of 125 mm, for Haiti.**

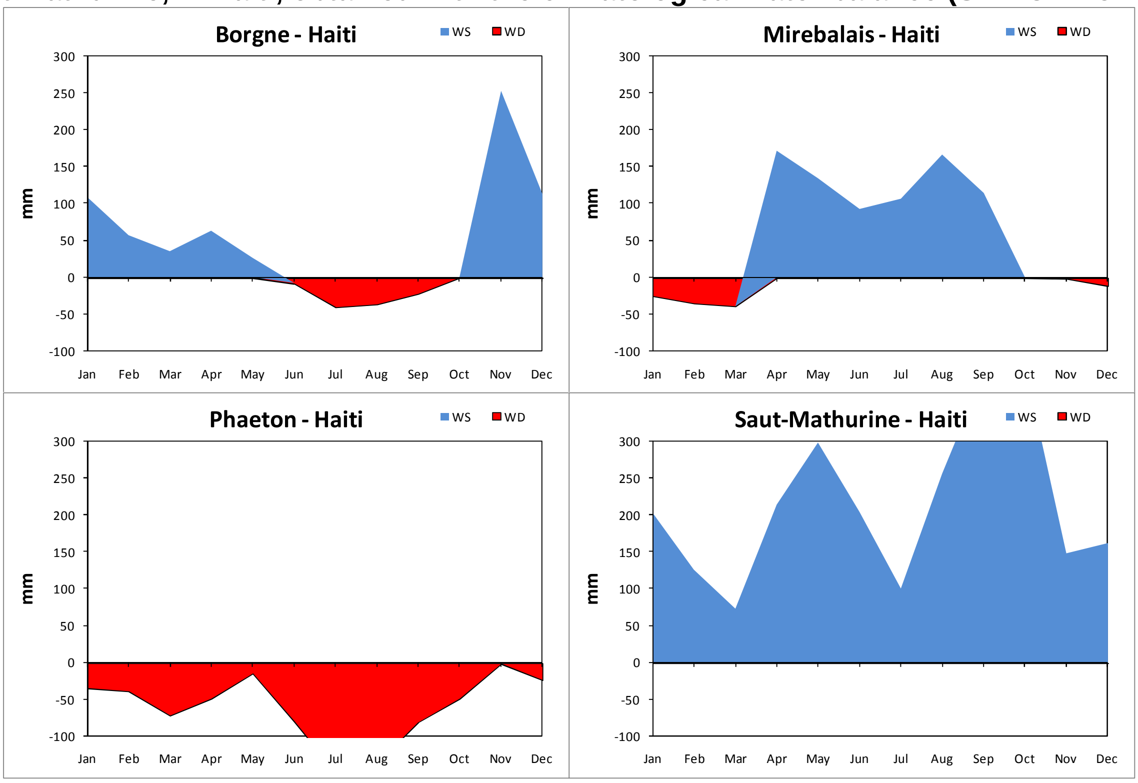



The seasonality and variability of the water availability, expressed by water deficiency (WD) and water surplus (WS) data in different regions of the country are presented in the Figure 35. In Haiti, there is a considerable variation in the climates across the country, as can be seen in the graphs of WD and WS for Borgne, Mirebalais, Phaeton and Saut-Mathurine (Figure 35).

In Borgne, the climate is humid, with a wet season (WS = 656 mm) from November to May and a dry season (WD = 108 mm) from June to October. In Mirebalais, the climate is also classified as humid, however the wet season (WS = 789 mm) goes from April to September and dry season (WD = 111 mm) from October to March. In Phaeton, located in the dry lowland region, the climate is semi-arid, with the dry season lasting all year long, accumulating a WD of 720 mm. On the other hand, in Saut-Mathurine, in the very high mountains of the southern peninsula, the climate is super-humid, with WS in all months, totaling more than 2,000 mm.

These places are an example of how the climate spatial and temporal variability are in Haiti, which will influence the agricultural activities. Humid climates, alternating wet and dry seasons, are normally suitable for the majority of crops, under the climatic point of view. However, super-humid or semi-arid climates used to be marginal to unsuitable. Under super-humid conditions the lack of a dry season lead to problems regarding crop maturation process as well as favoring the occurrence of plant diseases. On the other hand, under semi-arid conditions irrigation will be required, which will be just possible if a water source is available.

**Figure 35**
**Average water deficiency (WD) and water surplus (WS) for Borgne, Mirebalais, Phaeton and Saut-Mathurine, in Haiti, obtained with the climatological water balance (SWHC=125 mm).**




## 4.4 Agroclimatic Crop Zoning

After the agroclimatic zoning of **Haiti**, this chapter presents agroclimatic zoning by the type of crop. From a comparison of the two zonings, it is possible to obtain a more precise position concerning the regions suitable for biofuel feedstock crops.

### 4.4.1 Sugarcane

According to FAO (2007), most of the rainfed and irrigated commercial sugarcane (*Saccharum officinarum* L.) is grown between 35°N and S of the equator. The crop flourishes under a long, warm growing season with a high incidence of radiation and adequate moisture, followed by a dry, sunny and fairly cool but frost-free ripening and harvesting period.

A long growing season is essential for high yields. The normal length of the total growing period varies between 9 months with harvest before winter to 24 months in Hawaii, but it is generally 12 to 16 months. Plant (first) crop is normally followed by 2 to 6 ratoon crops, and in certain cases up to a maximum of 10 crops are taken, each taking about 1 year to mature. Growth of the stool is slow at first, gradually increasing until the maximum growth rate is reached after which the growth rhythm slows down as the cane begins to ripen and mature. The flowering of sugarcane is controlled by daylength, but it is also influenced by temperature and water and nitrogen supply. Flowering has a progressive deleterious effect on sucrose content, so non-flowering varieties are recommended.

In Haiti, temperature conditions are widely favorable for sugarcane growth and development. Just in the high lands in the center, southeast and southern peninsula of the country, temperatures are below 18$^{o}$C, unfavorable for sugarcane production (Figure 36).

Considering the limitations for sugarcane production related to water deficiency (Figure 37), a great part of Haiti's lands is favorable for rainfed crop, mainly in the high lands of the center-north and southern peninsula, where WD is below 200 mm per year. In the middle lands, where rainfall is lower than in high lands and ETP is higher, WD increases staying between 201 and 400 mm, being marginal for rainfed sugarcane but suitable with irrigation. In the low lands, mainly in the west coast, where the rainfall is between 900 and 1,200 mm and ETP is above 1,600 mm per year, conditions are unsuitable for rainfed sugarcane. However, with full irrigation the crop could be grown with success, since enough water could be available for that.

Overlapping now temperature and water deficiencies maps (Figure 38), the country can be divided in 7 zones of aptitude for sugarcane production. The largest zone, with a little more than 31% of the country (8,427 ha), is favorable for sugarcane production with any kind of climate restriction (Table 19). This region is concentrated in middle-high lands in the center-north and southern peninsula. Great part of the country (65.4% or 17,650 ha) presents some kind of restriction for sugarcane production, being considered as marginal. Around 44% of the country (11,840 ha) has water deficiency as the main restriction. In these areas irrigation could be used to avoid damages to the crop. In 21.6% of the country (5,830 ha), supplementary irrigation would be enough, whereas in 22.1% of the country (5,966 ha), sugarcane just could be cultivated with full irrigation.

In the other places (21.7% or 5,876 ha), the limitations are related to thermal insufficiency or lack of a dry season for maturation process. Just 3.3% of the country (891 ha) are totally unsuitable for sugarcane production, because thermal deficiency (risk of frosts), since this lands correspond to the top of the high mountains.

**Figure 36**
**Map of average temperature zones for sugarcane in Haiti.**

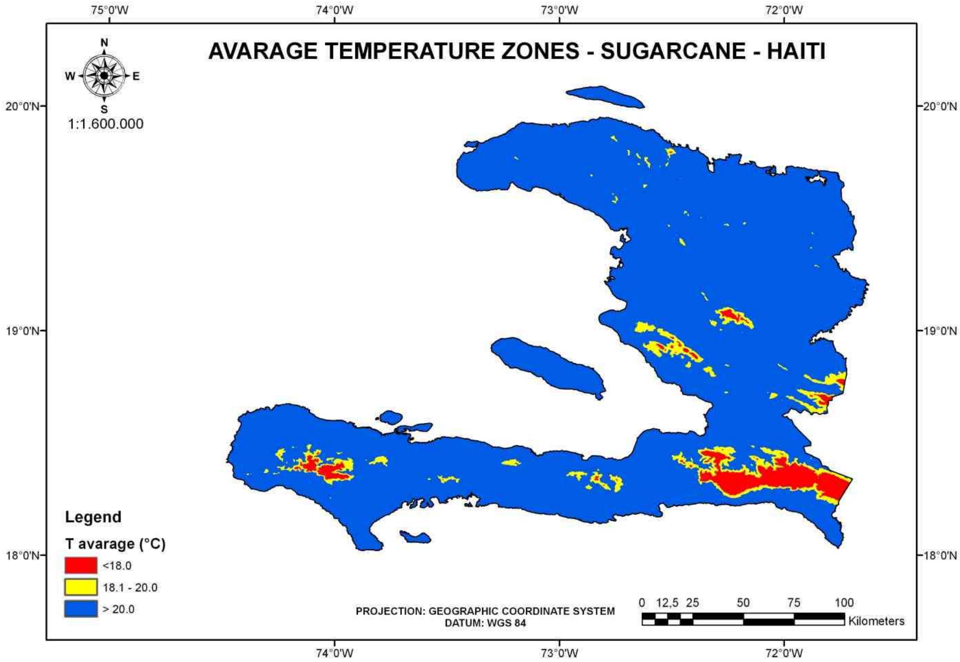


**Figure 37**
**Map of water deficiency zones for sugarcane, considering a soil water holding capacity of 125 mm, in Haiti.**

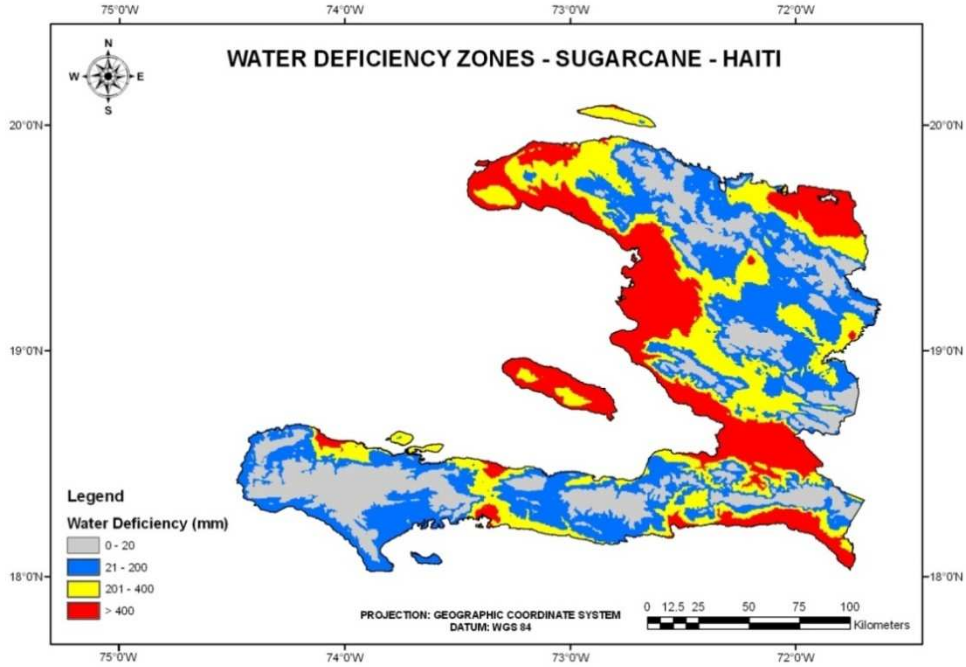



**Figure 38**
**Agroclimatic zoning for sugarcane in Haiti.**

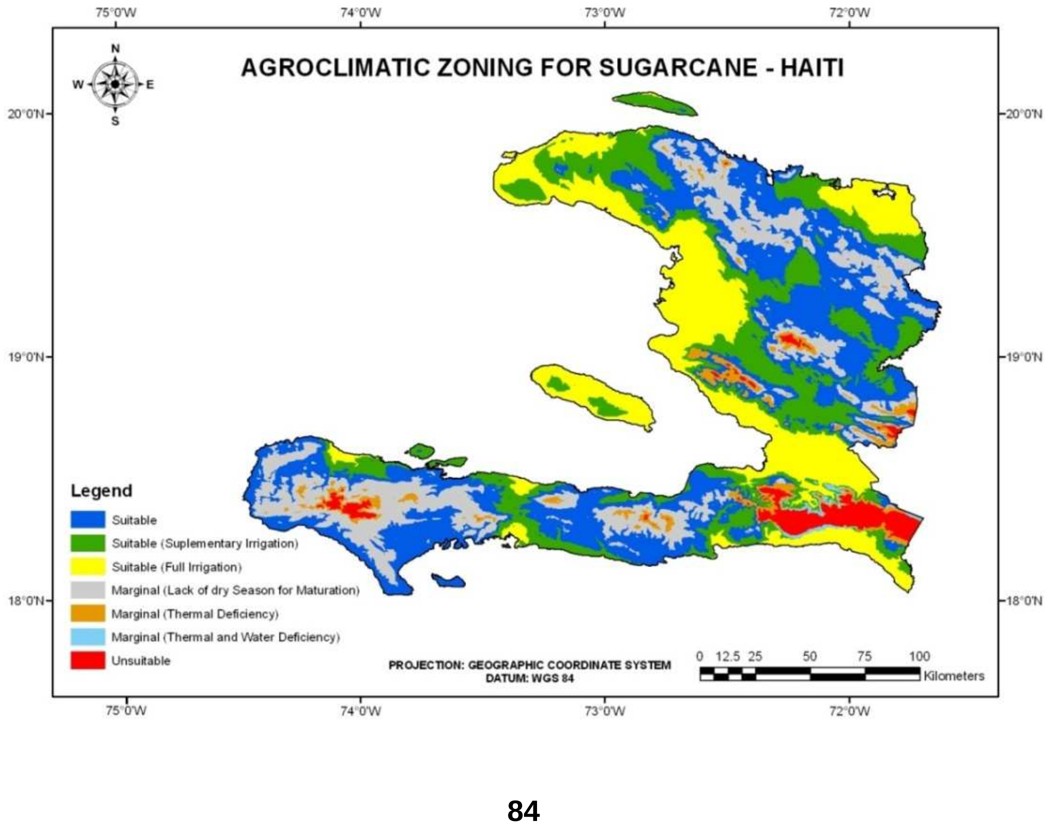


**Table 19**
**Aptitude categories for sugarcane in Haiti with their respective areas.**

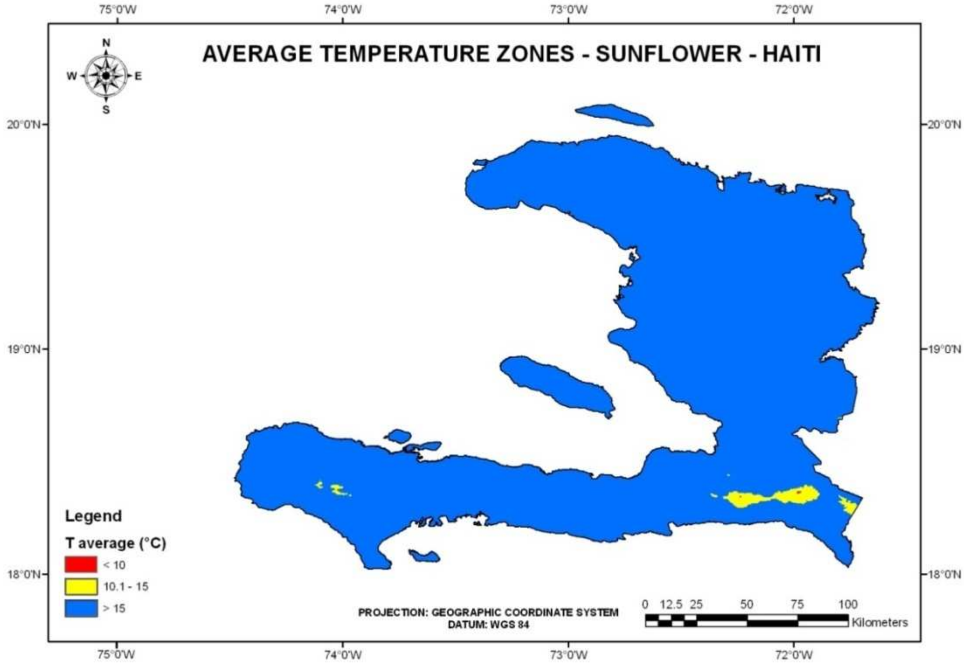
| Categories | Area (ha) | % |
|---|---|---|
| Suitable (Rainfed) | 842,764.6 | 31.25 |
| Suitable (Supplementary Irrigation) | 582,988.2 | 21.62 |
| Suitable (Full Irrigation) | 596,598.4 | 22.12 |
| Marginal (Lack of Dry Season of Maturation) | 471,332.3 | 17.48 |
| Marginal (Thermal Deficiency) | 99,565.7 | 3.69 |
| Marginal (Water and Thermal Deficiency) | 14,518.4 | 0.54 |
| Unsuitable | 89,137.8 | 3.31 |
| **Total** | **2,696,905.4** | **100** |

## 4.4.2 Sunflower

Sunflower (Helianthus annuus) originates from central and north America. Lately its importance as an oil crop has grown and at present it is tile second most important oil crop next to soybean. Total annual world production is some 31.3 million tons of seed from some 23.7 million ha (FAO, 2006).
Sunflower is grown in climates ranging from arid under irrigation to temperate under rainfed conditions, but is susceptible to frost. Mean daily temperatures for good growth are between 18 and 25℃. The total growing period varies from 7 0 days in parts of Russia where the season is short to 200 days at higher altitudes in Mexico. In the subtropics under irrigation the total growing period is about 130 days. For temperate climates the optimum planting date for early as well as late maturing varieties is between late spring and early summer. Delay in planting results in shortening of the vegetative period and early maturity, causing a decrease in head diameter and seed weight. Sunflower is a short-day plant with a variable response to daylength, but day-neutral varieties exist. In the tropics, planting date can vary, but normally follows the rainy season. In some areas of South America, sunflower is cultivates in two different seasons, being one during the summer and other during the fall.

Haiti presents few limitations for sunflower crop growth and development considering temperature conditions (Figure 39). Just few areas localized in high altitudes in the mountains of the south of the country and at southern peninsula are considered as marginal, with annual average temperature below 15℃, or inapt, with average temp erature below 10℃. The great majority of the lands have Ta above 15℃, which make conditions wid ely favorable to this crop.

**Figure 39**
**Map of average temperature zones for sunflower in Haiti.**




The same can be considered for limitations related to water surplus (Figure 40), which is an index to represent the length of the wet season. Great part of the country, represented by the high lands, has a very long wet season (WS > 400 mm), which results in problems for maturation process and favorability for plant diseases occurrence, like alternaria leaf blight, rusts, downy mildew, among others, limiting sunflower growth. In the middle lands, WS is between 100 and 400 mm, which is considered suitable for sunflower, since there is enough rainfall during the growing season allowing cultivation under rainfed conditions. Where WS is between 50 and 100 mm conditions for sunflower are just marginal, with risk of losses due to water deficiencies during some years. For places in the low land areas, where WS is below 50 mm, sunflower crop is considered unsuitable.

In relation to the aptitude zones for sunflower in Haiti, the country is divided in 5 zones (Figure 41 and Table 20). Just a very small area of the country (1.1% or 293.6 ha) is considered unsuitable, whereas the great majority, 53.5% or 14,430 ha, is marginal for some reason (thermal or water deficiencies or excess of humidity). The suitable land for sunflower in Haiti represents 36.3 % of the country, with a total area of 9,778.6 ha, located mainly in the middle lands of the center-north and in the southern peninsula, where temperature, length of the wet season, and the occurrence of a dry period at the maturation are favorable for a successful production.

**Figure 40**
**Map of water surplus zones for sunflower, considering soil water holding capacity of 125 mm, in Haiti.**

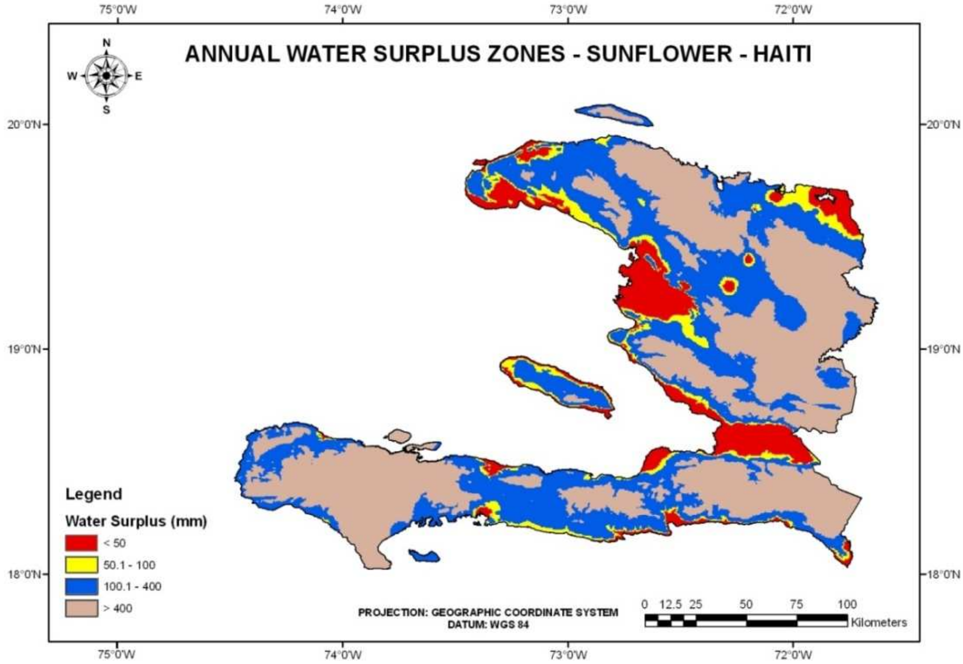



**Figure 41**
**Agroclimatic zoning for sunflower in Haiti.**

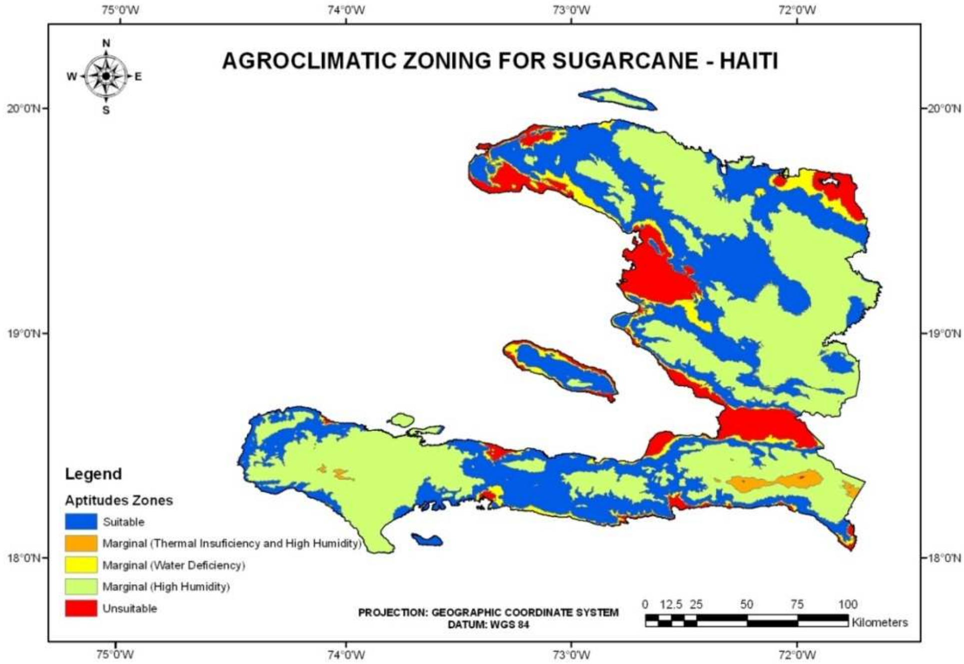


**Table 20**
**Aptitude categories for sunflower in Haiti with their respective areas.**

| Categories | Area (ha) | % |
|---|---|---|
| Suitable | 276,017.3 | 10.24 |
| Marginal (Water Deficiency) | 154,255.9 | 5.72 |
| Marginal (High Humidity) | 977,852.8 | 36.25 |
| Marginal (High Humid and Thermal Deficiency) | 1,259,425.0 | 46.7 |
| Unsuitable | 29,354.4 | 1.09 |
| **Total** | **2,696,905.4** | **100** |

### 4.4.3 Eucalyptus

Eucalyptus comprises over 700 species, and accounts for more than two-thirds of Australia's vegetation. They populate almost every habitat, from high snowy mountains to arid deserts to tropical rainforests. Their range extends from sub-alpine areas to wet coastal forests, temperate woodlands and the arid inland. In fact, the only major environment where eucalypts are absent is probably rainforest.

Eucalyptus have proven to be reliable and adaptable over a wide range of environments (Jovanovic et al., 2000), but consideration needs to be given to the natural environment and climate of the species. If this is vastly different to that of the local environment, alternative selections may be more satisfactory, mainly in relation to climate and soil conditions.

Considering the huge diversity of eucalyptus species, this crop is can be grown in different climate conditions, from tropical to temperate and from wet to dry climates. The agroclimatic zoning for eucalyptus confirms the previous statement. In Haiti, in general, climate is not restrictive for this crop (Figure 42 and Figure 43). As shown on Figure 44, not all Haiti eucalyptus can be cultivated as commercial crops with any restriction. However, the species chosen to be cultivated in each region of the country will be influenced by climate conditions. So, the selection of a species must be based on their climate requirements. According to Table 21, in Haiti 57.6% of the area (15,531 ha) is recommended for species of Group 1 (E. camaldulensis, E. deglupta, E. robusta, E. tereticornis, E. urophylla), which corresponds to species adapted to humid and hot climates. The other areas are recommended for Group 3 (19.5% or 5,247 ha), Group 4 (14.1% or 3,815 ha), and Group 5 (8.8% or 2,376 ha), which corresponds respectively to sub-humid/humid, sub-humid/dry, and semi-arid climates.

**Figure 42**
**Map of potential evapotranspiration zones for eucalyptus in Haiti.**

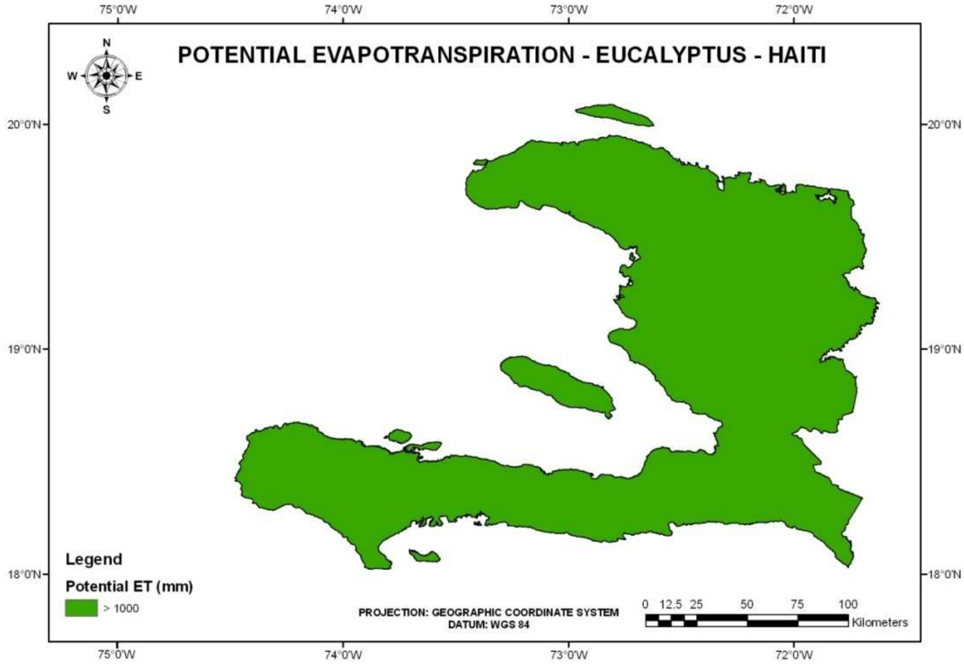



**Figure 43**
**Map of humidity index zones for eucalyptus in Haiti.**

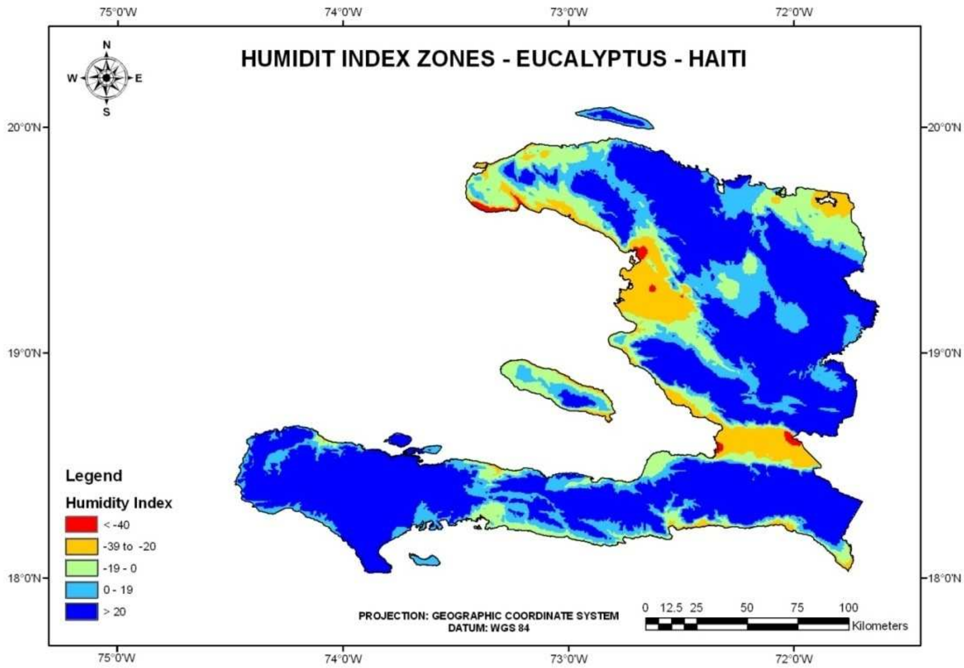


**Figure 44**
**Agroclimatic zoning for eucalyptus in Haiti, considering four different groups of species adaptable for different climate conditions.**

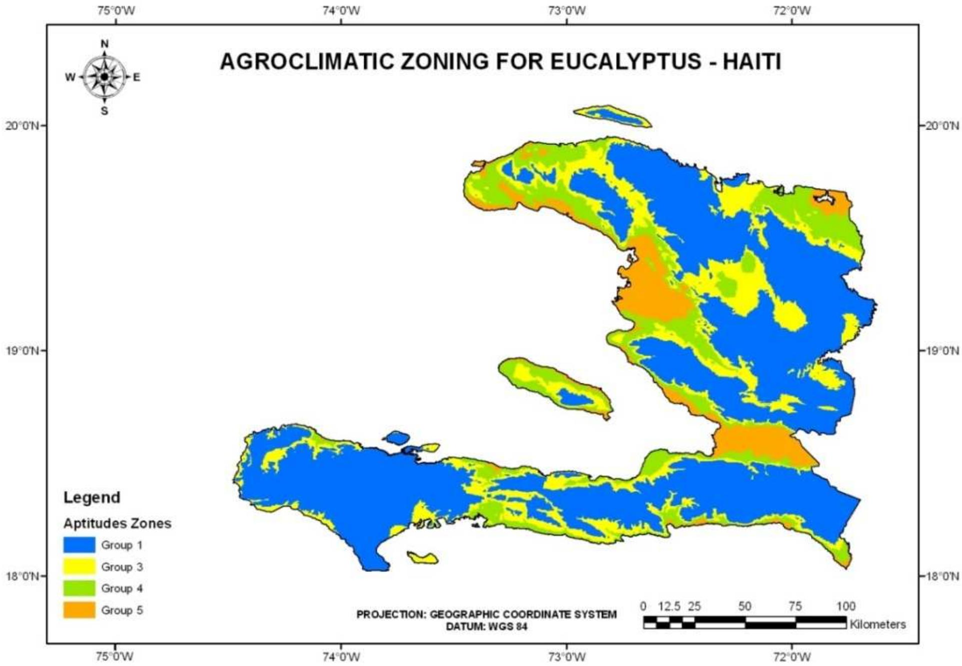



**Table 21**
**Suitable groups of species of eucalyptus for Haiti with their respective areas.**

| Species Group | Area (ha) | % |
|---|---|---|
| 1 | 1,553,105.8 | 57.59 |
| 2 | 524,704.0 | 19.46 |
| 4 | 381,507.6 | 14.15 |
| 5 | 237,588.0 | 8.80 |
| **Total** | **2,696,905.4** | **100** |

## 4.4.4 Jatropha

Jatropha (*Jatropha curcas*) is originated in the Caribbean. It is a drought-resistant perennial plant, growing well in marginal soils. Easy to establish, grows relatively quickly and lives producing seeds for 40-50 years. Jatropha plant produces seeds with about 35% oil content[23].

Jatropha was identified to be a more viable source of biodiesel due to the following aspects:

[23] Estimativas Preliminares

- It can be planted in idle lands not suited for any other food crops. It is reported to grow even in marginal soils and tolerate drought or rainfall as low as 600 mm per year;

- It can flower and bear fruits as early six months after planting for those planted from cuttings and eight months if the plants are from seedlings;

- It is a perennial shrub which can reach up to five meters but can be managed to reach only two meters for easy harvesting; and

- It can produce about 600 kg/ha during the first year and up to as much as 5,000 kg in the third year. In good soil and management, yield could reach as much as 10 t/ha.

As jatropha is originated from Caribbean, the climate of Haiti is normally favorable for this crop. According to Figure 45 and Figure 46, temperature and rainfall conditions in Haiti are totally favorable for jatropha in the great majority of the areas. Just in very few areas where temperature is below 18$^o$C, there is thermal insufficiency, which is not totally restrictive for this crop, since it can tolerate light frosts. Based on this information, 87% of the country is considered suitable for jatropha cultivation under rainfed condition (Figure 47 and Table 22).

**Figure 45**
**Map of average temperature zones for *Jatropha curcas* in Haiti.**

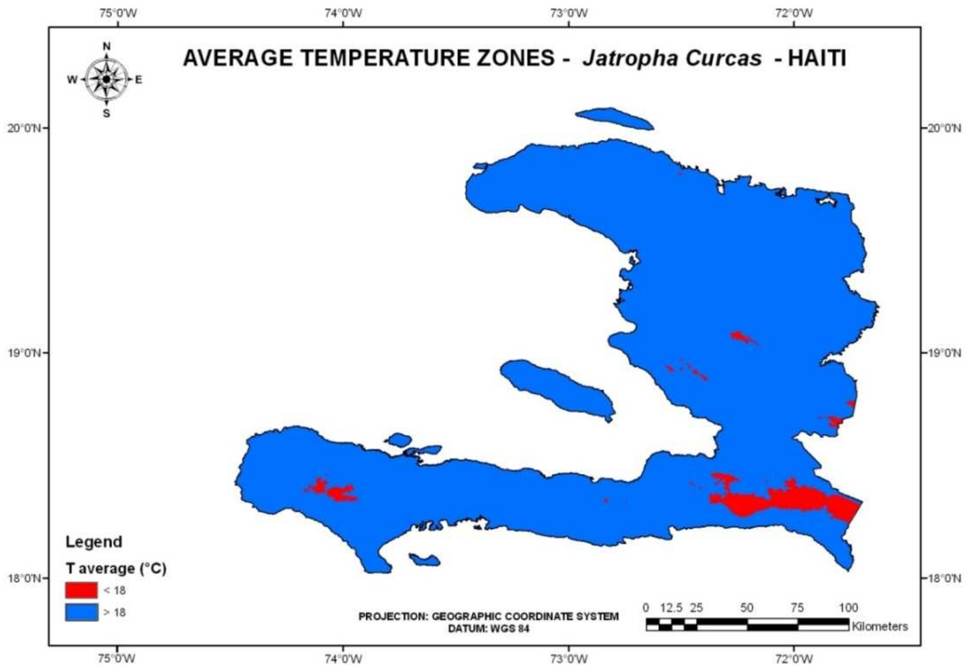


**Figure 46**
**Map of annual rainfall zones for *Jatropha curcas* in Haiti.**

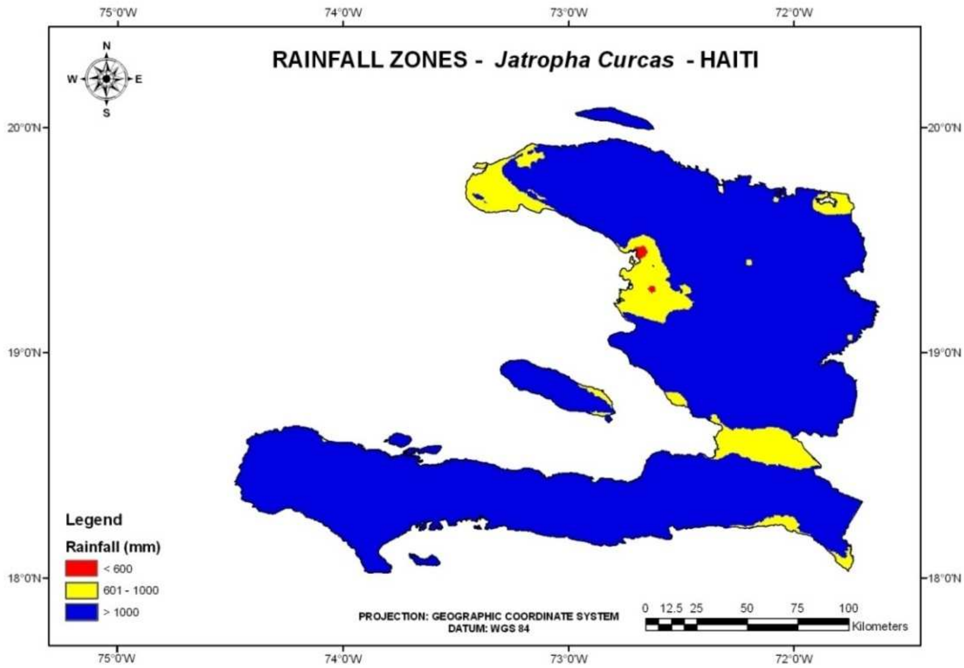



**Figure 47**
**Agroclimatic zoning for *Jatropha curcas* in Haiti.**

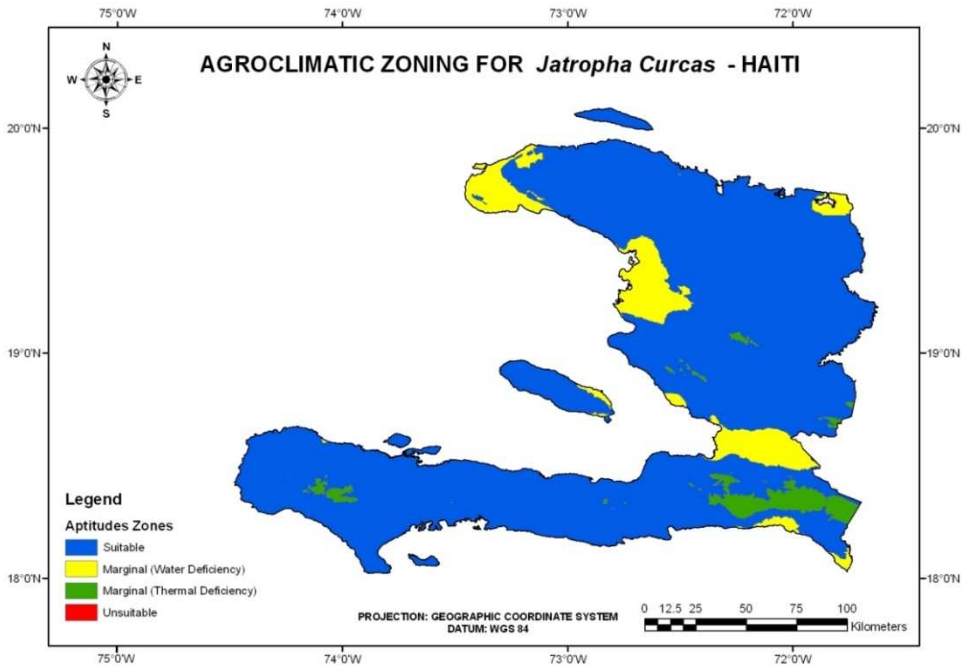


**Table 22**
**Zones of climatic aptitude for *Jatropha curcas* in Haiti with their respective areas.**

| Categories | Area (ha) | % |
|---|---|---|
| Suitable | 2,351,843.7 | 87.21 |
| Marginal (Water Deficiency) | 255,924.5 | 9.49 |
| Marginal (Thermal Deficiency) | 89,031.9 | 3.3 |
| Unsuitable | 105.4 | 0.004 |
| **Total** | **2,696,905.4** | **100** |

## 4.4.5 Elephant Grass

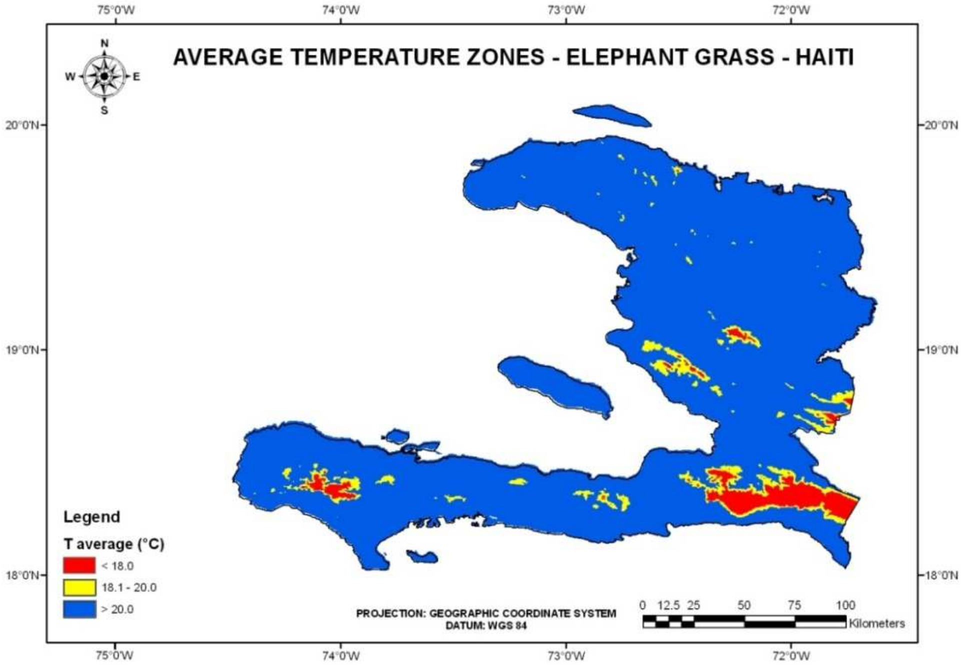
Elephant grass, also known as Napier Grass, is a species of grass native of the tropical grasslands of Africa. It is a tall perennial plant, growing to 2-4.5 m, with razor-sharp leaves 30–120 cm long and 1–5 cm broad. It has a very high productivity, both as a forage grass for livestock and as a biofuel crop. The name elephant grass derives from it being a favorite food of elephants.

Elephant grass gives heavy yields. A record of productivity was established in 1959, when 84,800 kg of dry matter (DM) per ha per year was achieved when it was fertilized with 897 kg N/ha per year and cut every 90 days under natural rainfall of some 2,000 mm per year. Other recorded yields are 35,500 kg DM/ha per year over three years in Tobago, 32,400 kg DM per hectare per year when cut every 56 days at CIAT, Colombia, 20,800 kg DM/ha per year in Nigeria and 40,000-50,000 kg green matter per hectare when cut each 35-40 days at the Tulio Ospina Station, Colombia.

The optimum temperature for elephant grass growth is usually between 25-40℃, whereas the minimum temperature is 14℃, since the crop is susc eptible to frosts. Normally, it is cultivated between 30°N and 30°S of latitude and between sea-l evel and 2,000 m. Elephant grass grows best in high-rainfall areas (in excess of 1,500 mm per year), but its deep root system allows it to survive during short dry periods, mainly because of its deep root system.

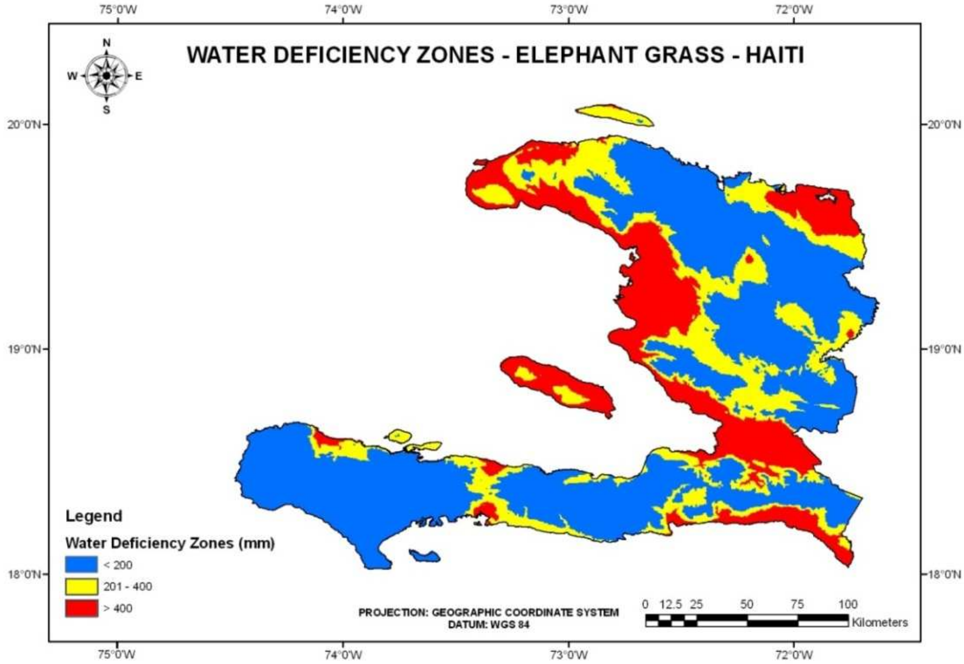
Based on the information above, Figure 48 shows that there are very few thermal limitations for elephant grass cultivation in Haiti. Just small areas in the high mountains present thermal restrictions.

**Figure 48**
**Map of average temperature zones for elephant grass in Haiti.**




The crop is suitable only in the upper lands Figure 49), where water deficiencies are less than 200 mm. In the middle lands, where WD varies between 200 and 400 mm per year, the crop is considered as marginal, since the intensity of the dry season can result in crop damage in some years. In the low lands, where there is less rainfall, ETP is higher, and water deficiency above 400 mm per year is totally unfavorable for rainfed crop, making these regions unsuitable for elephant grass.

**Figure 49**
**Map of water deficiency zones for elephant grass, considering a soil water holding capacity of 125 mm, in Haiti.**




In relation to the aptitude zones for elephant grass in Haiti, the country is divided in 6 zones (Figure 50 and Table 23). Around 25% of the country (6,800 ha) is unsuitable due to water and/or thermal restrictions, whereas 26% of the territory is considered to be marginal for elephant grass cultivation because of water and/or thermal insufficiency. However, almost 49% of the country, which corresponds to more than 13,000 ha, is considered totally suitable for this crop, considering climatic aspects.

**Figure 50**
**Agroclimatic zoning for elephant grass in Haiti.**

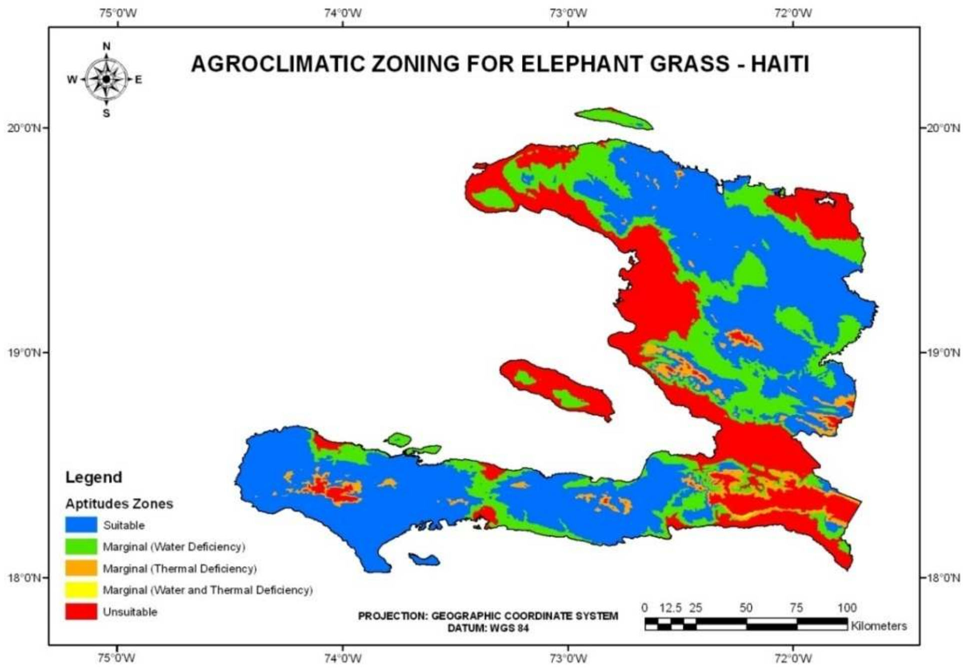



**Table 23**
**Zones of climatic aptitude for elephant grass in Haiti with their respective areas.**

| Categories | Area (ha) | % |
|---|---|---|
| Suitable | 1,315,604.6 | 48.78 |
| Marginal (Water Deficiency) | 582,268.7 | 21.59 |
| Marginal (Thermal Deficiency) | 114,004.2 | 4.23 |
| Marginal (Water and Thermal Deficiency) | 1,394.5 | 0.05 |
| Unsuitable | 683,633.5 | 23.35 |
| **Total** | **2,696,905.4** | **100** |

## 4.5 Considerations on agroclimatic zoning

The present report brings a detailed study about biofuel crops climatic suitability in Haiti. Five crops (sugarcane, sunflower, eucalyptus, jatropha and elephant grass) were assessed and maps of the climatic parameters and suitability were made.

The results from the agroclimatic zoning for these crops indicate the areas where they can be cultivated under a very low climatic risk or where marginal conditions, due to thermal or water restrictions, make the risk a little higher.

Haiti is climatically suitable for all these crops, although it is more suitable for jatropha than for any other crop analyzed.

Even considering the usefulness of agroclimatic zoning for biofuel crops for crop planning and strategic support, some of the results presented in this report must be used with caution, since for some crops, like jatropha and elephant grass, there are no established climatic parameters for elaborating a crop zoning. In these specific cases, the information presented by this report gives only a first approach on which could be the suitable zones for these crops. Therefore, more studies and analysis are required to have more specific information and a better knowledge about the crop and the zones with suitable climatic characteristics for its cultivation.

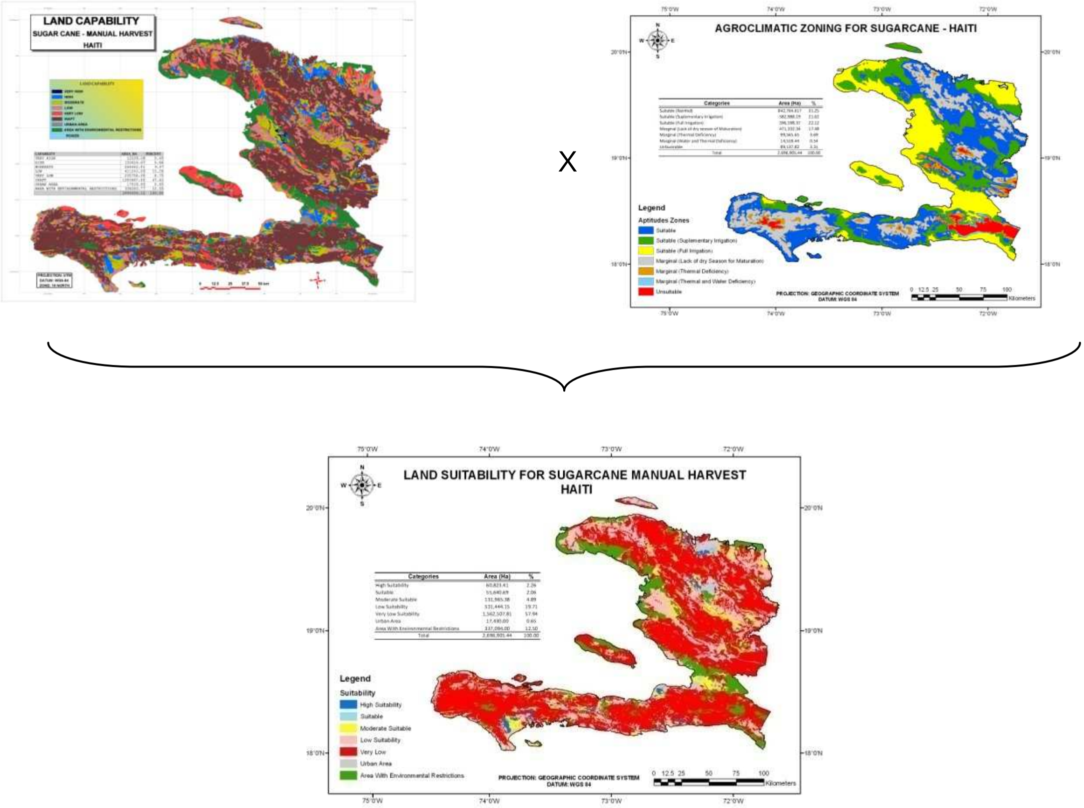
# 5. Land suitability

Land suitability is defined, in this project, as the result of the combination of the land capability and agroclimatic zoning maps. The combination of these levels of information summarizes the most important land and climatic variables that affect land uses in different locations into one classification system. This simplification of information into well defined classes is important for land planners to assess the suitability of the land for different uses. As for land capability, land suitability assessment was done on a qualitative base.

The matching between the land capability information and the agroclimatic zoning was done using decision trees in which the combined data was classified into six suitability classes. These classes were named as follows: high suitability (HS) for excellent land capability and climatic conditions, suitable (S) for good land capability and climatic conditions, moderate suitability (MS) for medium land capability and climatic conditions, low suitability (LS) for poor land capability and climatic conditions, and very low suitability (US) for totally inapt conditions of land capability and climate. During the classification of these classes not always land capability and climate qualifications coincided. In some cases where the land capability or the climate were extremely limiting even though the other pair in the matching process was excellent or good, the suitability class could be considered low or unsuitable.

Figure 51 illustrates the matching process between the land capability data and the agroclimatic zoning.

**Figure 51**
**Map matching process for the generation of a land suitability map.**




Example: Land suitability for manually harvested sugarcane in Haiti

## 5.1 Land Suitability for biofuel crops

In this section we will present the results of the data matching process explained in the previous section where the land suitability classes were defined. Land suitability was defined for each of the evaluated biofuel crops (sugarcane, sunflower, eucalyptus, jatropha and elephant grass) in Haiti. Sugarcane class was subdivided into manually harvested and mechanically harvested subclasses. This was done to help future decision making concerning what type of sugarcane harvesting system should be eventually implemented in this country. The choice should be made between a labor intensive system with environmental restrictions (manual harvest), and a high technological system with low labor demand, which is environmentally friendly (mechanical harvest).

### 5.1.1 Sugarcane

Table 24 presents the decision key for defining the suitability classes of sugarcane harvested manually and mechanically. The six land capability classes were defined in section 0. Seven agroclimatic classes for sugarcane were: suitable (rainfed), suitable (supplementary irrigation), suitable (full irrigation), marginal (water and thermal deficiency), marginal (thermal deficiency), marginal (lack of dry season for maturation) and unfavorable.

**Table 24**
**Land suitability definition for sugarcane manually and mechanically harvested.**

| Soil Categories | Climate Categories | Climate x Soil | Land Suitability |
|---|---|---|---|
| VERY HIGH | MARGINAL (WATER AND THERMAL DEFICIENCY) | WTD/VH | US |
| VERY HIGH | MARGINAL (LACK OF DRY SEASON MATURATION) | LDSM/VH | LS |
| VERY HIGH | SUITABLE (FULL IRRIGATION) | FI/VH | MS |
| VERY HIGH | SUITABLE (SUPLEMENTARY IRRIGATION) | SI/VH | S |
| VERY HIGH | SUITABLE | S/VH | HS |
| VERY HIGH | MARGINAL (THERMAL DEFICIENCY) | TD/VH | US |
| VERY HIGH | UNFAVORABLE | UN/VH | US |
| HIGH | MARGINAL (WATER AND THERMAL DEFICIENCY) | WTD/H | US |
| HIGH | MARGINAL (LACK OF DRY SEASON MATURATION) | LDSM/H | LS |
| HIGH | SUITABLE (FULL IRRIGATION) | FI/H | LS |
| HIGH | SUITABLE (SUPLEMENTARY IRRIGATION) | SI/H | LS |
| HIGH | SUITABLE | S/H | MS |
| HIGH | MARGINAL (THERMAL DEFICIENCY) | TD/H | US |
| HIGH | UNFAVORABLE | UN/H | US |
| MODERATE | MARGINAL (WATER AND THERMAL DEFICIENCY) | WTD/MD | US |
| MODERATE | MARGINAL (LACK OF DRY SEASON MATURATION) | LDSM/MD | US |
| MODERATE | SUITABLE (FULL IRRIGATION) | FI/MD | LS |
| MODERATE | SUITABLE (SUPLEMENTARY IRRIGATION) | SI/MD | LS |
| MODERATE | SUITABLE | S/MD | LS |
| MODERATE | MARGINAL (THERMAL DEFICIENCY) | TD/ MD | US |
| MODERATE | UNFAVORABLE | UN/ MD | US |
| LOW | MARGINAL (WATER AND THERMAL DEFICIENCY) | WTD/ L | US |
| LOW | MARGINAL (LACK OF DRY SEASON MATURATION) | LDSM/ L | US |
| LOW | SUITABLE (FULL IRRIGATION) | FI/L | US |
| LOW | SUITABLE (SUPLEMENTARY IRRIGATION) | SI/L | US |
| LOW | SUITABLE | S/L | LS |
| LOW | MARGINAL (THERMAL DEFICIENCY) | TD/L | US |
| LOW | UNFAVORABLE | UN/L | US |
| VERY LOW | MARGINAL (WATER AND THERMAL DEFICIENCY) | WTD/VL | US |
| VERY LOW | MARGINAL (LACK OF DRY SEASON MATURATION) | LDSM/VL | US |
| VERY LOW | SUITABLE (FULL IRRIGATION) | FI/VL | US |
| VERY LOW | SUITABLE (SUPLEMENTARY IRRIGATION) | SI/VL | US |
| VERY LOW | SUITABLE | S/VL | US |
| VERY LOW | MARGINAL (THERMAL DEFICIENCY) | TD/ VL | US |
| VERY LOW | UNFAVORABLE | UN/VL | US |
| INAPT | MARGINAL (WATER AND THERMAL DEFICIENCY) | WTD/IN | US |
| INAPT | MARGINAL (LACK OF DRY SEASON MATURATION) | LDSM/IN | US |
| INAPT | MARGINAL (WATER AND THERMAL DEFICIENCY) | WTD/IN | US |
| INAPT | MARGINAL (LACK OF DRY SEASON MATURATION) | LDSM/IN | LS |
| INAPT | SUITABLE (FULL IRRIGATION) | FI/IN | MS |
| INAPT | SUITABLE (SUPLEMENTARY IRRIGATION) | SI/IN | S |
| INAPT | SUITABLE | S/IN | HS |

Figure 52 and Table 25 show the distribution of the land suitability classes for manually harvested and Figure 53 and Table 26 for mechanically harvested sugarcane in Haiti. Large areas in Haiti have low to inapt land capabilities and demand intense irrigation to achieve some success. This explains the large low suitability and unsuitable areas on the map for this crop. 77.65% of the area of Haiti is occupied by low suitability and very low suitability areas for sugarcane. The larger area of unsuitable land for mechanically harvested sugarcane compared to manual harvest is due to the limitation in slope that the first type of harvest method requires. The high suitability, suitable and moderately suitable areas sum up to 9.21 % of the area or 248,438 ha.

**Figure 52**
**Land suitability map for sugarcane manual harvest.**

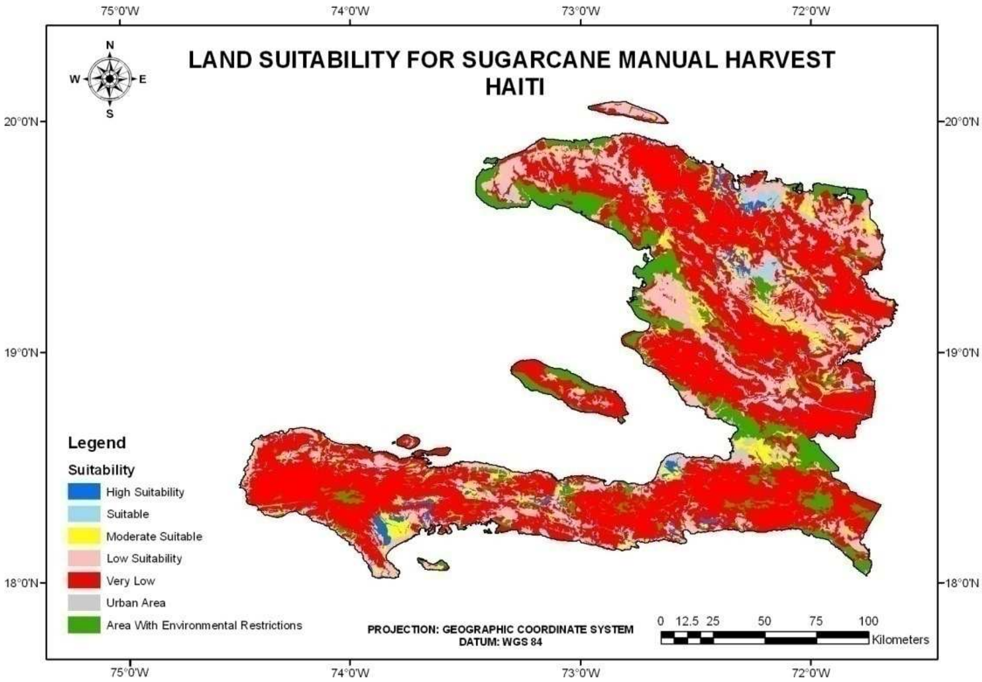



**Table 25**
**Area quantification for sugarcane manual harvest.**

| Categories | Area (ha) | % |
|---|---|---|
| High Suitability | 60,823.41 | 2.26 |
| Suitable | 55,640.69 | 2.06 |
| Moderate Suitable | 131,965.38 | 4.89 |
| Low Suitability | 531,444.15 | 19.71 |
| Very Low Suitability | 1,562,507.81 | 57.94 |
| Urban Area | 17,430.00 | 0.65 |
| Area With Environmental Restrictions | 337,094.00 | 12.50 |
| **Total** | 2,696,905.44 | 100.00 |

**Figure 53**
**Land suitability map for sugarcane mechanical harvest.**

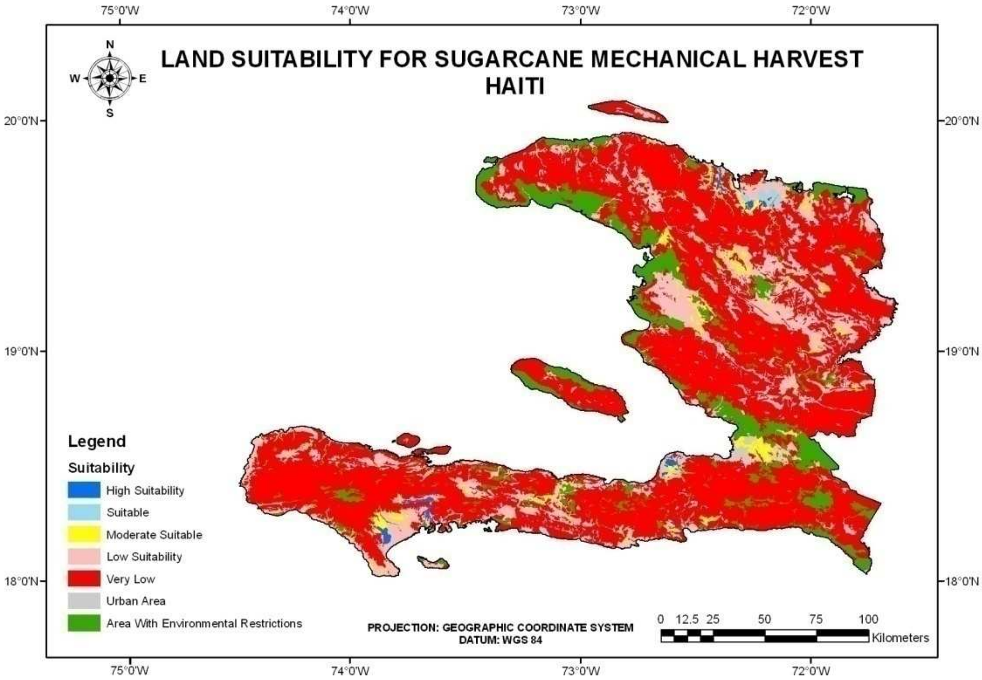



**Table 26**
**Area quantification for sugarcane mechanical harvest.**

| Categories | Area (ha) | % |
|---|---|---|
| High Suitability | 17,643.63 | 0.65 |
| Suitable | 17,093.34 | 0.63 |
| Moderate Suitable | 70,496.86 | 2.61 |
| Low Suitability | 491,327.06 | 18.22 |
| Very Low Suitability | 1,745,820.55 | 64.73 |
| Urban Area | 17,430.00 | 0.65 |
| Area With Environmental Restrictions | 337,094.00 | 12.50 |
| Total | 2,696,905.44 | 100.00 |

## 5.1.2 Sunflower

Table 27 presents the results of the matching between land capability data and agroclimatic zoning for this crop for Haiti. Five land capability classes were matched with five agroclimatic classes. The land capability and climatic classes were defined in previous reports.

Analyzing Table 27, we observe a great number of lines falling into the “unsuitable” class. These coincide with high land capability and/or climatic restrictions. If one of the base maps presented a high restriction in any class the land suitability class would be penalized because of this restriction.

**Table 27**
**Land suitability definition for sunflower in of Haiti.**

| Soild Categories | Climate Categories | Climate x soil | Land sustentability categories |
|---|---|---|---|
| VERY HIGH | UNFAVORABLE | UN/VH | US |
| VERY HIGH | MARGINAL (WATER DEFICIENCY) | WD/VH | MS |
| VERY HIGH | FAVORABLE | FA/VH | HS |
| VERY HIGH | MARGINAL (HIGH HUMIDITY) | HH/VH | MS |
| VERY HIGH | MARGINAL (THERMAL DEFICIENCY) | TD/VH | S |
| HIGH | UNFAVORABLE | UN/H | US |
| HIGH | MARGINAL (WATER DEFICIENCY) | WD/H | LS |
| HIGH | FAVORABLE | FA/H | S |
| HIGH | MARGINAL (HIGH HUMIDITY) | HH/H | MS |
| HIGH | MARGINAL (THERMAL DEFICIENCY) | TD/H | MS |
| MODERATE | UNFAVORABLE | UN/MD | US |
| MODERATE | MARGINAL (WATER DEFICIENCY) | WD/MD | US |
| MODERATE | FAVORABLE | FA/MD | MS |
| MODERATE | MARGINAL (HIGH HUMIDITY) | HH/MD | LS |
| MODERATE | MARGINAL (THERMAL DEFICIENCY) | TD/MD | LS |
| LOW | UNFAVORABLE | UN/L | US |
| LOW | MARGINAL (WATER DEFICIENCY) | WD/L | US |
| LOW | FAVORABLE | FA/L | LS |
| LOW | MARGINAL (HIGH HUMIDITY) | HH/L | US |
| LOW | MARGINAL (THERMAL DEFICIENCY) | TD/L | US |
| VERY LOW | UNFAVORABLE | UN/VL | US |
| VERY LOW | MARGINAL (WATER DEFICIENCY) | WD/VL | US |
| VERY LOW | FAVORABLE | FA/VL | US |
| VERY LOW | MARGINAL (HIGH HUMIDITY) | HH/VL | US |
| VERY LOW | MARGINAL (THERMAL DEFICIENCY) | TD/VL | US |

Figure 54 and Table 28 illustrate the distribution of land suitability classes for sunflower in Haiti. The matching of land capability and agroclimatic zoning showed that 79% of the country presented a very low suitability for sunflower. The main restrictions to land suitability are due to restrictive land capability conditions and marginal climatic conditions due to water deficiency, high humidity or high humidity and thermal insufficiency. High suitability and suitable regions sum up to 0.77% of the area or 20,764 ha and are concentrated in the areas with better soils and low slopes. Moderate suitability areas occupy 2.7% of the area and these areas could be used either with varieties of sunflower adapted to the local climatic or soil conditions, or with the application of technology to overcome, if possible, any land capability or climatic restriction. The same can be said about the low suitability classes, but a socioeconomic analysis must be done to understand whether the cost/benefit relation to improve the land capability and climatic restrictions is worthwhile.

**Figure 54**
**Land suitability map for sunflower.**

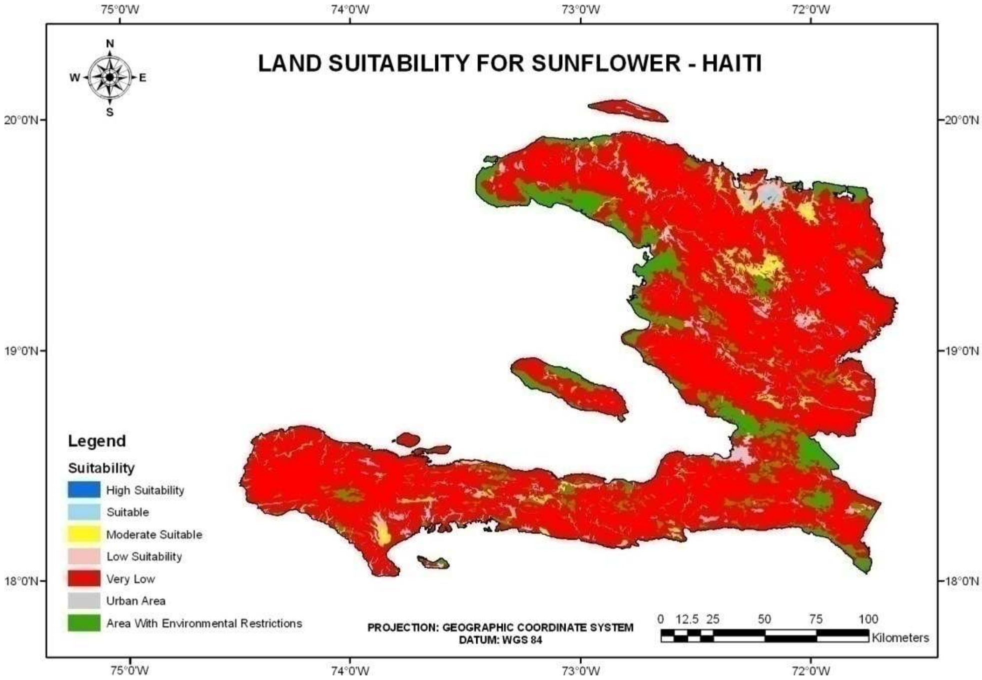



**Table 28**
**Area quantification for sunflower.**

| Categories | Area (ha) | % |
|---|---|---|
| High Suitability | 1,285.43 | 0.05 |
| Suitable | 19,479.14 | 0.72 |
| Moderate Suitable | 72,860.66 | 2.70 |
| Low Suitability | 123,831.86 | 4.59 |
| Very Low Suitability | 2,124,479.35 | 78.77 |
| Urban Area | 17,461.00 | 0.65 |
| Area With Environmental Restrictions | 337,508.00 | 12.51 |
| Total | 2,696,905.44 | 100.00 |

## 5.1.3 Eucalyptus

The definition of the land suitability classes for eucalyptus followed a different format compared to the other evaluated crops. Due to the definition of four different groups of species adaptable to different climate conditions in the agroclimatic zoning analysis, the land suitability classification was divided into 24 suitability groups. For each group of species a land suitability category was created when matched with one of the land capability classes. The result of this matching process can be observed in Table 29.

**Table 29**
**Land suitability definition for eucalyptus.**

| Soil Categories | Climate Categories | Land Suitability Categories |
|---|---|---|
| VERY HIGH | GROUP 5 | 5/VH |
| VERY HIGH | GROUP 4 | 4/VH |
| VERY HIGH | GROUP 3 | 3/VH |
| VERY HIGH | GROUP 1 | 1/VH |
| HIGH | GROUP 5 | 5/H |
| HIGH | GROUP 4 | 4/H |
| HIGH | GROUP 3 | 3/H |
| HIGH | GROUP 1 | 1/H |
| MODERATE | GROUP 5 | 5/MD |
| MODERATE | GROUP 4 | 4/MD |
| MODERATE | GROUP 3 | 3/MD |
| MODERATE | GROUP 1 | 1/MD |
| LOW | GROUP 5 | 5/L |
| LOW | GROUP 4 | 4/L |
| LOW | GROUP 3 | 3/L |
| LOW | GROUP 1 | 1/L |
| VERY LOW | GROUP 5 | 5/VL |
| VERY LOW | GROUP 4 | 4/VL |
| VERY LOW | GROUP 3 | 3/VL |
| VERY LOW | GROUP 1 | 1/VL |
| INAPT | GROUP 5 | 5/IN |
| INAPT | GROUP 4 | 4/IN |
| INAPT | GROUP 3 | 3/IN |
| INAPT | GROUP 1 | 1/IN |

The dominant group of eucalyptus species in Haiti is Group 1. In this group, the suitability class that dominates is 1/MD (group 1 with moderate land capability) (Figure 55 and Table 30). This suitability group occupies approximately 11% of the area, representing 289,767 ha. Other more restrictive groups also are present and are located in the more mountainous areas of the country. As commented on page 56, eucalyptus is a crop that adapts itself to quite restrictive environments and can be used in areas where other more sensible crops do not grow.

**Figure 55**
**Land suitability map for eucalyptus.**

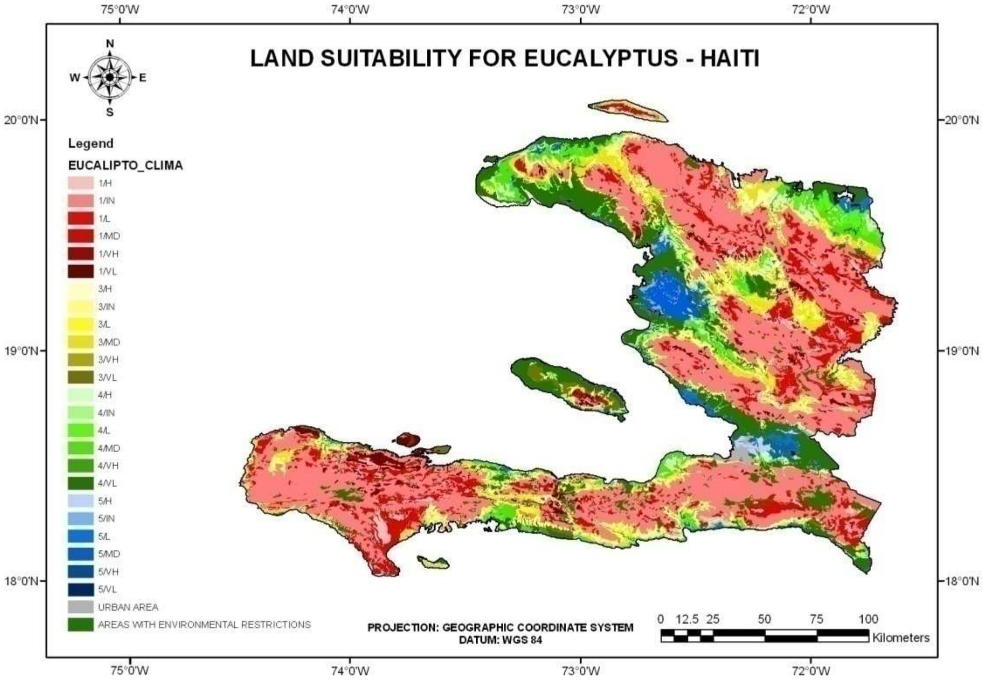



**Table 30**
**Area quantification for eucalyptus.**

| Weather | Soil | Categories | Area (ha) | % |
|---|---|---|---|---|
| Group 1 | Very High | 1/VH | 3,649.62 | 0.14 |
| Group 1 | High | 1/H | 67,982.60 | 2.53 |
| Group 1 | Moderate | 1/MD | 289,767.56 | 10.77 |
| Group 1 | Low | 1/L | 12,276.61 | 0.46 |
| Group 1 | Very Low | 1/VL | 73,428.92 | 2.73 |
| Group 1 | Inapt | 1/IN | 1,029,510.98 | 38.27 |
| Group 3 | Very High | 3/VH | 4,706.94 | 0.17 |
| Group 3 | High | 3/H | 55,538.93 | 2.06 |
| Group 3 | Moderate | 3/MD | 146,714.62 | 5.45 |
| Group 3 | Low | 3/L | 15,228.60 | 0.57 |
| Group 3 | Very Low | 3/VL | 55,246.56 | 2.05 |
| Group 3 | Inapt | 3/IN | 192,087.61 | 7.14 |
| Group 4 | Very High | 4/VH | 4,114.92 | 0.15 |
| Group 4 | High | 4/H | 39,978.98 | 1.49 |
| Group 4 | Moderate | 4/M | 104,165.94 | 3.87 |
| Group 4 | Low | 4/L | 29,368.93 | 1.09 |
| Group 4 | Very Low | 4/VL | 51,138.62 | 1.90 |
| Group 4 | Inapt | 4/IN | 48,882.60 | 1.82 |
| Group 5 | Very High | 5/VH | 3,856.56 | 0.14 |
| Group 5 | High | 5/H | 15,643.61 | 0.58 |
| Group 5 | Moderate | 5/MD | 56,396.92 | 2.10 |
| Group 5 | Low | 5/L | 17,553.98 | 0.65 |
| Group 5 | Very Low | 5/VL | 16,150.94 | 0.60 |

| | | | | |
|---|---|---|---|---|
| Group 5 | Inapt | 5/IN | 13,666.93 | 0.51 |
| Urban Area | | | 17,465.00 | 0.65 |
| Areas With Environmental Restrictions | | | 332,382.00 | 12.36 |
| **Total** | | | 2,696,905.44 | 100.25 |

### 5.1.4 Jatropha

As shown on Table 33, land suitability for jatropha, integrating climate and soil information, was divided into five categories, from high suitablility (HS) to unsuitable (US). The six land capability classes were defined in the land capability report for this crop. In the agroclimatic zoning report, the four agroclimatic classes for jatropha: suitable, marginal (water deficiency), marginal (thermal deficiency), and unsuitable.

**Table 31**
**Categories of suitability adopted for *Jatropha curcas*, according to climate and soil information.**

| Soil Categories | Climate Categories | Climate x Soil | Land Suitability Categories |
|---|---|---|---|
| VERY HIGH | MARGINAL (WATER DEFICIENCY) | VH/WD | MS |
| VERY HIGH | SUITABLE | VH/S | HS |
| VERY HIGH | UNSUITABLE | VH/UN | US |
| VERY HIGH | MARGINAL (THERMAL DEFICIENCY) | VH/TI | S |
| HIGH | MARGINAL (WATER DEFICIENCY) | H/WD | LS |
| HIGH | SUITABLE | H/S | S |
| HIGH | UNSUITABLE | H/UN | US |
| HIGH | MARGINAL (THERMAL DEFICIENCY) | H/TI | MS |
| MODERATE | MARGINAL (WATER DEFICIENCY) | MD/WD | LS |
| MODERATE | SUITABLE | MD/S | MS |
| MODERATE | UNSUITABLE | MD/UN | US |
| MODERATE | MARGINAL (THERMAL DEFICIENCY) | MD/TI | LS |
| LOW | MARGINAL (WATER DEFICIENCY) | L/WD | US |
| LOW | SUITABLE | L/S | LS |
| LOW | UNSUITABLE | L/UN | US |
| LOW | MARGINAL (THERMAL DEFICIENCY) | L/TI | US |
| VERY LOW | MARGINAL (WATER DEFICIENCY) | VL/WD | US |
| VERY LOW | SUITABLE | VL/S | US |
| VERY LOW | UNSUITABLE | VL/UN | US |
| VERY LOW | MARGINAL (THERMAL DEFICIENCY) | VL/TI | US |
| INAPT | MARGINAL (WATER DEFICIENCY) | IN/WD | US |
| INAPT | SUITABLE | IN/S | US |
| INAPT | UNSUITABLE | IN/UN | US |
| INAPT | MARGINAL (THERMAL DEFICIENCY) | IN/TI | US |

Even considering that jatropha is a native crop from Central America and the Caribbean, having a very high suitability under the climate point of view – 87.2% of the country has a very good climate for its growth and development – the area of high suitability (HS) and suitable (S) for jatropha in

Haiti corresponds to only 5% of the land, totaling 134,354 ha. Moderate suitability (MS) occupies 12% of the lands of Haiti totaling 325,470 ha. The remaining available areas are with very low suitability (US) or with low suitability (LS), totaling 1,882,127 ha or 69.8% of the country (Figure 56 and Table 32).

**Figure 56**

**Land suitability for *Jatropha curcas*.**

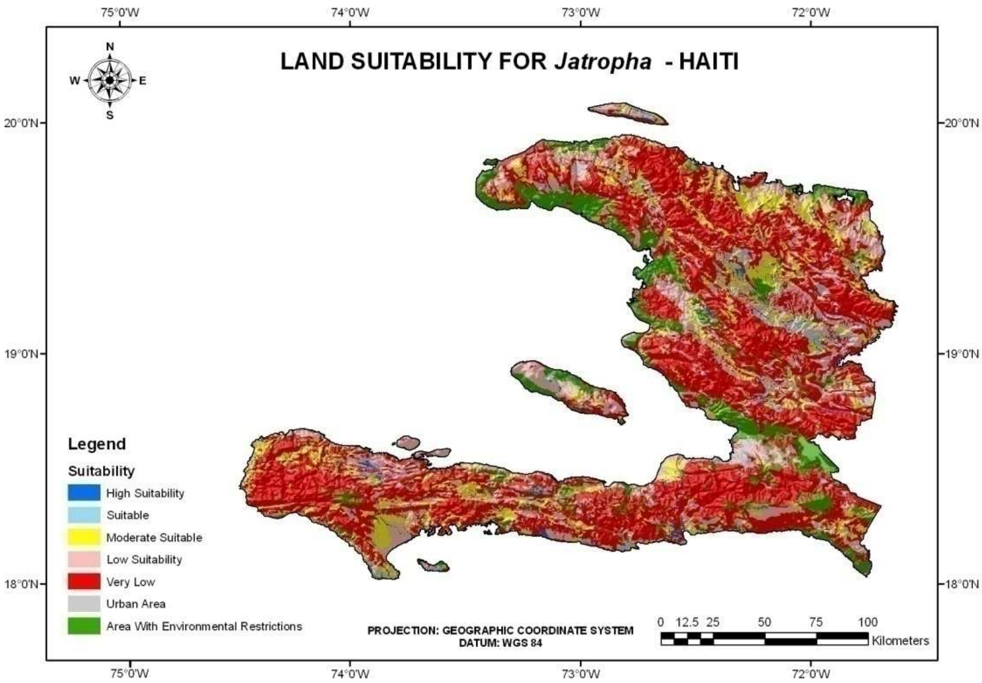



**Table 32**
**Area quantification for Jatropha curcas.**

| Categories | Area (ha) | % |
|---|---|---|
| High Suitability | 42,778.03 | 1.59 |
| Suitable | 91,576.74 | 3.40 |
| Moderate Suitable | 325,470.26 | 12.07 |
| Low Suitability | 479,333.46 | 17.77 |
| Very Low Suitability | 1,402,794.95 | 52.01 |
| Urban Area | 17,458.00 | 0.65 |
| Area With Environmental Restrictions | 337,494.00 | 12.51 |
| Total | 2,696,905.44 | 100.00 |

### 5.1.5 Elephant grass

According to Table 33, the land suitability for elephant grass, integrating climate and soil information, was divided in five categories, from high suitable (HS) to unsuitable (US). The six land capability classes were defined in section 3.6. In section 4.4.5, the five agroclimatic classes for elephant grass were: suitable, marginal (water deficiency), marginal (thermal deficiency), marginal (water and thermal deficiency), unsuitable.

**Table 33**

**Table 4: Suitability categories adopted for elephant grass, according to climate and soil information.**

| Soil Categories | Climate Categories | Climate x Soil | Land Suitability Categories |
|---|---|---|---|
| VERY HIGH | UNSUITABLE (WATER DEFICIENCY) | UNWD/VH | US |
| VERY HIGH | MARGINAL (WATER DEFICIENCY) | MWD/VH | MS |
| VERY HIGH | SUITABLE | S/VH | HS |
| VERY HIGH | MARGINAL (THERMAL DEFICIENCY) | TR/VH | MS |
| VERY HIGH | UNSUITABLE (THERMAL INSUFICIENCY) | UNTI/VH | US |
| VERY HIGH | MARGINAL (WATER AND THERMAL DEF) | MWTD/VH | LS |
| HIGH | UNSUITABLE (WATER DEFICIENCY) | UNWD/H | US |
| HIGH | MARGINAL (WATER DEFICIENCY) | MWD/H | MS |
| HIGH | SUITABLE | S/H | S |
| HIGH | MARGINAL (THERMAL DEFICIENCY) | TR/H | MS |
| HIGH | UNSUITABEL (THERMAL INSUFICIENCY) | UNTI/H | US |
| HIGH | MARGINAL (WATER AND THERMAL DEF) | MWTD/H | LS |
| MODERATE | UNSUITABLE (WATER DEFICIENCY) | UNWD/MD | US |
| MODERATE | MARGINAL (WATER DEFICIENCY) | MWD/MD | LS |
| MODERATE | SUITABLE | S/MD | MS |
| MODERATE | MARGINAL (THERMAL DEFICIENCY) | TR/MD | LS |
| MODERATE | UNSUITABEL (THERMAL INSUFICIENCY) | UNTI/MD | US |
| MODERATE | MARGINAL (WATER AND THERMAL DEF) | MWTD/MD | US |
| LOW | UNSUITABLE (WATER DEFICIENCY) | UNWD/L | US |
| LOW | MARGINAL (WATER DEFICIENCY) | MWD/L | US |
| LOW | SUITABLE | S/L | LS |
| LOW | MARGINAL (THERMAL DEFICIENCY) | TR/L | US |
| LOW | UNSUITABEL (THERMAL INSUFICIENCY) | UNTI/L | US |
| LOW | MARGINAL (WATER AND THERMAL DEF) | MWTD/L | US |
| VERY LOW | UNSUITABLE (WATER DEFICIENCY) | UNWD/VL | US |
| VERY LOW | MARGINAL (WATER DEFICIENCY) | MWD/VL | US |
| VERY LOW | SUITABLE | S/VL | US |
| VERY LOW | MARGINAL (THERMAL DEFICIENCY) | TR/VL | US |
| VERY LOW | UNSUITABEL (THERMAL INSUFICIENCY) | UNTI/VL | US |
| VERY LOW | MARGINAL (WATER AND THERMAL DEF) | MWTD/VL | US |
| INAPT | UNSUITABLE (WATER DEFICIENCY) | UNWD/IN | US |
| INAPT | MARGINAL (WATER DEFICIENCY) | MWD/IN | US |
| INAPT | SUITABLE | S/IN | US |
| INAPT | MARGINAL (THERMAL DEFICIENCY) | TR/IN | US |
| INAPT | UNSUITABEL (THERMAL INSUFICIENCY) | UNTI/IN | US |
| INAPT | MARGINAL (WATER AND THERMAL DEF) | MWTD/IN | US |

In Haiti, elephant grass crop is basically limited by soil potential conditions, since climate is favorable for this crop in 48.8% of the country. Soil limitations restrict the areas classified as high suitability (HS) and suitable (S) for elephant grass crop to 1.42% of the country, totaling approximately 38,395 hectares. Areas considered of moderate suitability (MS) and low suitability (LS) totalize 19.2% of the country (517,447 ha), whereas very low suitability (US) zones comprise 66.5% of the lands (Figure 57 and Table 34).

**Figure 57**
**Land suitability for elephant grass.**

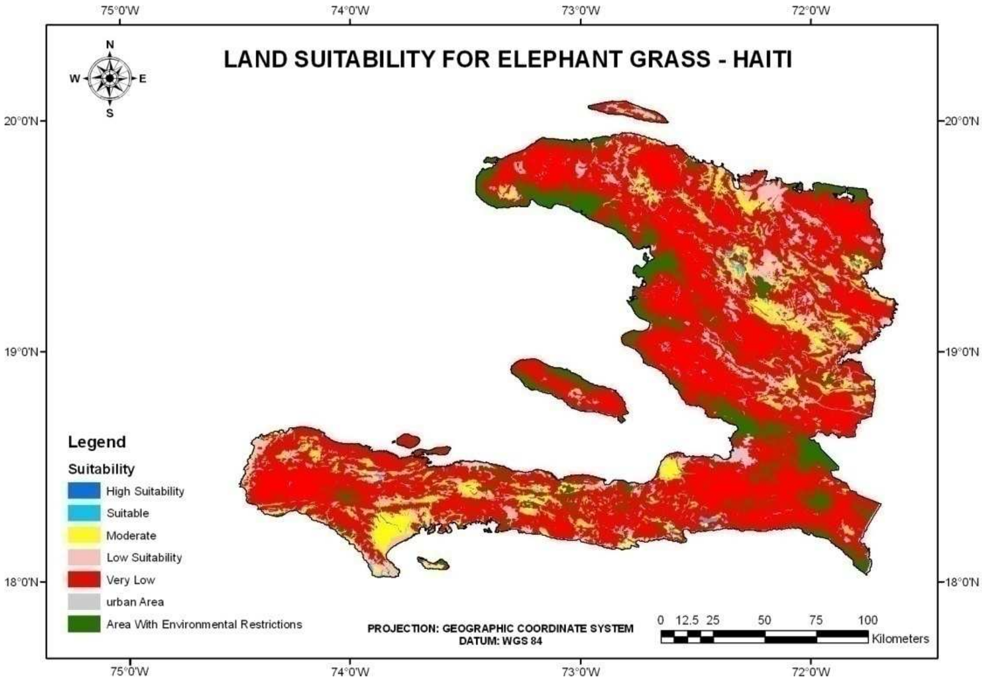



**Table 34**
**Area quantification for elephant grass.**

| Categories | Area (ha) | % |
|---|---|---|
| High Suitability | 9,412.23 | 0.35 |
| Suitable | 28,983.06 | 1.07 |
| Moderate Suitable | 233,955.09 | 8.67 |
| Low Suitability | 283,492.75 | 10.51 |
| Very Low Suitability | 1,793,322.32 | 66.50 |
| Urban Area | 17,305.00 | 0.64 |
| Area With Environmental Restrictions | 330,435.00 | 12.25 |
| Total | 2,696,905.44 | 100.00 |

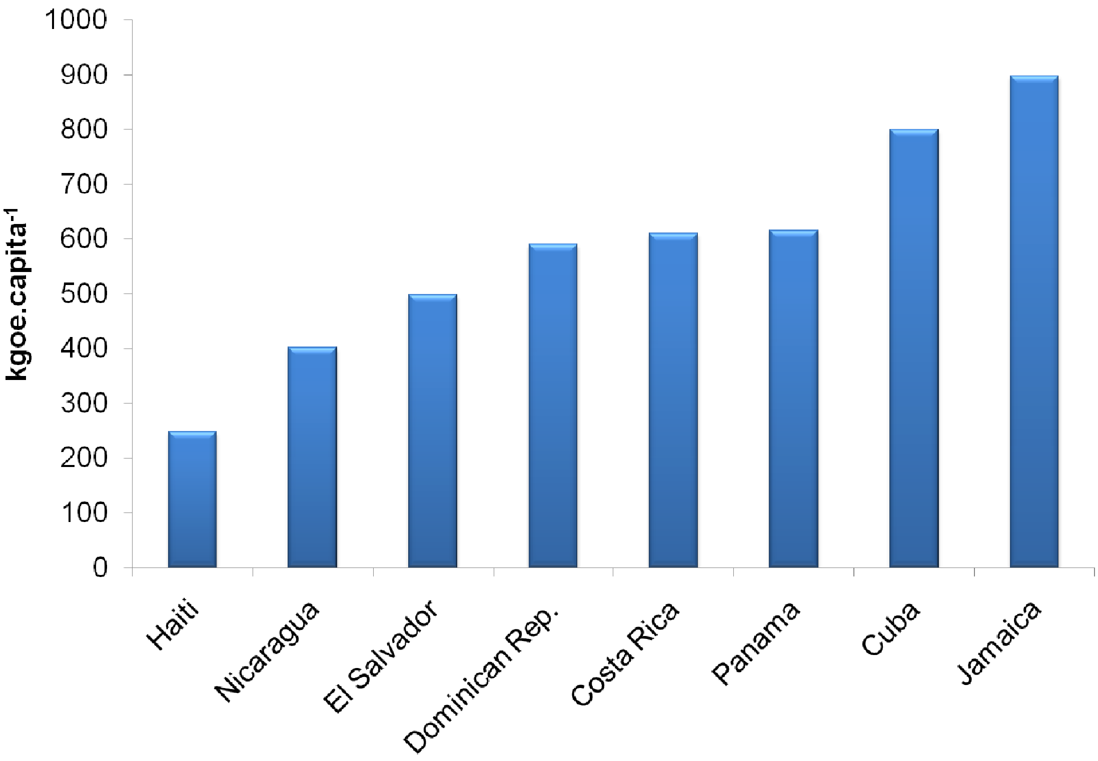
## 5.1.6 Final Remarks

The Land Suitability analysis performed for five biofuel crops showed that Haiti presents large amount of land unsuitable for the cultivation of these crops. Main restrictions for these crops come from the weak soil potential evaluation in Haiti and also from the mountainous landscape which limits agriculture activities on the high slopes. Although the land in Haiti presents high restrictions for the cultivation of biofuel crops, enough high and moderate suitable areas are found to support biofuel projects in Haiti. Ethanol, biodiesel or electricity can be produced at sufficient scales for Haiti with the amount of land available classified as very high suitability, suitable and moderate suitability. Evaluation of local infrastructure, industrial capabilities and transport logistics should be evaluated for cost/benefit relations.

# 6. Identification and Analysis of the Energy Matrix

The history of energy use in Haiti has as its principal characteristic the low consumption *per capita*. Currently, this values is approximately 250 kgoe (kilograms of oil equivalent), representing a small consumption when compared with some neighboring countries, amongst them, Dominican Republic and Cuba, shown in Figure 58.

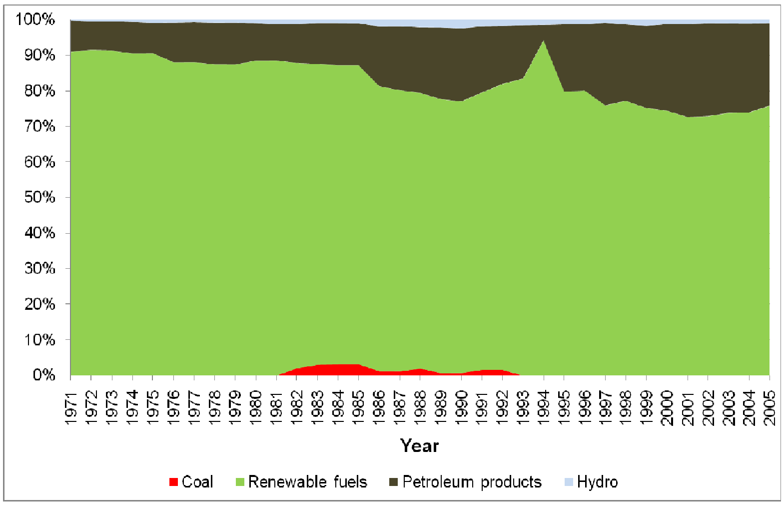
**Figure 58**
**Final energy consumption of countries in Central America and the Caribbean.**




Source: Haiti Energy Sector Development Plan 2007-2017, 2006.

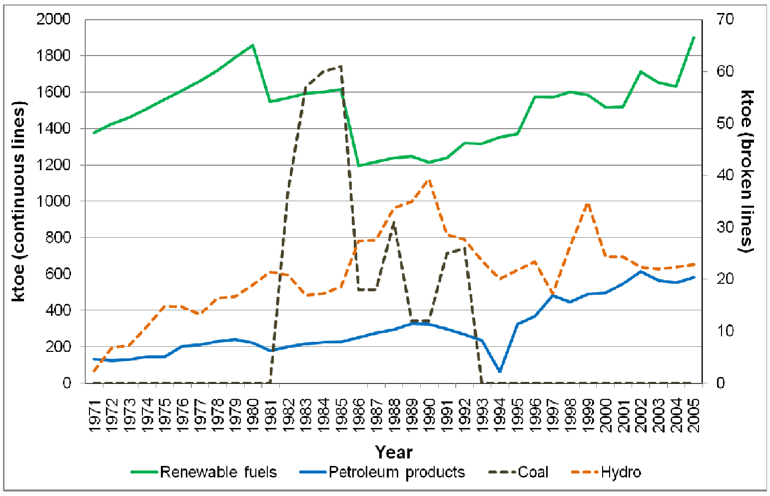
The graphs in Figure 59 represent a time series, from 1971 to 2005, with the relative distribution and energy consumption of the various sources available in Haiti. The composition of the energy matrix and the consumption of each type of energy source have undergone large oscillations throughout the years in response to the political and social situation. For example, in 1991, Haiti had a coup d'État, whose executers dominated the country until 1994, under strong international pressure, culminating with an economic embargo promoted by several countries from the American States Organization, preventing Haiti from importing, amongst other things, petroleum products (Pierre-Pierre, 1994).

**Figure 59**
**Relative energy consumption from different energy sources available in Haiti from 1971 to 2005.**




Source: Prepared by FGV with data from IEA.

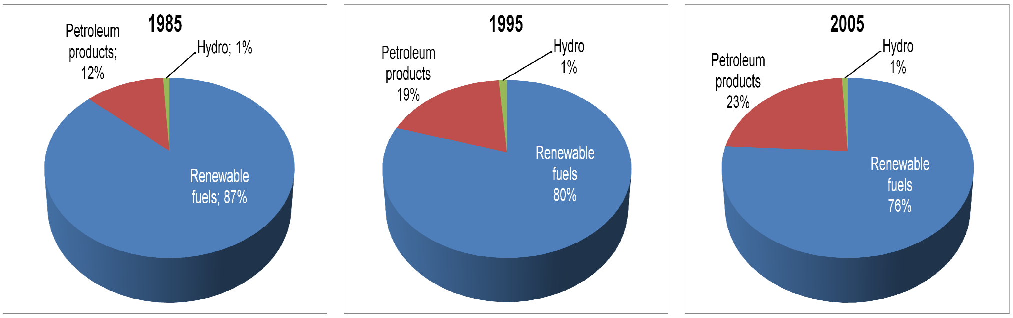
**Figure 60**
**Energy consumption from different energy sources available in Haiti from 1971 to 2005.**




Source: Prepared by FGV with data from IEA.

On the other hand, a relatively uniform growth trend, decrease or replacement of one energy source by another throughout the last 3 decades can be observed (Figure 60). Therefore, in some situations within this analysis, it was more convenient to compare 3 specific years that reflect this tendency, covering a period of 20 years, instead of discussing the whole time series.

**Figure 61**
**Haiti's energy matrix for 1985, 1995 e 2005.**




Source: Prepared by FGV with data from IEA.

The Haitian energy matrix is chiefly composed of renewable fuels that represent 84% (out of a total of 1,920 ktoe) of the energy supply of the country in 1985, 80% (out of a total of 1,717 ktoe) in 1995, and 78% (out of a total of 2,503 ktoe) in 2005 (Figure 61). In spite of the fact that, according to data from the IEA, the relative contribution of renewable fuels had decreased throughout the last two decades, the absolute consumption in 2005 (1,898 ktoe) was the greatest since 1971, year in which the IEA started statistical surveys for Haiti.

The term "renewable fuel", however, may be misleading, as in the case of Haiti, the timber used directly as fuel or raw material for the production of charcoal is classified as a "renewable fuel". In 1982, the timber reserves of Haiti were estimated at 34.7 million cubic meters (BME, 2006). There are no reliable up-to-date statistics on the subject, but taking into account the consumption of timber and by the efficiency of reforestation currently observed, one could conclude that today these reserves correspond to less than half the volume available in 1982. If the consumption of timber and reforestation continue at the current rhythm, the country may completely run out of its timber reserves in the very near future.

The contribution of petroleum products to the energy matrix was 12%, in 1985; 19%, in 1995; and

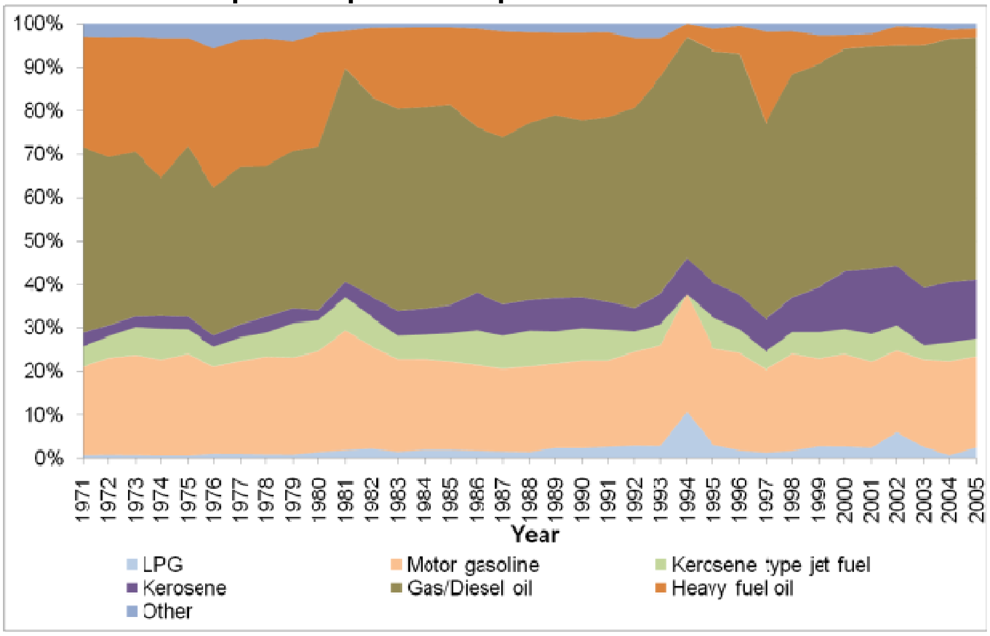
23%, in 2005 (Figure 61). In absolute values, the decade from 1995 to 2005 had the highest average level of consumption of petroleum products (506 ktoe), representing an increase of 83% in relation to the period from 1985 to 1993 (the year 1994 was excluded from this average because the supply of petroleum dropped in an atypical manner due to the economic embargo). There are no statistical data later than 2005, but as a consequence of the PetroCaribe Agreement, an initiative by Venezuela to supply petroleum at lower prices to Caribbean countries (Venezuela, 2005), it is probable that currently the percentage occupied by petroleum products in the energy matrix of Haiti has increased even more.

The contribution of electric energy to the composition of the Haitian energy matrix has oscillated around 1% since the decade of 1980. But, in absolute values, the average consumption in the period from 1995 to 2005 was 38% greater to the average of the period from 1985 to 1993.

## 6.1 Consumption of petroleum derivatives

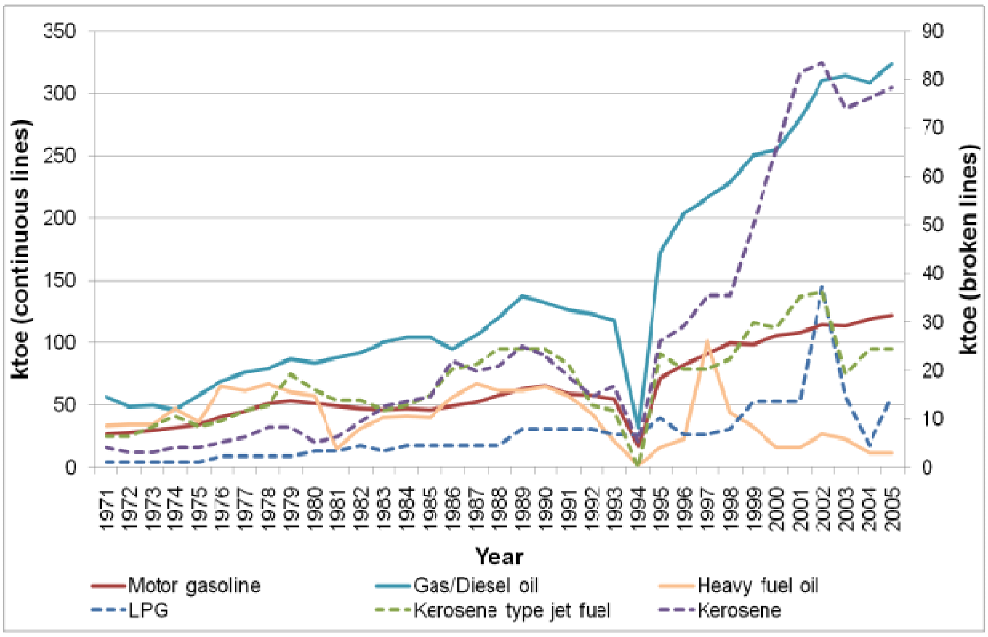
The whole Haitian petroleum supply is imported, and around 91% of the petroleum products are consumed without undergoing conversion into other types of energy. As the country depends on importation, the supply levels of petroleum and its products in Haiti are highly sensitive to internal and external policies adopted by each government. For example, the economic embargo applied by OEA countries against the government of Marc Louis Bazin caused a drop of 73% in the supply of petroleum derivatives in the year of 1994 in comparison with 1993 (Figure 62; Figure 63).
Data for the years 1985, 1995 and 2005 (Figure 64; Table 35) allow the construction of an objective estimate of petroleum products consumption trends in response to the demand and the financial resources available for importation, without the need to comment on the political causes involved. Therefore, this discussion will be based on those years.

**Figure 62**
**Relative consumption of petroleum products in Haiti from 1971 to 2005.**




Source: Prepared by FGV with data from IEA

**Figure 63**
**Consumption of petroleum products in Haiti from 1971 to 2005.**



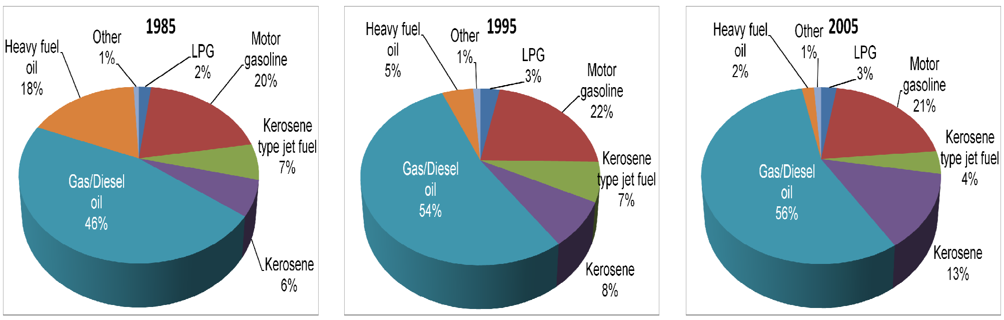

Source: Prepared by FGV with data from IEA.

In 2005, the consumption of gas/diesel oil corresponded to 56% of the whole supply of petroleum products in Haiti (Figure 64), which was 323.95 ktoe (Table 35). There was a sharp increase in the relative consumption of gas/diesel oil, between the year of 1985 and 1995, which reflected the replacement of heavy fuel oil by diesel oil in some sectors. The sum between the relative consumption of gas/diesel oil and heavy fuel oil, however, remained relatively constant in the comparison of the years 1985, 1995 and 2005. On the other hand, in absolute values, the combined consumption of gas/diesel oil and heavy fuel oil grew 77% between 1985 (144.85 ktoe) and 1995 (189.16 ktoe) and 30% between 1995 and 2005 (335.47 ktoe).

In the year of 2005, the second most consumed petroleum product in Haiti was automotive gasoline, with 121.98 ktoe (Table 35), corresponding to little more than ⅓ of the consumption of gas/diesel oil in the same year. The consumption of gasoline increased 56% between 1985 and 1995 and 70% between 1995 and 2005. The consumption of kerosene grew, both relatively and absolutely, between the years of 1985 (6%; 14.63 ktoe) and 1995 (8%; 26.12 ktoe), in which the increase was 78%, as between the years of 1995 and 2005 (13%; 78.37 ktoe), a period in which the consumption of kerosene increased 200% in absolute terms.

Other (kerosene type jet fuel, LPG and others) summed represent only 9% of consumption in 1985, 12% in 1995 and 8% in 2005.

**Figure 64**
**Relative consumption of petroleum products in 1985, 1995 and 2005.**




Source: Prepared by FGV with data from IEA.

**Table 35**
**Consumption of petroleum products in 1985, 1995 e 2005 (em ktoe).**

| Product | 1985 | 1995 | 2005 |
|---|---|---|---|
| Gás/diesel oil | 104.53 | 172.84 | 323.95 |
| Motor gasoline | 46.01 | 71.69 | 121.98 |
| Heavy fuel oil | 40.32 | 16.32 | 11.52 |
| Kerosene | 14.63 | 26.12 | 78.37 |
| Kerosene type jet fuel | 14.91 | 23.43 | 24.49 |
| LPG | 4.52 | 10.17 | 14.69 |
| Other | 1.92 | 3.84 | 6.72 |
| Total | 226.84 | 324.41 | 581.72 |

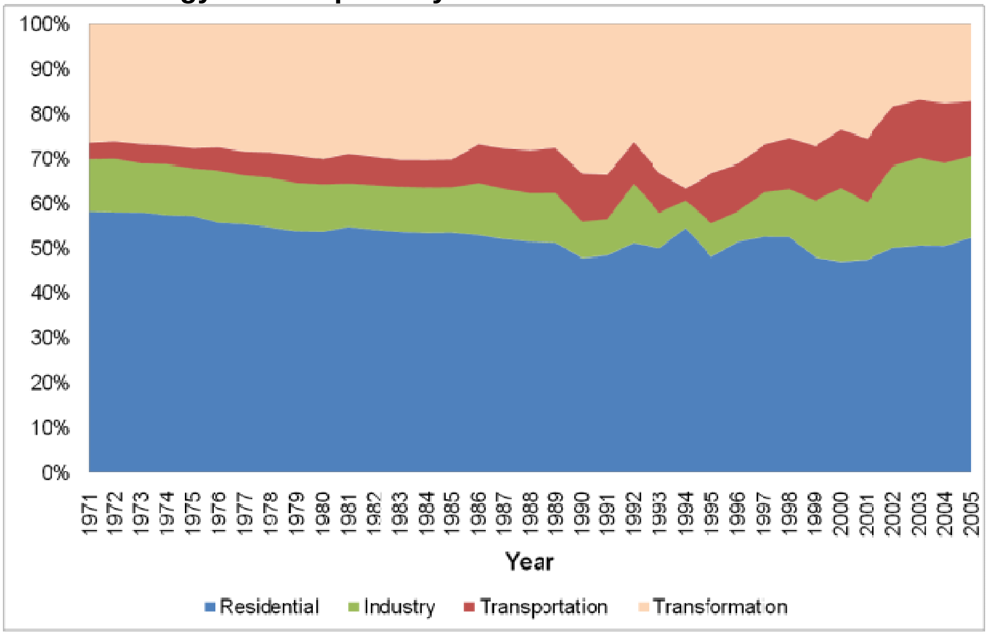
Source: Prepared by FGV with data from IEA.

## 6.2 Consumption of energy per sector

Historically, the sector that most consumes energy in Haiti is the residential one (Figure 65). Although, proportionally, the participation of the residential sector in the consumption of energy show a trend of decline, in absolute numbers, between 1995 and 2005, the consumption grew 59% (Table 35).

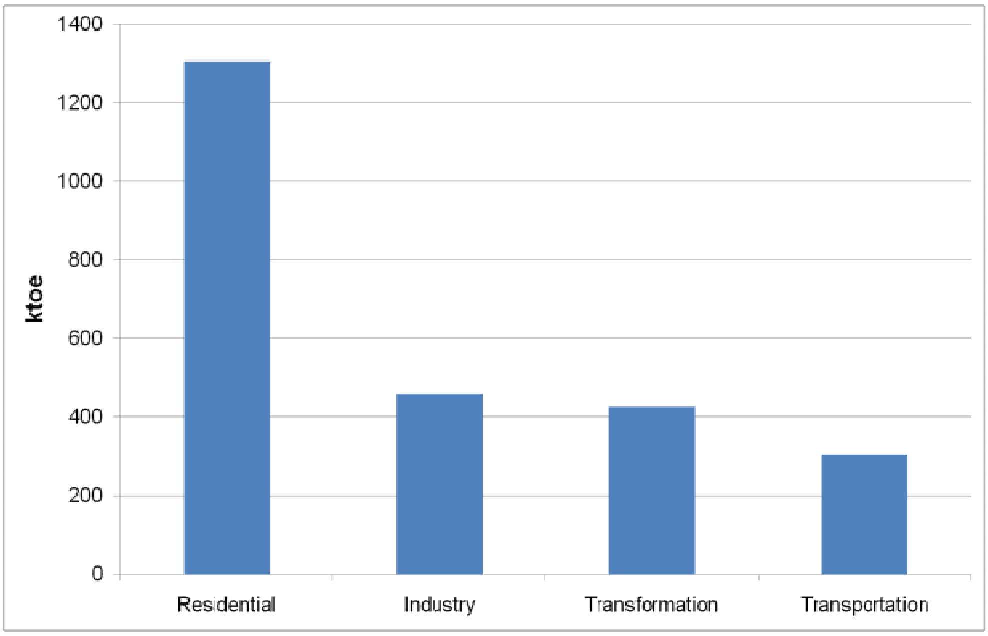
In fact, this relative reduction in the consumption by the residential sector is the response to an even greater growth in consumption by industry (257%) and by the transport sector (60%). Although there was an average growth of 46% in all sectors analyzed, the transformation sector consumed 25% less in 2005 than in 1995.

**Figure 65**
**Relative energy consumption by sector between 1971 and 2005 in Haiti.**




Source: Prepared by FGV with data from IEA.

**Figure 66**
**Energy consumption by sector in 2005 in Haiti.**




Source: Prepared by FGV with data from IEA.

**Table 35**
**Variation in energy consumption by sector between 1995 and 2005 in Haiti.**

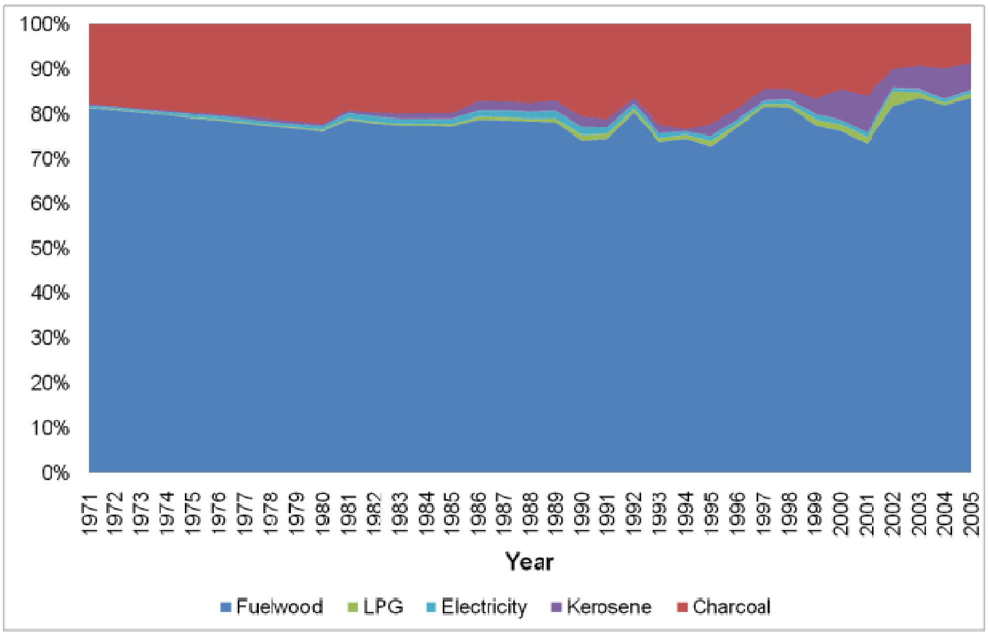
| Sector | 1995 (ktoe) | 2005 (ktoe) | Variation (%) |
|---|---|---|---|
| Residential | 820 | 1,306 | 59 |
| Industry | 128 | 458 | 257 |
| Transformation | 566 | 426 | –25 |
| Transportation | 190 | 304 | 60 |
| Total | 1,704 | 2,494 | 46 |

Source: Prepared by FGV with data from IEA.

## 6.3 Consumption of Energy in the Residential Sector

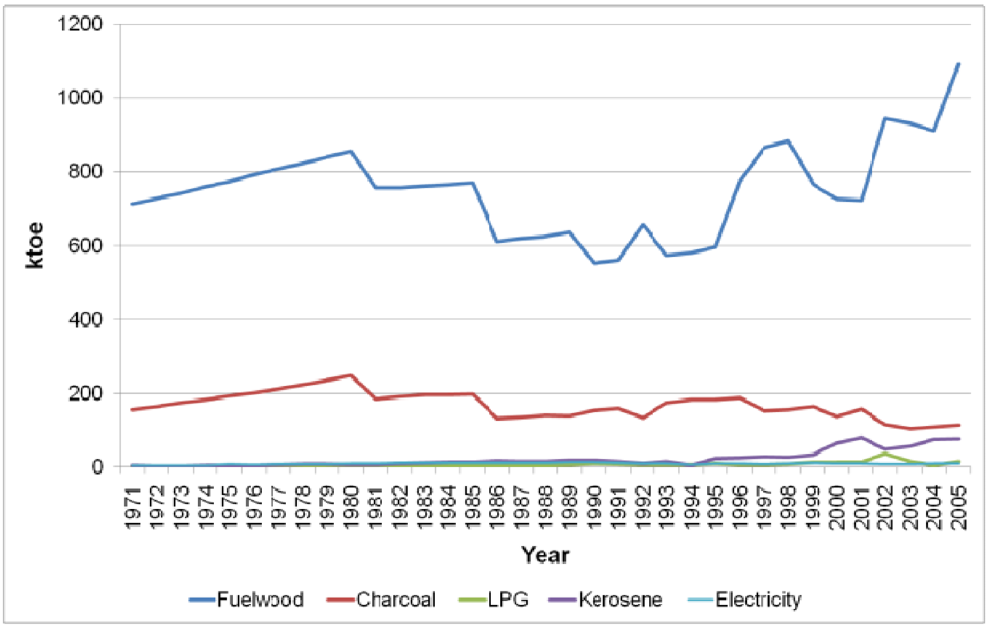
The residential sector consumes energy mainly from primary biomass, both in the form of firewood as in the form of charcoal (Figure 70 and Table 36). Firewood is used especially in rural areas, while in large urban centers primary biomass is mostly consumed in the form of charcoal. Contrary to what happens in the industrial and the transformation sectors, replacement of the sources of energy in the domestic consumption is not easy. This replacement needs to be done at the household level, but there are economic (low purchasing power of the population) and cultural barriers that need to be overcome. According to Portnoff, 2007, even with efforts to replace primary biomass by other fuel sources in the residential sector, charcoal will continue to be the preferred fuel for the vast majority of the urban population of Haiti.

**Figure 67**
**Relative energy consumption by the residential sector in Haiti between 1971 and 2005.**




Source: Prepared by FGV with data from IEA.

**Figure 68**
**Energy consumption by the residential sector in Haiti between 1971 and 2005.**




Source: Prepared by FGV with data from IEA.

**Table 36**
**Fuelwood and charcoal consumption by the domestic sector in Haiti.**

| Year | Fuelwood | Charcoal | Total primary solid biomass |
|---|---|---|---|
| 1985 | 772 | 197 | 969 |
| 1995 | 596 | 181 | 777 |
| 2005 | 1,093 | 112 | 1,205 |
| CV (%) | 20 | 18 | 16 |

Source: Prepared by FGV with data from IEA.

Various reports ((ESMAP, 1991), (BME, 2006)) point out the problem of residential use of charcoal and firewood as one of the most important issues to be resolved in Haiti's energy framework. Only between 2003 and 2005, the increase in the total consumption of primary biomass was 17% and in the decade between 1995 and 2005, growth in consumption was 83%.  Although primary biomass is a renewable resource, in Haiti, the timber reserves have been used in an unsustainable manner.

**Figure 69**
**Sale of charcoal for residential use in the streets of Port-au-Prince.**

Source: FGV, 2008.

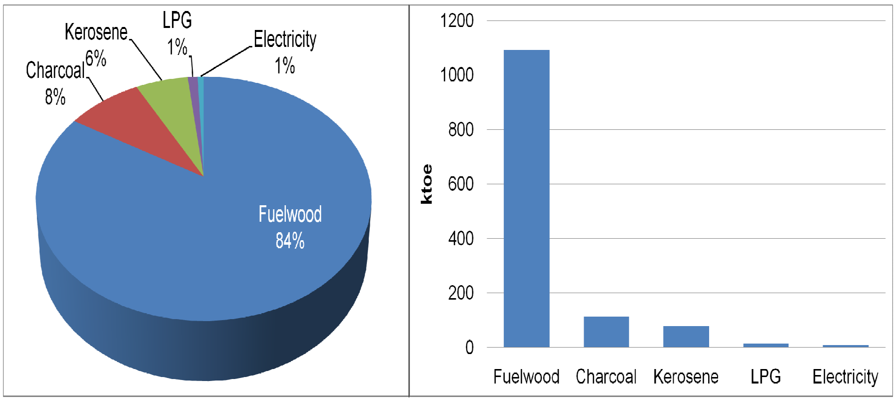
There are plans by the Haitian government to promote the replacement of charcoal by other sources of energy, especially liquefied petroleum gas (LPG) (BME, 2006).  In .
, the incipient increase in the consumption of LP, that appears as from 1999 accompanied by a

small reduction in the consumption of charcoal, may be a reflex of the effective replacement of charcoal by LPG in residential use. On the other hand, the consumption of firewood appears not to have been affected by these policies and continues to increase at the highest rates in history.

Firewood, charcoal and LPG have different costs and depend of different equipment to be used, but the objective of their use in the residential sector of Haiti is common: cooking. Therefore, at least theoretically, it is possible to replace any one of theses three fuels by any other in the same group. Kerosene, however, is used for lighting, especially in the rural area and suburbs (ESMAP, 2007), and cannot be easily replaced by another fuel, but competes directly with electricity. If there was a greater effort to popularize electricity, it is probable that the consumption of kerosene would fall drastically in a few years.

**Figure 70**

**Energy consumption by the residential sector in Haiti, 2005.**

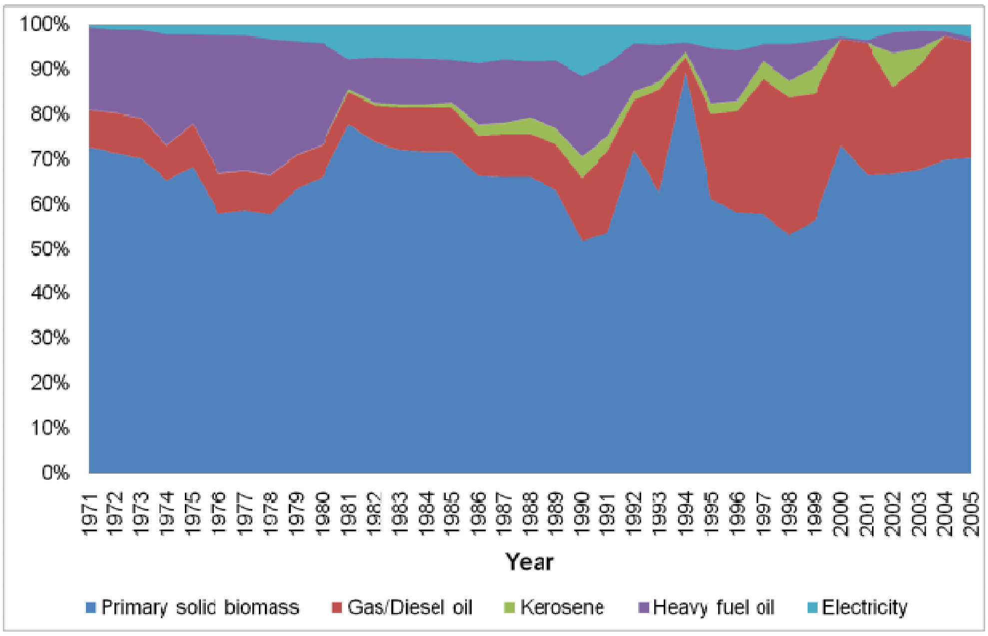



Source: Prepared by FGV with data from IEA.

## 6.4 Consumption of Energy in the Industrial Sector

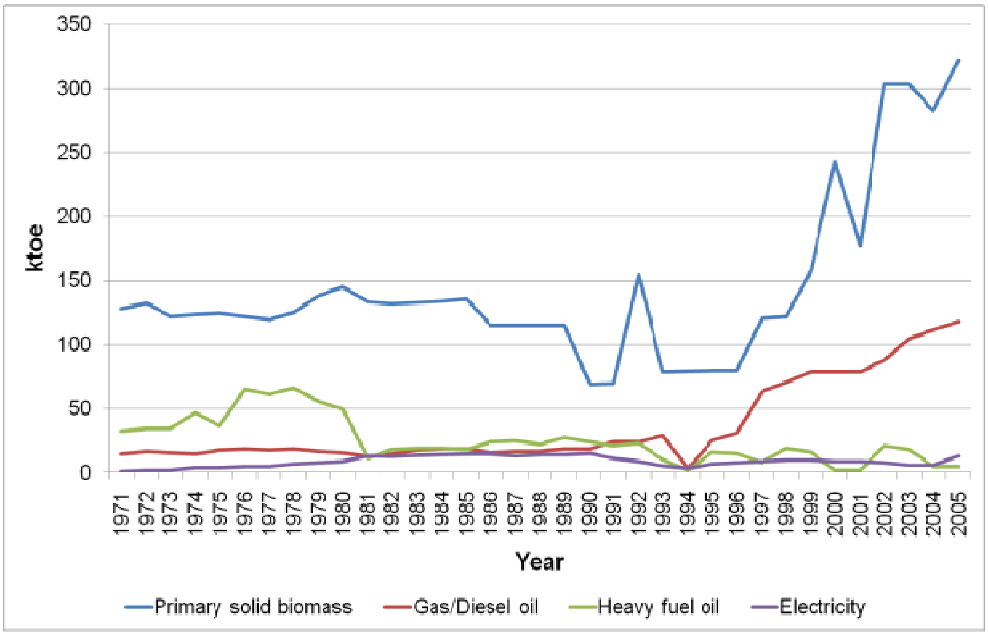
The total energy consumption in the industrial sector increased in 2005 to three and a half times than it was in 1995 and 70% of this energy came from primary biomass (Figure 71), which has been consumed both in the form of firewood (53%), as in the form of charcoal (16%) and bagasse (31%) (Portnoff, 2007). The consumption of gas/diesel oil by Haitian industry was the one that increased most between 1995 and 2005 (375%), followed by the consumption of primary biomass (302%). It is probable that the increase in consumption of gas/diesel oil prevented an even more sharp growth in the consumption of primary biomass, as some types of industry may replace primary biomass by diesel oil and vice-versa quite easily. The use of electricity by industry has a large growth potential thanks to its versatility and efficiency in comparison with other sources of energy. The increase in consumption is not observed simply because there is not sufficient electricity available in the country.

**Figure 71**
**Relative energy consumption by the industry sector in Haiti between 1971 and 2005.**



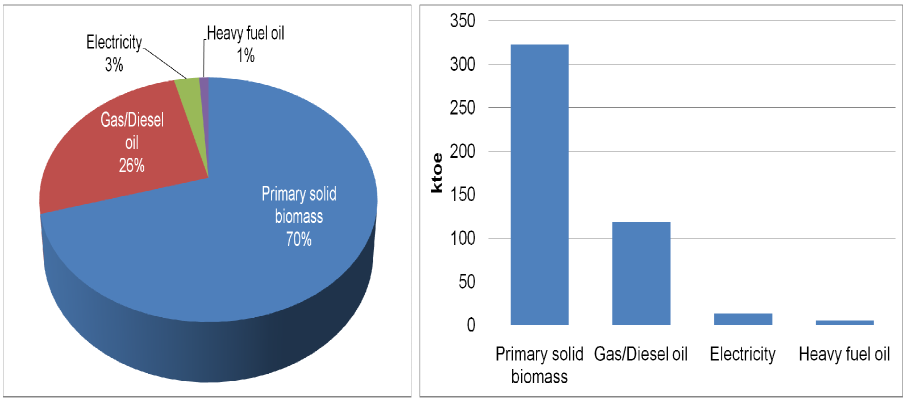

Source: Prepared by FGV with data from IEA.

**Figure 72**
**Energy consumption by the industry sector in Haiti between 1971 and 2005.**




Source: Prepared by FGV with data from IEA.

**Figure 73**
**Energy consumption by the industry sector in Haiti, 2005.**




Source: Prepared by FGV with data from IEA.

## 6.5 Consumption of Energy in the Transformation Sector

In 2005, 70% of the energy consumed by the transformation sector used primary biomass as a source (Figure 74). In 1985 and 1995, this proportion was 72% and 62% respectively. The proportional increase in the consumption of primary biomass is due especially to the increase in the total consumption of energy by the sector, as other sources of energy, which depend on importation, are used in much smaller quantities, suffering proportionally less expressive oscillations.

**Table 37**
**Total supply of primary solid biomass (ktoe) and quantity consumed by the transformation sector (ktoe) in Haiti.**

| Year | Total Supply | Transformation Sector | Percent (%) |
|---|---|---|---|
| 1985 | 1,614 | 371 | 23 |
| 1995 | 1,371 | 513 | 37 |
| 2005 | 1,898 | 506 | 27 |
| CV (%) | 13 | 8 | |

Source: Prepared by FGV with data from IEA.

Of the total primary biomass supply in Haiti in 2005 (1,614 ktoe), 27% was used in charcoal production plants (Table 37), producing a total of 140 ktoe in charcoal, with an efficiency of 38%. Until 1991, primary biomass was also converted into electricity, consuming up to 279 ktoe, *i.e.*, 62% of the total primary biomass energy used by the transformation sector.

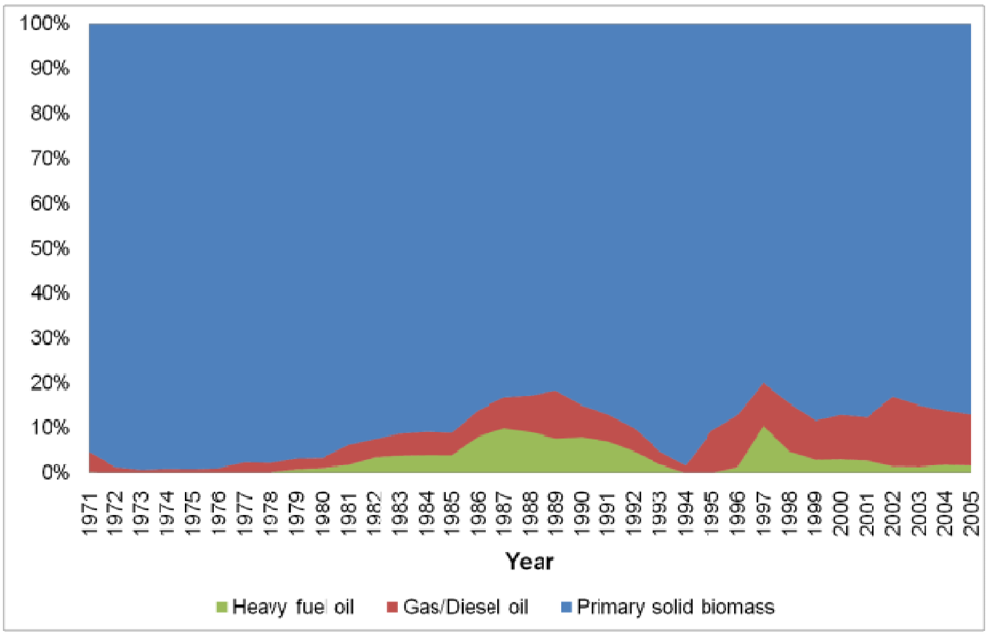
**Table 38**
**Total gas/diesel oil (ktoe) and quantity consumed by the transformation sector (ktoe) in Haiti.**

| Year | Supply Total | Sector de Transformation | Percentage (%) |
|---|---|---|---|
| 1985 | 105 | 28 | 27 |
| 1995 | 173 | 53 | 31 |
| 2005 | 324 | 49 | 15 |
| CV (%) | 46 | 39 | |

Source: Prepared by FGV with data from IEA.

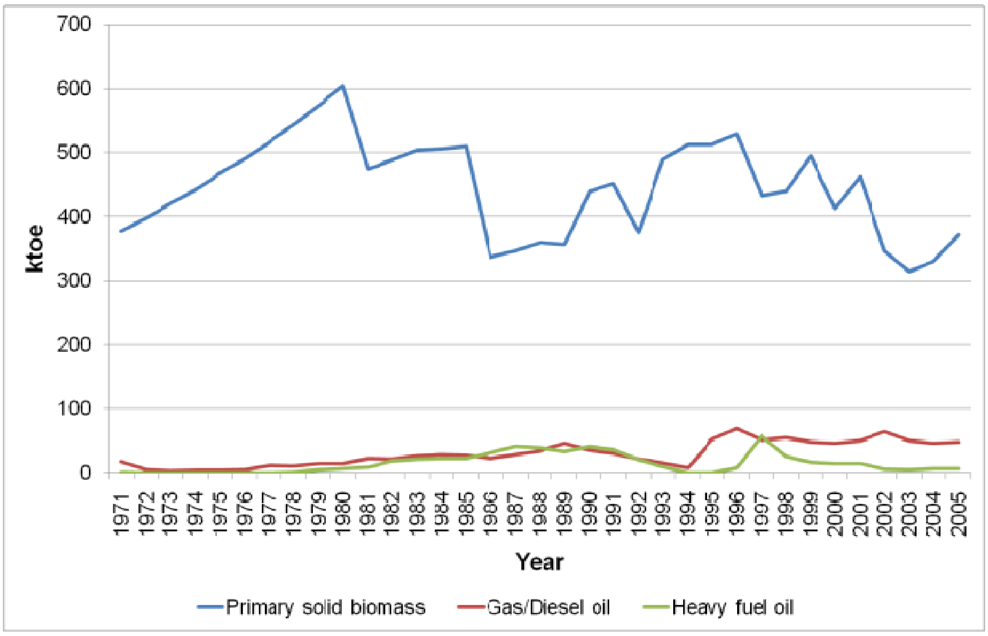
The transformation sector consumed 27% of the supply of gas/diesel oil of Haiti in 2005, which was 324 ktoe (Table 38). According to the IEA, since 1993, all the gas/diesel oil used in the transformation sector was converted into electricity by companies or institutions that have the production and sale of energy as their principal activity. Between 1982 and 1992, from 30 to 50% of the diesel oil consumed by the transformation sector was used for the production of electricity in companies and institutions main principal activity was not the production of electric energy, *i.e.*, companies that produced electricity especially or exclusively for their own consumption.

**Figure 74**
**Relative energy consumption by the transformation sector in Haiti between 1971 e 2005.**



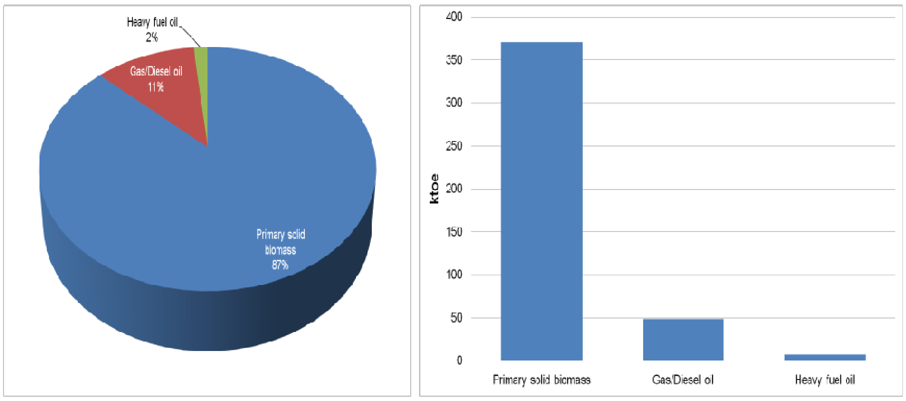

Source: Prepared by FGV with data from IEA.

**Figure 75**
**Energy consumption by the transformation sector in Haiti between 1971 e 2005.**




Source: Prepared by FGV with data from IEA.

**Figure 76**
**Energy consumption by the transformation sector in Haiti, 2005.**



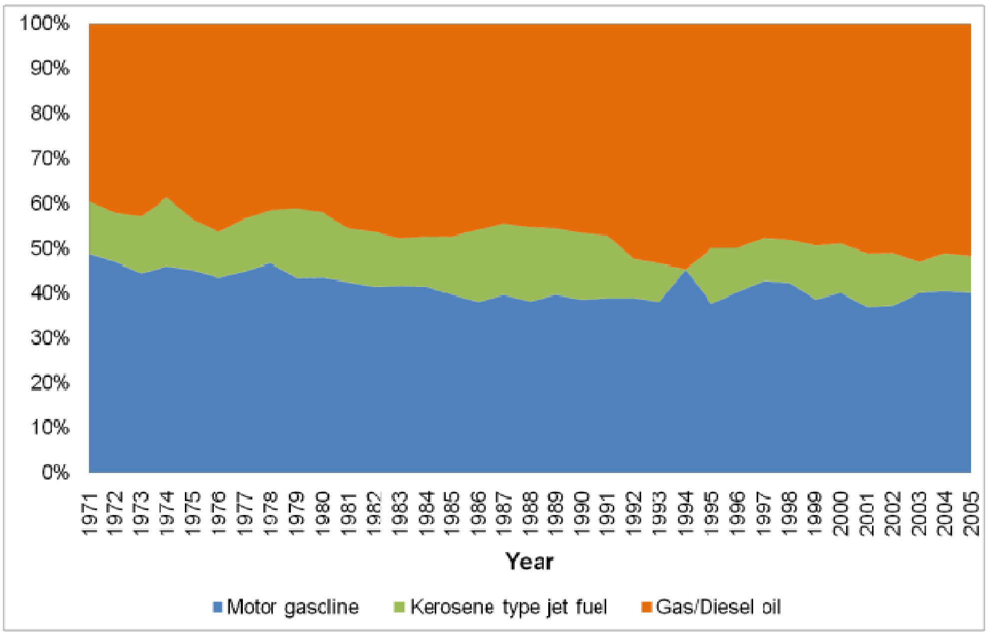

Source: Prepared by FGV with data from IEA.

## 6.6 Consumption of Energy in the Transport Sector

All the energy consumed by the transport sector in Haiti comes from petroleum products. The sector consumes especially gas/diesel oil, which represented 52% of the consumption in 2005 and automotive gasoline, with 40% (Figure 78). The remaining 8% was consumed in kerosene type jet fuel. The consumption of diesel oil and gasoline increased progressively throughout the years, between 1971 to 2005 (period for which statistical data are made available by the IEA), with the exception of the year of 1994, when the consumption of all products fell drastically (Figure 77), due to the economic embargo that the country suffered. The consumption of kerosene type jet fuel, although it also showed a growth tendency as from 1999, suffered a sharp drop in 2003, without showing signs of recovery up to 2005.

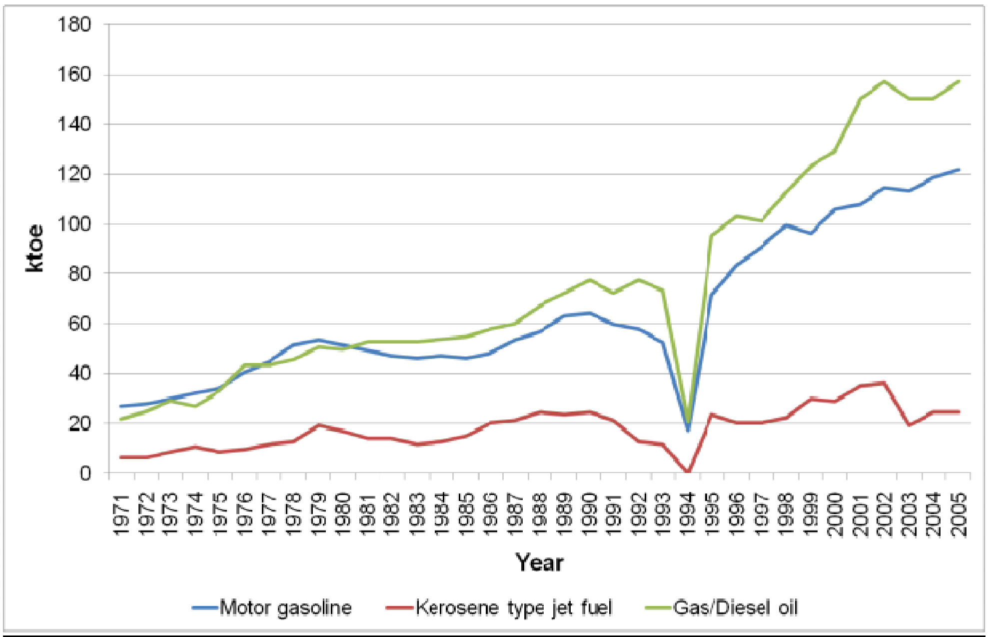
Diesel oil and gasoline are consumed domestically and the demand is proportional to the number of vehicles in the country. Kerosene type jet fuel, on the other hand, is used exclusively in international transportation. In 2003, consumption of kerosene type jet fuel dropped drastically, probably due to a reduction in the number of flights to and from Haiti, brought about by an aggravation of the political-social instability in the country in that year.

**Figure 77**
**Relative energy consumption by the transportation sector in Haiti between 1971 e 2005.**



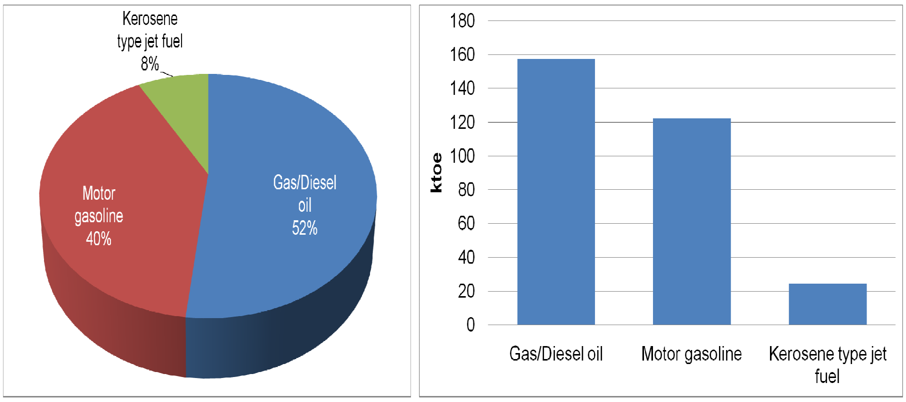

Source: Prepared by FGV with data from IEA.

**Figure 78**
**Energy consumption by the transportation sector in Haiti between 1971 e 2005.**




Source: Prepared by FGV with data from IEA.

**Figure 79**
**Energy consumption by the transportation sector in Haiti, 2005.**




Source: Prepared by FGV with data from IEA.

## 6.7 Potential for the use of biofuels

Although, currently, the energy consumed in Haiti in the greater part comes from primary biomass, that is renewable and produced internally, the exploration of these resources has not been done in a sustainable manner due to the growth in demand, which should intensify with the population growth and with the possible recover of the economy. In 1982, the timber reserves in Haiti were estimated at 34.7 million cubic meters. There are no reliable current statistics on the subject, but judging from the consumption of timber and by the efficiency of reforestation, today these reserves may correspond to less than half the volume available in 1982 (BME, 2006). If the consumption of timber and reforestation continue at the current rhythm, the country will face the threat of completely running out of its timber reserves in the very near future.

Replacement of biomass by fossil fuels, although apparently desirable from the practical point of view, is unfeasible from the economic point of view. Any measures aiming to increase importation for energy purposes need to be taken with extreme care, due to the low income of the population and consequent inability to pay. The petroleum products, that represent only around 20% of the domestic energy supply (Figure 61), use more than 35 to 50% of the external incomes of the country (BME, 1996). In this manner, there is a need for proposals for alternative methods for the production of energy within the country and in a sustainable manner.

In the current situation, the residential sector is the one that demands the most urgent action, as it is responsible for the greater part of energy consumption in the country. As a first step, some ONGs with support from the Haitian government have adopted the strategy of minimizing the consumption of charcoal in residences, through the replacement of traditional coal stoves by improved, more efficient models, that may save up to 40 to 50% of the energy used to cook (Portnoff, 2007). But reforestation with the objective of charcoal production is estimated to supply only around 23% of demand. Therefore, even if all the coal stoves in Haiti were replaced by efficient models, the current reserves still would run the risk of being totally exhausted, though somewhat slowly, if no parallel measures are taken to increase the production of charcoal.

Considering this reality, the government intends to gradually replace some coal stoves by LPG stoves. This replacement, however, will be very difficult and time-consuming, as most of Haitian families cannot afford an LPG stove, and the measure would require the country to spend some of its financial resources on LPG importation. In one way or another, the best short-term strategy appears to be an increase in the production of biomass in the country, whether through intensification of reforestation with fast growing species or other measures.

Taking advantage of the tradition of the country in the production of sugarcane and, initially, adapting the existing industry framework, it is possible to produce ethanol for the preparation of meals, replacing the charcoal currently used. When the replacement of the fuel used to cook is mentioned, a concern in respect of its acceptance within the culture of the people in question arises. However, there are records of success in the replacement of charcoal by ethanol in the liquid form or gel for residential use in countries like Zimbabwe and Ethiopia (ESMAP, 2007), therefore, there is possibility of a similar success in Haiti.

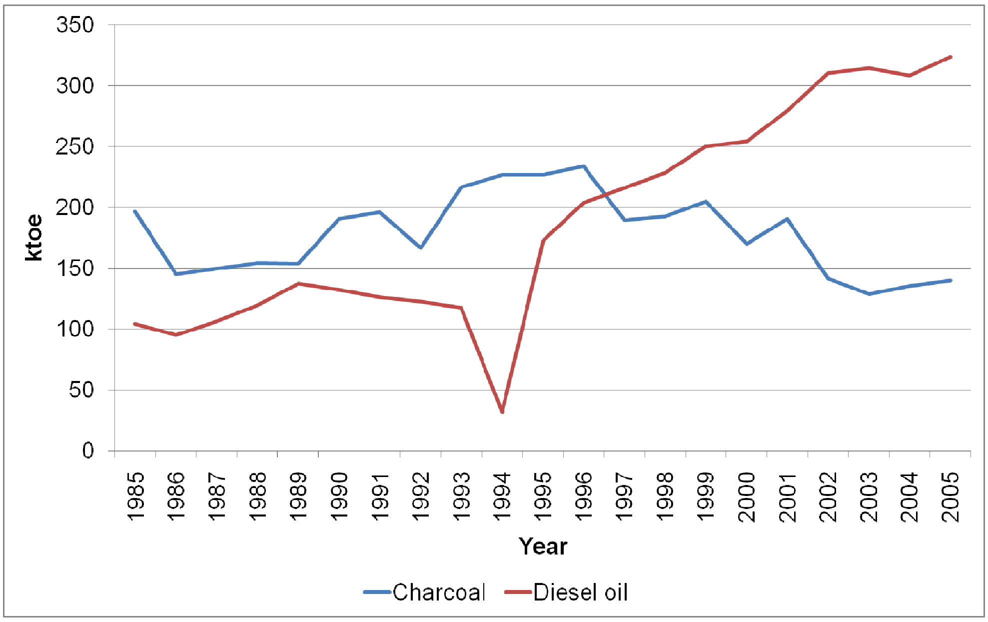
**Table 39**
**Cost of energy in Haiti in 2003.**

| Sources | National Consumption (MT) | Percentage (%) | Price/ton (US$) | Value (US$) | Percentage (%) |
|---|---|---|---|---|---|
| Fuelwood | 401,355 | 36 | 100 | 40,135,500 | 9 |
| Charcoal | 207,000 | 18 | 300 | 62,100,000 | 14 |
| Gasoline | 118,650 | 10 | 1,050 | 124,582,500 | 27 |
| Kerosene | 78,220 | 7 | 750 | 57,165,000 | 13 |
| Diesel | 321,300 | 29 | 523.6 | 168,232,680 | 37 |

Source: Bureau of Mines and Energy (BME), 2005

In industry, there is also the intensive use of primary biomass, which responds for 70% of the energy consumed by this sector (Figure 80). Biomass is used by industry mostly in the form of firewood or charcoal. This fact aggravates the problem on non sustainability in the use of biomass, because although a part of this biomass does come from bagasse, 69% correspond to the direct use of firewood or charcoal.

**Figure 80**
**Consumption of charcoal and diesel oil in Haiti, from 1985 to 2005.**




Source: Prepared by FGV with data from IEA.

The growing proportion in the use of gas/diesel oil (Figure 71) by the industrial sector shows the gradual replacement of biomass by diesel oil. In particular, there is an effort on the part of the government in the sense of promoting the replacement of charcoal by diesel oil in the industrial and services sectors. The results of this effort can be seen in Figure 80, where it can be observed that, as from the year 2000, the consumption of gas and diesel oil exceeded the consumption of charcoal in the country, following a consistent tendency.

As this replacement is desirable to make the use of energy by industry sustainable from the environmental point of view in the short term, the financial cost of importation of petroleum products may make it unfeasible. The expense with diesel oil represented 37% of all the expenses of Haiti with energy in 2003 (Table 39). In this scenario, the replacement, at least in part, of diesel oil by vegetable oils (biodiesel) produced domestically might become a viable alternative for this dilemma, both from the financial point of view as from the sustainability point of view. Biodiesel could replace a percentage of diesel oil through mixtures or even replace diesel oil completely, often without the need for any adaptations in the motors.

In the transport sector, 40% of the energy consumed in 2005 came from automotive gasoline and 52% from diesel oil (Figure 78). Diesel oil is used in all sectors in a quantity 2.7 times more than gasoline. However, a ton of gasoline costs double the cost of a ton of diesel oil (Table 39). Consumption of gasoline may be reduced promptly through mixing with ethanol, which can be produced within the country from sugarcane. This strategy is currently used successfully in Brazil, where up to 25% of ethanol is mixed with gasoline and used in ordinary vehicles without the need for adaptation in the motor.

The transformation sector consumes biomass chiefly in the form of timber, which is converted into charcoal. In second place, comes the production of electricity from various sources of energy, especially petroleum products in the form of diesel oil. Haiti does not have a hydroelectrical potential, therefore it cannot afford to depend exclusively on hydro energy to supply the demand for electricity in the future.

Some reports suggests the use of wind energy, through the implantation of windmill parks, for which the country has a good potential. Windmills have the great advantage of not polluting the environment and needing little labor for their operation. The cost of implantation per MW, however, is even greater that that of hydroelectric plants. Besides, there are other questions that should be considered carefully when planning the implantation windmill parks, such as the seasonality of the winds, especially in respect of the hurricanes that regularly hit the country.

The use of solar energy for the production of electricity has been suggested for remote areas, away from transmission lines. In this case, solar energy would be used in a limited manner, especially in public health centers, for the preservation of vaccines in refrigerators, and in telecommunication services. As the cost of production of electricity from sun light is quite high, it is necessary to make a cost/benefit evaluation, considering the cost of implantation of photocells and the cost of extending the electricity distribution lines.

It seems, therefore, that the ideal strategy involves the diversification of the sources of energy used for the production of electricity. Amongst the sources of energy that may be used without compromising the national timber reserves and in an economically viable manner are annual crops with high biomass production capacity. Elephant grass, for example, can produce around 30 t of dry matter a year per hectare. That is amount is enough to generate up to 27 MWh of electricity.

## 6.8 Electricity

The installed capacity in the country is approximately 240 MW and the generation of energy for the distribution network is close to a 620 GWh (US-DOE, 2004). Due to the long distances between the energy producing plants and other locations in the country, the voltage in the transmission and distribution lines is 13.2/23 kV; 7.2/12.47 kV or 2.4/4.16 kV.

The metropolitan region of Port-au-Prince is the most important for the electric energy sector. The three power plants (two thermoelectric and one hydroelectric) together comprise a total installed capacity of 171.87 MW. Other power plants are in the North, Artibonite, South, Center-West and Jacmel regions (Table 40).

**Table 40**
**Regions, localities and capacities of the electric plants installed in Haiti.**

| Region | Installed Capacity (MW) |
|---|---|
| Metropolitan | 171.87 |
| Norte | 10.65 |
| Artibonite | 16.10 |
| Sul | 8.25 |
| Center-West | 4.92 |
| Jacmel | 4.32 |

Source: Haiti Energy Sector Development Plan 2007-2017, 2006..

In spite of the installed capacity summing more than 200 MW, the available capacity is much less, influenced by climatic seasons and by company problems, factors that are mainly due to the lack of maintenance and absence of spare parts. Electricity losses in 2002 were from 46 to 54% [24], and, due to bad business management, some installations have their structure compromised and financial problems make it impossible for Haiti to attain the production demanded nationally.
The undeveloped potential of hydroelectric energy in Haiti is estimated at approximately 150 MW, a value that includes the potential 45 MW that may be generated from the bi-national plant of Dos Bocas (total capacity 90 MW)[25].

[24] IEA, 2002.
[25] Haiti Energy Sector Development Plan, 2006.

The electrification rate[26] in the country is low, not exceeding 5.6% in the metropolitan region. In other regions, like the South and Center-West, for example, these values are close to 1.06% and 0.90% respectively (Table 41).

**Table 41**
**Electrification rate by region in Haiti.**

| Region | Electrification Rate (%) |
|---|---|
| Metropolitan | 5.60 |
| Norte | 1.12 |
| Artibonite | 1.32 |
| Sul | 1.06 |
| Center-West (Jacmel) | 0.90 |

Source: Haiti Energy Sector Development Plan, 2006.

## 7. Analysis of the Infrastructure

The study of the infrastructure necessary to make the production and distribution of biofuels feasible involves analyses of various sectors, such as logistics of the importation, production and distribution, mixing capacity (alcohol–gasoline and biodiesel–diesel oil), storage capacity, existing ports, and also producing plants and sugar manifactures that may receive investments for the production of biofuels.

The deterioration in the infrastructure in Haiti reached critical levels, and the situation has worsened since, at the end of the decade of the 1980s, the maintenance services stopped being executed. The privatization of various sectors and the attribution of the administration of the Port-au-Prince port to the national government was suggested. Progress in this sense, however, has stagnated.

Haiti has the highest port costs amongst the Caribbean countries. A port project came to be idealized, but the result was classified as unsatisfactory.

A project, revised in 1997, for development and industrial restructuring to support the privatization of state public services, ended up collapsing. A technical preparatory work for large state

[26] Proportion of homes with a legal connection to the electric energy network.

companies (electricity, telephone, water, ports and airports) for privatization was concluded. However, the lack of political stability and the debility of the judicial picture impeded any kind of progress[27].

The transport sector has ignored the experience of pervious projects. Since the end of the eighties, Haiti has not shown any program for regular maintenance. The only maintenance program for transport infrastructure in existence was suspended due to deviation of funds destined to road works not included in the project. Other problems include a lack of audits, wrong calculations, connected to the continuous deterioration of the roads and long delays in releasing imported by customs.

As to the agricultural infrastructure, a lack of modern production technology for the small farmers, basic infrastructure, like sheds, silos to store the harvests and, as noted before, means for distributing the production (roads, ports etc.)

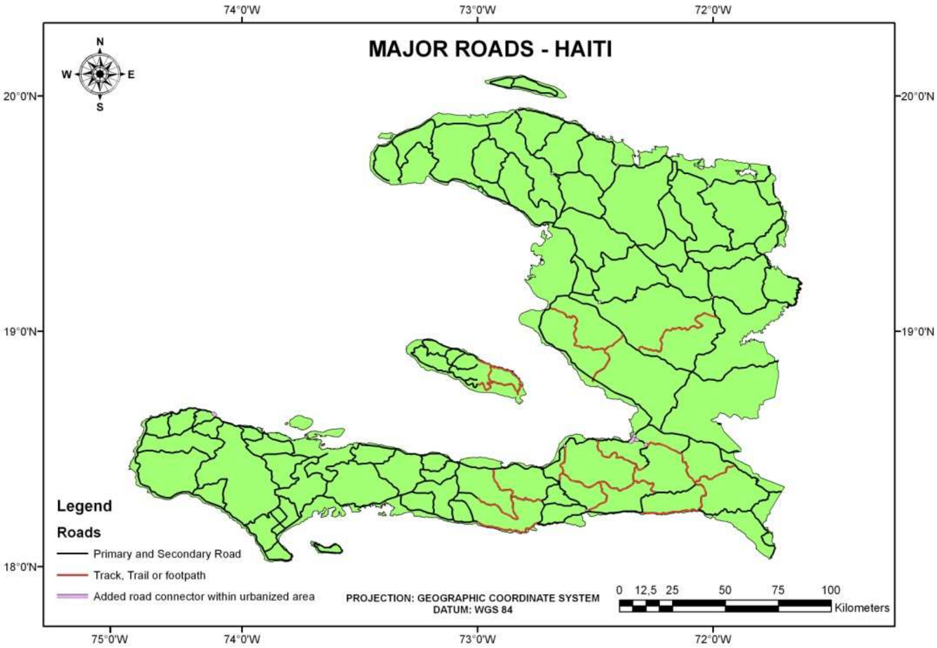
## 7.1 Transport

### 7.1.1 Roads

In the year of 1989, Haiti had 3,700 kilometers of roads, out of which, only 17% were paved, 27% covered with gravel or another material, and the rest (56%) had no type of covering. In 2002, the road network extended for about 4,160 kilometers, and the ratio of paved roads reached 24.3% (Table 42, Figure 81).

[27] Rural Development and Environment – Report N°. 23637 .

**Figure 81**
**Major roads and tracks in Haiti.**




Source: Prepared by FGV with data from Geocommunity

The roads that connect the agricultural regions to consumer markets are scarce. The agricultural production is transported to the consumer centers with the use of animals or humans.

**Table 42**
**Road infrastructure of Haiti.**

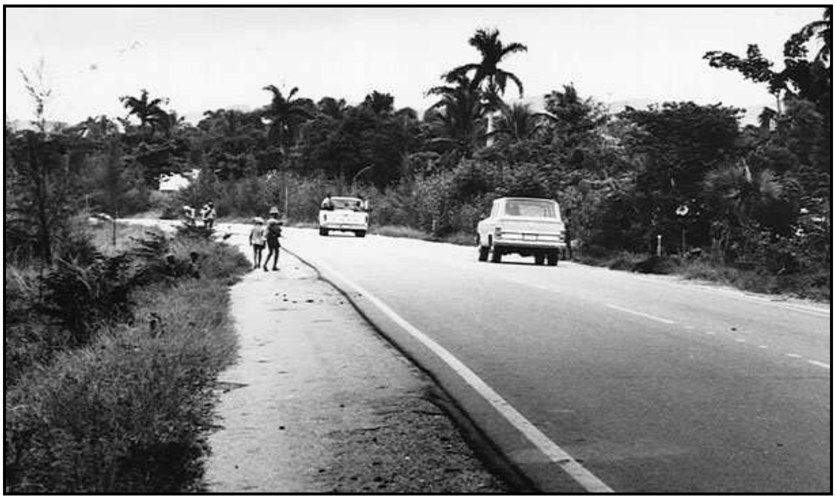
| Infrastructure | 1989[1] | 2002[2] |
|---|---|---|
| Roads (km) | 3,700 | 4,160 |
| Paved Roads (km) | 629 | 1,011 |
| Paved Roads (%) | 17 | 24.3 |

[1] Source: Library of Congress, 2006.
[2] Source: Encyclopedia of the Nations, 2008.

In the year 1980, a road connecting Porto-au-Prince to Les Cayes was inaugurated, and some improvement projects in the road system were completed successfully. The deterioration of the roads, on the other hand, continued, due to the constant floods and lack of maintenance until then.

Necessary institutional reforms, including reorganization of the ministry and the creation of a fund destined to road maintenance, were not implemented. The project was canceled in 2001, and its operations were considered not viable from the sustainability point of view.

**Figure 82**
**Route National 2 (RN2), close to Miragoâne.**



Source: Inter-American Development Bank

**Figure 83**
**Route National 1 (RN1), close to Limbé, north of Haiti.**

Source: www.haitiinnovation.org.

**Figure 84**
**Unpaved Road close to Cap Haïtien.**

Source: FGV, 2008.

**Figure 85**
**Road close to Mole Saint-Nicolas, Northwest of the country.**

Source: Rich and Marj Byers.

In 2005, a task force promised to invest US$ 5 million in the recovery of more than 80 kilometers of rural roads in Haiti. The roads to be reformed are used to transport sugar, coffee, cocoa beans, bananas and pineapples from the villages of Port de Paix and Limbé, in the North and Northwest of Haiti, to Cap Haïtien, second largest city in the country, where there is a port and a large consumer market. The works in the Northwest of the country constitute only the initial stage of the agreement signed between the IADB and the Haitian government. The investment in infrastructure is a one of the fronts of action of the IADB in Haiti. The bank authorized funds in the order of US$ 70 million for the recovery of the roads and rural paths by the UN peace forces. The resources that the bank provided for the country summed US$ 320 million and served for the financing of projects in areas considered fundamental for the socio-economic[28] recovery.

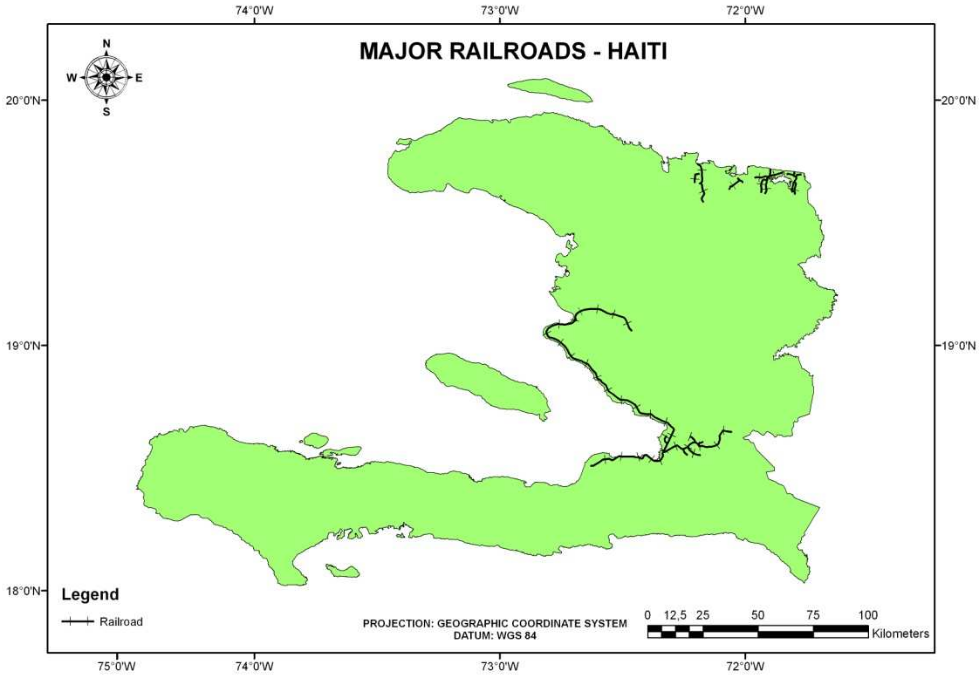
## 7.2 Railways

Haitian railways were used exclusively for the transport of sugarcane, serving some port regions in the country. Originally, two railway systems were functioning: the Haiti National Railway and the Cul-de-Sac Railway, which, combined, had 301 km of extension (Figure 88), operating lines from Port-au-Prince up to Varretes and Léogâne, and from the south of Cap-Haiten up to Bahon. In 1982, the greater part of the system became inoperative, and the remaining 40 km of railway lines, which were being used for the transport of sugarcane, were closed down at the start of the decade of 1990[29].

Since then, a large part of the tracks and sleepers were stolen from the railway lines and currently they cannot be reopened, unless they receive large investments for their recovery.

[28] PNUD – United Nations Program for Development, 2005.
[29] http://permanent.access.gpo.gov/lps35389/2000/railways.html

**Figure 86**
**Original trajectory of Haitian railway lines.**




## 7.3 Waterways

Haiti has less than 100 km of navigable rivers. Most of the rivers in the country have small lengths and a fast flow. These characteristics are determined by the mountainous terrain and its narrow peninsulas. All the rivers in Haiti are influenced by the rainy seasons and, therefore, do not have a constant volume during the year[30].

## 7.4 Ports and Maritime Transport

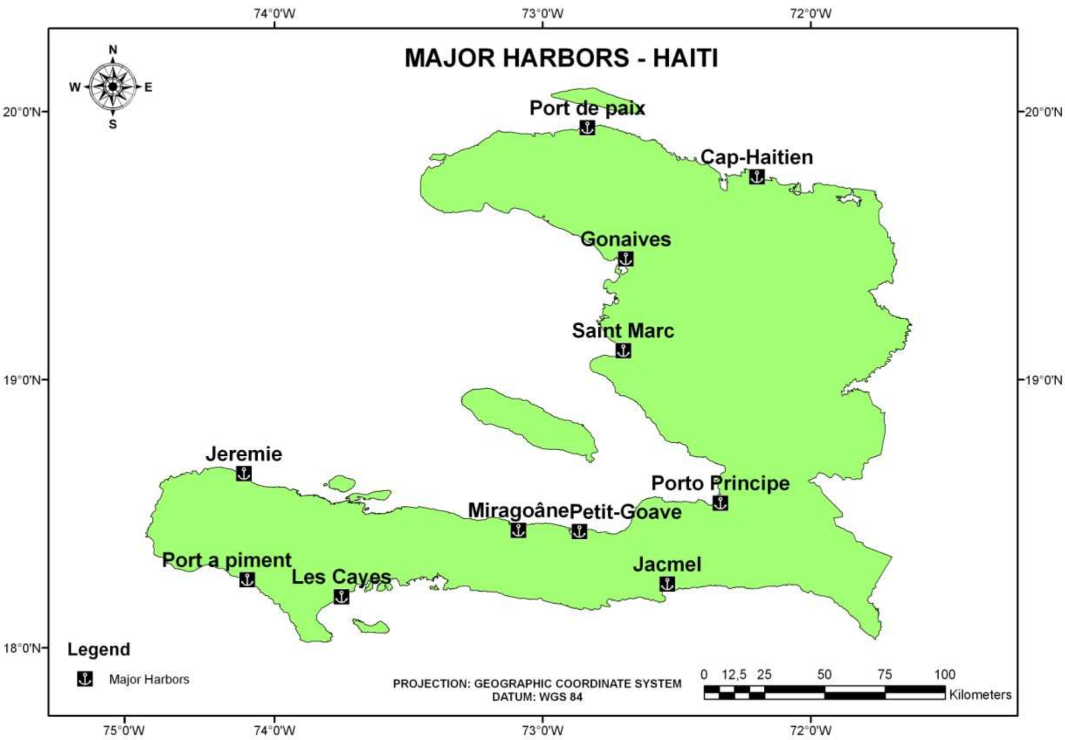
Haitian commercial shipping is composed of a small fleet of small sailing vessels, involved in coastal business transactions, and some motorized vessels, responsible for transport o flight cargos.

[30] Library of Congress, 2006.

Port-au-Prince is the primary port for maritime transport of cargos and passengers. Currently, the government has the possession and administers the port. However, privatization plans are undergoing studies (privatization proposals were repeatedly postponed).

The Port-au-Prince port occupies an area of approximately 15 hectares and has a crane service with a capacity to lift loads of up to 30 tons. In Miragoâne and Cap-Haïtien there are other important exportation ports. Small ports in activity are installed in Pêtit Goâve, Gonaïves, Jacmel and Port-de-Paix, Fort Liberté, Saint-Marc, Carriès, Anse-a-Galets, Cite Soleil, La Saline, Baradères, Jérémie, Anse-d'Hainault, Corail, Port-à-Piment and Cayes, but they lack equipment for moving loads with large volumes and some of these ports are to be found inoperative at the moment.

**Figure 87**
**Location of Haitian ports.**




Source: FGV, 2008.

**Figure 88**
**Unloading containers in Port-au-Prince port.**


Source: Banco Inter-Americano de Desenvolvimento.

**Figure 89**
**Port in Miragoâne.**

Source: www.pbase.com

**Figure 90**
**Port in Saint-Marc.**

Source: www.briarpatchmagazine.com.

**Figure 91**
**Port in Jérémie.**

Source: www.picasaweb.google.com

Haiti is heavily dependent of overseas maritime transport. During the start of the decade of 1980, Word Bank sought to stimulate business among ports through the construction of port installations in Jérémie, Port–au-Prince and Port-de-Paix. Other ports involved are: Cap-Haïtien, Gonaïves, Jacmel, Les Cayes, Miragoâne and Saint-Marc.

## 7.5 Air transport

In 2007, there were 14 airports in Haiti, with paved runways and 8 without any kind of paving. Due to the precarious situation of Haitian airports, helicopters have performed an important role as a means of transport for the international forces in Haiti.

Domestic flights are made by the company *Air Haiti*, connecting the major regions with regular programmed flights. Companies responsible for operating operational flights are: *ALM, American Airlines, Air Canada, Canada 3000, Caribintair, Tropical Airways, Haiti International Airlines, Air France and COPA.*

## 7.6 Biofuel Storage Capacity

Haiti imports petroleum products from Venezuela, Trinidad and Tobago and Panama. The storage capacity for petroleum products is approximately 1.7 million barrels. Out off this total, storage for diesel oil is 850 thousand barrels, for gasoline, 370 thousand barrels, for fuel oil, 178 thousand barrels, for kerosene, 139 thousand barrels, and for LPG (liquefied petroleum gas), 23 thousand barrels (Table 43). This capacity is sufficient for a period of 5 to 6 months, in view of the low annual consumption of petroleum products. This infrastructure may be also used for storage of biofuels produced in the country, but if of petroleum products importation continues and a biofuel industry emerges in Haiti, it will probably be necessary to increase the fuel storage capacity in the country.

**Table 43**
**Storage capacity for petroleum derivative products.**

| Companies | GLP | Gasolina | Diesel | Kerosene | Aviation Gasoline | Fuel Oil | Asphalt | Others | Total |
|---|---|---|---|---|---|---|---|---|---|
| Esso | | | | | | | | | 83,400 |
| National | 3,340 | | | | | | | | 143,420 |
| Texaco | | | | | | | | | 231,500 |
| Tropigas | 3,000 | | | | | | | | 3,000 |
| Haitigas | 714 | | | | | | | | 714 |
| Total/Elf | 14,265 | 300,000 | 650,000 | 76,200 | | | | | 1,040,465 |
| Ecogas | 1,952 | | | | | | | | 1,952 |
| State Enterprises | | | | | | 84,000 | | | 84,000 |
| Government | | | 61,905 | | | 38,095 | | | 100,000 |
| **Total** | 23,721 | 369,000 | 852,405 | 139,200 | 112,000 | 178,095 | 6,780 | 7,700 | 1,688,451 |

Souce: Haiti Energy Sector Development Plan, 2006.

## 7.7 Current Vehicle Fleet Situation and Prospective

Mixing up to 10% of ethanol in gasoline (E10) allows its use, without the need for any adjustments, in current gasoline powered vehicles. When this mixture (*blend*) exceeds 85% ethanol (E85), there is a need for major changes in the motor. Biodiesel, on the other hand, may be used directly or mixed (*blend*) with conventional diesel oil in diesel injection cycle motors directly with little or no need for modification.

Data from the Haiti National Energy Sector Development Plan (2006) show that approximately 59% of automotive vehicles are used for the transport of passengers. The number of automobiles per person, on the other hand, is relatively low, if compared with others countries in Latin America (Table 44).

**Table 44**
**Ratio between automobiles and passengers in Latin American countries in 1994**

| Country | No. of automobiles per group of 100 people |
|---|---|
| Colombia | 45.3 |
| Brazil | 19.0 |
| Venezuela | 13.4 |
| Mexico | 11.0 |
| Argentina | 7.7 |
| Haiti | 1.0 |

The greater part of paved roads and services surround the capital Port-au-Prince, where 85% of the traffic is concentrated[31].

# 8. Survey of Available Technologies

With the possible establishment of a biofuel production industry in Haiti, appears a series of business opportunities, ranging from sale of industrial equipment (production plants, components for extension of existing plantations etc.), machines and agricultural implements, technical support in consultancy projects, technologies related to new precision agriculture techniques, even consultancy in the development of new varieties adaptable to local conditions.

Depending on the purpose and type of energy that it is intended to produce, the recommendations in relation to the crop species to be used may vary, for example, if the objective is to produce biofuel to replace the gasoline used in cars, the recommended option would be ethanol. Amongst the crops that may be used for the production of ethanol, sugarcane is the most productive. Therefore, if the climatic and soil conditions are favorable to the development of this culture, it should be recommended.

If, however, a renewable energy option is sought to power diesel cycle motors, ethanol is not suitable. The best proposal, in this case, would be the production of biodiesel, which may be used in this kind of motor with little or no need for adaptation. Several crops, such as palms, soya beans, sunflower, jatropha, etc. may serve as a source of vegetal oil for the production of biodiesel and, once again, the final decision will depend on the climatic and soil conditions available.

Electricity is a type of energy that can be obtained from many different sources, ranging from nuclear fission to the rotation of windmill blades. Some agricultural crops also may serve as sources of energy for the transformation into electricity. One of the most remarkable is sugarcane, whose bagasse, that are a residue obtained after the extraction of the juice that serves as a raw material for the production of sugar and ethanol, may be used for the production of electric energy.

[31] Library of Congress, 2006.

Other crops may be cultivated especially for this purpose, without, however, the possibility of the concomitant production of some kind of biofuel. Elephant grass is a plant whose biomass has a calorific power (energy content) greater than sugarcane and may be used for the production of electricity, for example, in areas where there is no intention to install ethanol plants.

In the case of Haiti, all the above hypotheses should be considered, since the country depends on the importation of petroleum products, especially diesel oil and gasoline, for use mainly in the transport and industry sectors. Current production of electricity is not sufficient to meet demand. Besides, it is based on the consumption of diesel oil. In this scenario, in the short term sugarcane has the perspective of being the most useful crop for the diversification of energy matrix, with a sustainable production of bioenergy. Furthermore, the country already has a tradition of cultivating this plant, making the implantation of projects based on sugarcane easy.

Haiti produces sugarcane for the manufacture of sugar and liquor. However, the current system has low productivity and a low technological level. Several technologies developed or adapted in Brazil may turn the production more competitive, with lower costs, higher quality and consequently greater profitability and sustainability, also assuring the environment preservation.

## 8.1 Sugarcane varieties

### 8.1.1 Varieties currently cultivated in Haiti

In Haiti, 3 varieties of sugarcane coming from India (CO-421, CO-290 and CO-419), 3 coming from Barbados (B-47258, B-1177 and B-4362), 1 coming from Indonesia (POJ-2878) and 1 coming from Taiwan (F-160) are cultivated now.

- **F-160**: was introduced from Florida and has been cultivated in country for more than 20 years because of its remarkable resistance to smut — a disease caused by the fungus *Ustilago scitaminea* —, one of the principal fitosanitary problems of the sugarcane crop in Haiti. F-160 is also resistant to rust and may be used in crossings to obtain new varieties with this characteristic.
- **POJ-2878**: Highly resistant to mosaic (caused by the SCMV virus), but susceptible to the Fiji Disease — a virosis caused by the FDV virus and transmitted by leafhoppers

*Perkinsiella saccharicida*, *P. vitiensis* and *P. vastatrix*, that are not found in the Americas. It has been on the market since 1928 and has been famous – known by the nicknamed "Wonder Cane" – for being highly productive and resistant to diseases. It is often used crossings and more than 80% of the hybrids in Brazil today come from this variety because of its resistance to mosaic[32].

- **CO-421**: Older than POJ-2878. Highly susceptible to sugarcane borer (*Eldana saccharina*), that has caused damage in Africa (South Africa and Kenya). Relatively susceptible to smut.
- **CO-290**: Legendary variety that was used in 80% of the plantations in the state of São Paulo at the beginning of the last century, before the creation of Brazilian hybrids with high productivity.
- **CO-419**: On the market since 1933, it is a highly productive variety and with high sucrose content, known in India, its country of origin, as a variety suitable for cultivation in tropical regions. For three decades, it dominated the cane plantations in the tropical regions of India.
- **B-4362**: Known for being highly susceptible to rust (caused by *Puccinia melanocephala*) and mottled stripe (caused by *Herbaspirillum rubrisubalbicans*).

No information was found on the other varieties coming from Barbados: B-47258, B-1177, B-1174. None of the above varieties are used in the neighboring Dominican Republic.

### 8.1.2 Development of sugarcane varieties

Generally speaking, the programs for genetic improvement of sugarcane seek to obtain certain characteristics by means of performing crossings among individuals or with transgenic techniques. These programs seek to obtain genotypes with characteristics like high productivity, high sucrose level, and suitability for harvesting, resistance to pest, diseases, water deficit and pith.

Currently, the principal programs for genetic improvement of sugarcane in Brazil are:

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[32] http://www.jornalparana.com.br/materia/ver_edicao.php?id=1507&tipo=84

- Interuniversity Network for the Development of the Sugar-Alcohol Sector (RIDESA), whose varieties are identified by the initials Rb. It is formed of the Ministry of Education and Sports and by federal universities (UFPR, UFSCAR, UFV, UFRRJ, UFS, UFAL, UFG, UFMT and UFRPE), with the aim of continuing the activities developed by the extinct Planalsucar. Currently, the institution has 31 experimental stations and holds a major position regarding area cultivated with sugarcane in Brazil.

- Sugarcane Technology Center (Centro de Tecnologia Canavieira – CTC): a private, non profit private association, aimed at the technological development of the sugarcane, sugar, alcohol and bioenergy sectors. It has various plants as partners in the development of new varieties. The center is currently supplying third generation varieties.

- Sugarcane Center, Agronomical Institute of Campinas (Instituto Agronômico de Campinas – IAC): with a headquarters in Ribeirão Preto, the program has the participation of researchers from the IAC, the Regional Centers of the São Paulo State Agribusiness Technology Agency (Agência Paulista de Tecnologia dos Agronegócios – APTA), as well as associated companies, sugarcane suppliers cooperatives, Copersucar, Sugarcane Technology Center (CTC), Universities (UNESP, UNICAMP, USP), research institutes from São Paulo state and EMBRAPA.

- Canavialis (CV): a company in the Votorantim group, founded in 2003 by researchers from the Sugarcane Genetic Improvement Program from the Federal University of São Carlos (UFSCAR). The institution has as its objective to become the largest provider of genetic solutions for the sugar-alcohol sector in the world.

The genotypes used in Haiti are old varieties, with up to 1 century of existence. Although varieties like F-160 and POJ-2878 do have some virtues, such as resistance to certain diseases and high productivity, in other countries they are mostly being used solely as genetic material for the creation of new varieties that combine resistance to several diseases with the suitability to given climate and soil conditions.

For example, there are drought — one of the problems faced by the sugarcane crop in Haiti — tolerant varieties today. There are also varieties with a high productive potential, capable of taking better advantage of fertile soils and/or a large doses of fertilizers; rustic varieties, that adapt better to poor soils; varieties adapted to different ranges of climatic conditions, whose combination in staged planting allows extending the harvest period for several months.

### 8.1.3 Planting

In Brazil, the preparation of the soil for staged planting of sugarcane is normally done in 3 to 4 operations: 1 plowing and 2 to 3 harrowings. Depending on the need, sub-soiling is also done and application of limestone. Planting is divided into, at least, 4 operations: grooving+fertilizer spreading, distribution of filter cake in the grooves, distribution of the seedlings and covering the grooves. In Haiti, however, at the most, only 3 mechanized operations are performed: plowing, harrowing and grooving. The planting operation is manually performed, with seedlings obtained directly from other areas of commercial planting. Ideally, however, the seedlings should come directly from greenhouses, and grown under specific treatments for the production of seedlings. This crop treatment, which includes the thermal treatment of the seedlings and inspection of the greenhouse area to eliminate cane plants from other varieties and/or plants that show symptoms of diseases, are very important to avoid propagation of diseases in the field. The lack of this care aggravates the problem of some diseases, like smut, currently faced by the Haitian farmers.

Sugarcane is a perennial culture, capable of producing reasonably for 6 years, with one cut per year. In Haiti, however, the cane is cultivated as if it were an annual crop, being replaced by another crop — such as corn and beans, for example — after the first cut. Although the first cut is in fact the most productive, the best cost/benefit ratio will only be reached after the 5th or 6th cut. The advantage of cultivating the same crop for successive harvests is in the economy with the operations necessary for planting: the cultivation cost up to the first cut gets to be 130% greater than the annual cost of maintenance of the crop after the second cut onwards.

### 8.1.4 Semi-Mechanized Planting

Semi-mechanized planting involves manual and mechanized operations, they are: grooving, distribution and planting of seedlings, fractioning and alignment of seedlings within the groove and covering the grooves.

Grooving is a mechanized operation, done concomitantly with the application of pesticides and fertilizers, such as NPK and micro-nutrients. In this operation, 150HP tractors are used, with an operational performance of 0.9 $ha.h^{-1}$. The planting machines available on the market have two or three lines of groovers, capable of planting with a controlled depth.

In relation to the distribution and seedling planting, operation, these are done in a manual manner, by teams formed of “carriers”, “pickers” and “planters” or “distributors”. The “carriers” drag the plant wagons so that the planters can distribute them in the planting grooves.

The “covering” of the seedlings is done mechanically, using a tractor and a special implement called “coverer”. There are coverer models with a different number of lines, suited fro each kind of groove. Covering is done soon after the operation of distributing the seedlings, seeking to avoid loss of humility from the soil and exposure to the sun that may cause dehydration of the seedlings.
Prior to planting, there is the bunch loading operation, done by the carriers, with an operational performance close to 2.9 $ha.h^{-1}$.

### 8.1.5 Mechanized planting

Mechanized planting eliminates the need for labor in the cutting operation and reduces the number of workers that would be necessary for other operations done during planting in the conventional system, allowing a reduction in the crop costs. In the mechanized system, the grooving, planting and covering of the planting operations, as well as the application of insecticide and liquid fertilizer, are done with a single pass of the planter.[33]

The labor involved in this operation consists of the tractor driver who handles the groovier and the fertilizer flow and an assistant, whose responsibilities are to control the flow of insecticide, the number of seedlings placed in the planting groove and the steam roller. To drive the planter, it is necessary to have a tractor with, at least, a power of 180 HP (Figure 92). There are also self-propelled planter models on the market (Figure 93).

[33] Segato 2006.

**Figure 92**
**Planter pulled by a tractor**

Source: http://www.fenasucro.com.br

**Figure 93**
**Plantadora auto-propelida Servspray – Modelo Tropicana.**

Source: www.servspray.com.br

## 8.1.6 Localized application of agricultural inputs

The localized application of agricultural inputs is a new technology based on geographic information systems (SIG) and used only in high-tech cultivations to obtain maximum productivity using only the quantity of inputs necessary for each area mapped by the SIG. In conventional application, on the other hand, the same quantity of product is applied uniformly over the whole area where the operation is done. Figure 94 shows an equipment model for localized application of inputs.

**Figure 94**
**Equipment for localized application of consumables: Jacto – Uniport Model.**

Source: www.jacto.com.

## 8.1.7 Irrigation

The availability of water is a decisive and limiting factor in agriculture. Irrigation many times may determine the success of the cultivation, because of the increase in productivity and longevity of the cane plantations, as well as allowing harvest outside the normal times.

Irrigation systems are classified basically into four types: by surface, by spray, localized and underground. The decision on which system to use should take into account several variables, amongst them, terrain topography and availability of energy.

Surface irrigation is characterized by opening grooves, whose function is the conduction and infiltration of water. In the spray system, the water is sprayed over the land surface, in a similar manner to rain. The use of this system in large areas is made difficult by the need for labor to transpose the pipes.

Irrigation by a central pivot (Figure 97) is a good option for sugarcane, showing as advantages the uniformity of application and the possibility of using ferti-irrigation (fountain). The use of a towable central pivot allows the transfer of the equipment to other areas. Irrigation by spraying also can be done by the linear relocation system, similar to the central pivot system, with the difference that the relocation is done in the sideways direction, being ideal for rectangular areas and slightly undulating relief.

The dropper irrigation system may be performed on the surface or underground (Figure 97). Generally, irrigation by dropping consists of the application of water directly over the surface with the greatest root concentration. Irrigation by underground dropping is a variation of the traditional system, and the pipes are buried to a depth of 0.15 to 0.40 m, depending on the crop for which they will be used. In this system the principal advantages are: reduction in the loss of water by direct evaporation from the soil surface, flexibility in the use of agricultural machines, greater difficulty for weed germination (since the soil surface is kept with a low water content).

As well as the characteristics cited previously, automation of the irrigation systems is becoming common, with partially or fully automated systems. In these systems control is done by sensors, responsible for the application of water in predetermined amounts. The following figures show the irrigation systems available for sugarcane.

**Figure 95**
**Irrigation by spray – jet.**

Source: www.cnpms.embrapa.br

**Figure 96**
**Localized irrigation – underground.**

Source: www.netafim.com.br

**Figure 97**
**Irrigation by spray – pivot**

Source: proex.reitoria.unesp.br

**Figure 98**
**Surface irrigation – canal.**

Source: www.dicionario.pro.br

### 8.1.8 Use of GPS in Agriculture

Created by the United States Defense Department, the GPS, an acronym for Global Positioning System, is used in agriculture in the most varied manners: registration surveys, monitoring roads and tracks, geo-referencing photographic and video graphic images, geo-referencing sample points, mapping of agricultural and forestry areas, mapping of tracks, determination of control points for satellite images, mapping of soils and watercourses etc. As well as the indispensable application of GPS in precision agriculture, this activity needs constant and often real-time geo-referencing in the field.

A new GPS application in use now in sugarcane plantations is the “automatic pilot”, used in the several driving stages of the culture. With the use of this equipment, it is possible to reduce fuel consumption in operations and obtain greater parallelism between the planting grooves.

### 8.1.9 Monitoring of the Harvest

Monitoring of the harvest through satellite images may supply information on the crop in its various phenological states. With this tool it is possible to monitor the development of the crop and obtain information regarding infestation by pests and diseases and to draw productivity estimates. In the same sense, harvest monitoring offers full data for the formulation of agricultural and supply policies.

The monitoring method consists of activities done in the office and in the field. Using satellite images and geo-referenced information obtained in field, this information can be combined and analyzed together, generating key information for agricultural planning

Currently, there is no record of the use of this kind of service in the country under investigation. The high cost to acquire updated satellite images is still the main barrier for offering this service.

### 8.1.10 Mechanized harvest

The adoption of a system of mechanized harvesting for sugar is a trend among the traditional producers, who are replacing manual harvesting and, thus, allowing for greater agricultural and industrial productivity. The harvesting may be done with or without burring the straw and for the success of harvesting raw cane, it is necessary to meet three requirements: well prepared land, high quality harvester and a well trained operator.

There are various harvester manufacturers, highlighting worldwide John Deere and Case IH (Figure 99 e Figure 100), which, currently, export agricultural machines to countries in Central

America. In the case of tractors and agricultural implements in general, the principal supplier is the United States.

However, when dealing with harvesters and sugarcane planters and specific implements for the culture, the chief supplier is Brazil, which, together with Australia, is the largest manufacturer of harvesters.

As to the classification of harvesters, these may be separated into: tracked/tired; one, two, three harvest rows, whole or divided cane. In choosing a harvester, there should be taken into consideration the agronomic conditions of the locale for doing the harvest, especially the slope of the land, it is recommended that mechanized harvesting is done in lands whose slope does not exceed 12%.

**Figure 99**
**Sugarcane divider harvester - John Deere, Model 3510.**

Source: www.deere.com

**Figure 100**
**Sugarcane divider harvester - Case IH, Model 7700.**

Source: www.caseih.com

In operations done with sugarcane divider harvesters, loading of the trucks is done simultaneously with the harvest (Figure 101). In this manner, one sugarcane loading operation is eliminated, reducing the cost. The capacity of the harvesters ranges from 15 to 20 $t.h^{-1}$, and the harvest operation may be done 24 hours per day.

**Figure 101**
**Loading sugarcane simultaneously with harvesting.**

Source: www.sugarcanecrops.com

# 9. Additional Reasons for the Development of a Biofuel Chain

Haiti does not produce any kind of biofuel in its territory, in spite of its potential and tradition in the production of sugarcane. The Food and Agriculture Organization of the United Nations (FAO) included in its development packet for the country the production of energy from renewable sources and listed benefits in the environmental, social and economic spheres.

The positive impacts coming from investments in the biofuel productive chain are of sum importance for countries under development and dependent on the importation of petroleum, like **Haiti:**

- Reduction of greenhouse effect gas emissions;
- Reduction of pressure on native forests;
- Reduction of the risks to public health associated to air pollution;
- Encouragement of agricultural development and the generation of income in the field;
- Encouragement of energy independence; and
- Broadening of export opportunities.

## 9.1 Environmental Benefits

### 9.1.1 Reduction of Greenhouse Effect Gas Emissions

Biofuels are sources of renewable energy, derivatives of agricultural products like sugarcane, oily plants, forest biomass and other sources of organic material. In some cases, biofuels may be used isolated, as additives to conventional fuels. As examples, we may quote biodiesel, ethanol, methanol, methane and charcoal[34].

[34] National Biofuel pole.

The use of biofuels brings a series of benefits associated to the reduction of greenhouse effect gases, and other atmospheric pollutants, such as sulfur, directly connected to the consumption of fossil fuels. However, in the process of manufacturing biofuels, a series of residues and industrial sub-products are generated, which may, when improperly generated, contribute to the economic viability of production. These residues of a liquid and solid nature have a potential for use in the food industry and for animal nutrition, as well as in the chemical-pharmaceutical industry, or in the generation of biofuels themselves, like for example, sugarcane husks, used in the co-generation of electric energy in alcohol plants.

The use of fossil fuels negatively influences the quality and balance of the environment. Two common examples of this problem are the high indices of pollution in the large urban centers and the spillage of petroleum in the sea. Both cause a large negative impact to the regional ecosystem.

The high emissions of carbon monoxide (CO), nitrogen oxides (NOX) and Sulfur Dioxide (SO2) are pointed out as the principal cause of acid rains, extremely prejudiciaol to forests, crops and animals. Ass well as this, these fossil fuels have a very high CO2 emission rate, a factor directly related to the greenhouse effect problem and its consequences (increase in the global temperature, melting of the icecaps, ecological imbalance, amongst others)[35].

Biofuels are said to be less polluting in relation to fossil fuels, in spite of having CO2 emissions, studies show indices of CO2 emission up to 80% less in relation to diesel from petroleum (in the case of the use of biodiesel) and 30% in the use of alcohol in flexfuel vehicles.

Due to this characteristic, biofuels have become a non aggressive option for the environment. Thus, the principal benefit in the use of biofuels consists in the reabsorption of the carbon gas produced in its burning by the sugarcane, sunflower, Jatropha curcas plantations and other bio-energetic cultures during their growth, making the emissions be reduced.

[35] National Biofuel pole.

### 9.1.2 Reduction of Pressure on Native Forests

The Haitian natural resources are limited, first by their small territorial area, but principally by the environmental degradation that afflicts the country.

The final consumption of energy in the country is composed of, predominantly renewable resources. Firewood and charcoal are the absolute majority of this composition. It is believed that charcoal supplies energetically more than 90% of the homes in Port-au-Prince and other large Haitian cities.

Table 45 shows the consumption of primary renewable energy, in kiloton equivalents of petroleum, in which it can be seen:

- Predominance of firewood as a source of energy;
- The rural sector exceeds the consumption of other sectors of society and its source of energy is formed, in its totality, by firewood;
- Consumption in the urban areas is formed basically of charcoal;
- The business and industry sectors show small consumption of energy and, at the same time, diversified, showing, in their composition, the sugarcane husks.

**Table 45**
**Consumption of Primary Renewable Energy in ktep (kiloton equivalent to petroleum) in Haiti in 2003.**

| Sources | Urban Consumption | Rural Consumption | Business and Industry | Total Consumption | Percentage of the Total (%) |
|---|---|---|---|---|---|
| Firewood | 17 | 862 | 112 | 991 | 79 |
| Coal | 162 | - | 35 | 197 | 16 |
| Husks | - | - | 66 | 66 | 5 |
| Total | 179 | 862 | 213 | 1,254 | 100 |
| Percentage (%) | 14 | 69 | 17 | 100 | - |

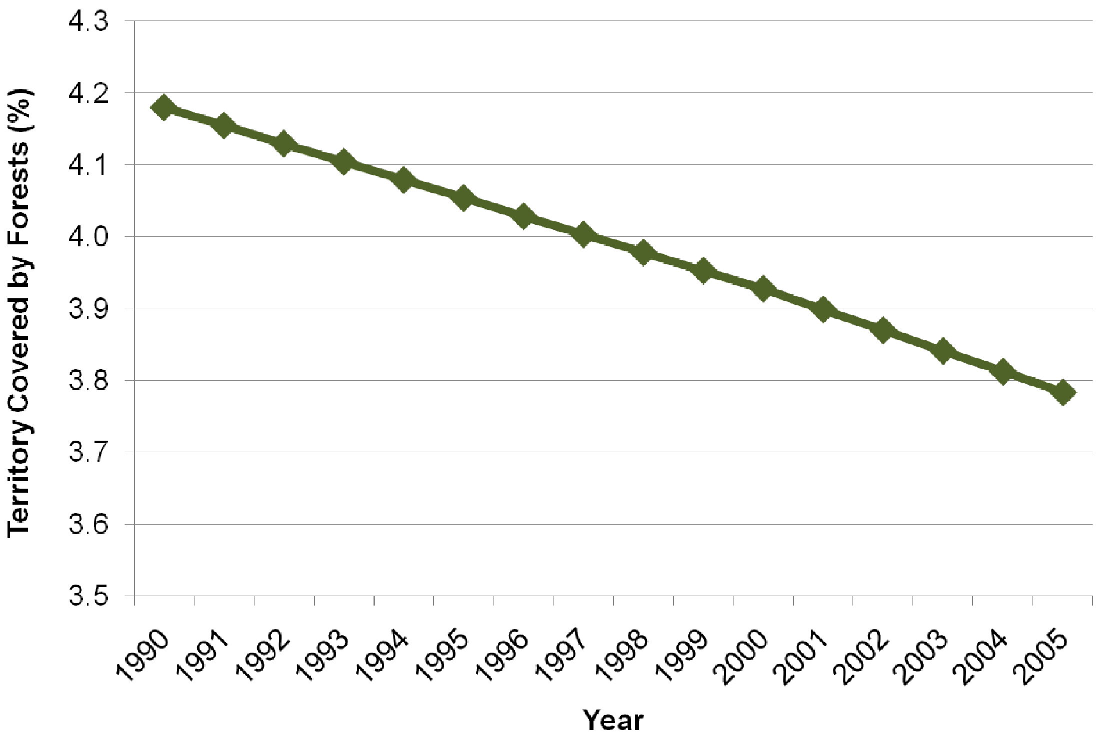
Source: Adapted from the BME – ESMAP report, July 2005.

In the 1982 year, the estimated stock of timber available was 37.4 million cubic meters, and around 6 million were used for the most varied purposes, including use in the civil construction area. Such consumption is equivalent to cutting 30 million trees annually. At the same time, it is calculated that only 20 million trees were planted in the same period, and their rate of survival was not taken into consideration[36].

Currently, the annual reforestation capacity is calculated at around 26% of consumption, which is equivalent to 1.6 million cubic meters. However, the annual capacity for self-reproduction is also calculated at 1.6 million (26% of the total amount of timber used). In this manner, it is presumed that the country has around half its stock calculated, in 1982. And the tendency is that in the near future, it will run out[37].

Figure 102 shows the accelerated decrease of Haitian forests, during the period referring to 1990-2005.

**Figure 102**
**Decrease in the Haitian forest area in a period of 15 years (1990-2005).**




Source: Prepared by FGV with data from FAOSTAT, 2008.

[36] Haiti Energy Sector Development Plan, 2006.
[37] Haiti Energy Sector Development Plan, 2006.

In order to preserve the existing forests, reducing, or even removing the pressure on them, production of biofuels seeks to attend the different sectors of the Haitian economy, whether replacing the charcoal and timber of the industries by biomass produced under suitable handling aspects, or the generation of energy in the urban and rural areas and by biodiesel produced from agricultural cultures.

## 9.2 Benefits connected to Health

The reduction of the pollutants released to the atmosphere and a significant decrease in particulate material ("black smoke") provides a large positive influence on public health.

**Figure 103**
**Combustion of fossil fuels is directly connected to the majority of respiratory illnesses, a public health problem.**

Sources (in clockwise direction)': www.g1.com; www.drscope.com; www.motonline.com.br.

Studies in the city of São Paulo (Brazil) report that approximately 6% of deaths registered are related to environmental pollution. Out of this number, most is caused by vehicles, such as cars,

buses and trucks. The pollution generated by gasoline or diesel oil causes allergic rhinitis, acute bronchitis, asthma attacks, amongst other respiratory illnesses.
With the use of biofuels, there is large benefit for the public health of any country[38].

Several factors contribute to increasing the energy demand (around 60 percent of the total volume of imported petroleum products) in the transport sector, and should therefore be controlled. This demand not only emanates from the number of motor vehicles, estimated at more than 100,000, but all categories are included. For the a large part, the demand results from the failure to control motor vehicles, roads in "bad conditions, huge traffic jams in the cities, as well as the inefficient control of traffic in urban centers".

## 9.3 The possibilities for the Generation of Income and Employment in Rural Areas

Employing modern techniques and producing a good for which demand is growing in the international market, the cultivation of species destined to the production of biofuels may output satisfactory financial yields. Besides, industries that process the harvest of these crops generally are situated close to the plantations, aiming to save on logistical resources. Therefore, the field-industrial plant conjunction may be an important source of income and employment for rural areas.

The creation of new sources of income, especially in the rural areas, is an important issue for **Haiti.** As previously observed (section 1), haitian population grows 2.453% every year. At the same time, the country had a net negative migration rate of 0.94 migrants per group of 1,000 individuals per year, signifying the existence of a very large population deficit. This migrant population, generally, is in search of employment opportunities and better wages.

[38] FAPESP, 2004.

## 9.4 Substitution of Petroleum Products

The energy sources imported by Haiti — petroleum products — represent, in terms of costs, more than twice the amount spent on domestic energy production (Table 46). On the other hand, the supply of fossil fuels amounts to no more than one forth of Haitian domestic consumption. This corresponds to three quarters of the whole national energy budget.

**Table 46**
**Energy spending in Haiti in 2003.**

| Sources | Percentage (%) | Price per Ton (US$) | Total value (US$) | Percentage (%) |
|---|---|---|---|---|
| Firewood | 36 | 100 | 40,133,500 | 9 |
| Coal | 18 | 300 | 62,100,000 | 14 |
| Gasoline | 10 | 1,050 | 124,582,500 | 27 |
| Kerosene | 7 | 750 | 54,165,000 | 13 |
| Diesel | 29 | 523.6 | 168,232,680 | 37 |

In latter years, the price of petroleum increased sufficiently to change the economic paradigm of the production of renewable and clean energy. The value of a barrel of petroleum exceeded all forecasts (whether for political matters or market distortions) and does not seem to be a market abnormality and this growth trend may continue in the long term, due to the world dynamics of supply and demand[39].

Therefore, as petroleum price should remain elevated, the crossover point of clean energy production costs and the cost of importation of petroleum are getting close. The biofuels (ethanol and biodiesel) now has prices as competitive as their fossil rivals.

The production of biofuels reduces dependency on petroleum derivatives, especially in the transport sector, but also in the electricity sector. Ethanol may serve as a supplement or replacement of gasoline, whilst biodiesel serve primarily as a supplement to common diesel. Additionally, electricity can be generated from sub-products of the industrial phases of the

[39] EIA, 2005.

production of ethanol and biodiesel. In the case non petroleum producing countries, like Haiti, The implantation of the biofuel chain may represent a modern policy for replacement of importations.

Notably, various factors generate an increasing energy demand in the Haitian transport sector– around 60% of the total volume of petroleum products. This demand not only comes from the number of motor vehicles, but also from the lack of control of motor vehicles, the bad road conditions, traffic jams in the cities, as well as the inefficient control of traffic in urban centers[40].

Thus, the junction of the current scenarios connected to the Haitian energy sector is propitious for the development of policies that seek the production of biofuels in the country and that help to encourage replacement of the importations.

### 9.4.1 Electricity Co-generation

Co-generation is the simultaneous production of electricity and mechanical energy, from a single type of fuel, the mechanical energy also being converted into electric energy by means of an alternator.

Co-generation from renewable resources allows the use of energy resources often discarded at the end of some productive chain, reducing the consumption of fossil fuels and minimizing impacts on the environment. Among the main sources of renewable energy for use in co-generation systems and capable of use according to the scope of this study, the following are specially noteworthy: residues coming from the sugarcane productive chain – leaves and bagasse; residues coming from other agricultural crops; and forestry residues , coming from the harvest of reforestation.

The main benefits generated by this system, whether of an energetic, environmental, economic or social nature are shown in following:

[40] ESMAP, 2005.

### 9.4.1.1 Environmental Benefits

- Efficiency in the production of energy from the co-generation systems will provide a reduction in the need for other fuels. For this reason, it is possible to obtain reductions in the emission of pollutants and greenhouse effect gases;
- The possibility of elimination of burnoffs in cane plantation regions; and
- The possibility of the use of vinasse for the production of biogas, fuel for the co-generation of electric energy.

### 9.4.1.2 Economic Benefits for the Community

- The implementation of co-generation centers allows increasing the installed capacity for production of electric energy, reducing the need, in some cases, for the construction of new producing centers; and
- And, overall, to provide the population with an energy generation system notably less onerous than those that depend on petroleum products.

### 9.4.1.3 Economic Benefits for Companies

- The co-generation systems allow an important reduction in the energy bill;
- Supply of Energy without interruptions – the existence of a co-generation center is, in itself , a safety guarantee for the supply of electric energy; and
- The development of the system is relatively short – 2-3 years and the cost of energy production is competitive with other sources.

However, the implementation should be supported by a technical-economic viability study, in which the benefits coming from this system should be compared with the investments to be made.

#### 9.4.1.4 The use of bagasse in Co-generation

With the reduction in the Haitian cane industry activities, the generation of bagasse was reduced considerably. However, the potential of this energetic residue remains and, according to suggestions for projects, may compose the picture of energy alternatives to petroleum products. Only 15% of the 140 thousand tons of bagasse generated by small artisan alcohol plants are in fact used and that the current generation potential of the distilleries is between 37 and 56 thousand ton equivalents of petroleum annually[41].

Currently, the principal difficulty involved in the use of bagasse for the production of energy in the country is the hesitation of the owners of small alcohol plants, who believe that the calorific content in the bagasse is too low.

# 10. Concluding remarks

The energy problem in Haiti is not limited to the strategic question relative to self-sufficiency in the sector, nor to the commercial imbalance caused by the importation of petroleum products. Currently, the country faces the threat of the complete running out of their biomass reserves, the main domestic energy source, due to the exploration done in a non sustainable manner.

The introduction of alternative energy sources that may be produced domestically and used in a sustainable manner is one of the possible measures that the country may choose to adopt in order to, at least, ameliorate the problem. In this regard, encouragement of biofuel production is a suitable measure that may in fact be implemented, as described in this report. For that, however, it is necessary, besides the sources of financing, an effective Haitian government action in the sense of creating and maintaining specific regulations, in a manner so as to ensure the economic viability of the investments in the sector.

This study analyzed the production of agricultural crops had as raw material for the manufacture of biofuels and also as a source of biomass for the generation of electric energy in electric terms.

[41] Library of Congress, 2006.

There were evaluated sugarcane, sunflower, eucalyptus, *jatropha* and elephant grass. Haiti has suitable regions in its territory, even if moderately, for the five crops considered. However, due to the rugged topography, these areas are quite segmented. This is issue should be taken into account when considering the installation of projects that need large contiguous areas.

The transport infrastructure is also a limiting factor for agro-industry projects, since that the road access to the regions with an agricultural potential is quite precarious, due basically to the bad conditions of preservation of current roads and the lack of investment for the extension or construction of new access roads. The railway transport, that could be a low-cost option with good efficiency, is now out of operation and some of the railroads no longer exist. Currently, there are no waterways for cargo transportation in Haiti.

The fuel storage capacity, currently used to store petroleum derivatives, is sufficient for an amount equivalent to only 6 months current consumption. With the start of the production of biofuels, possibly accompanied by an increase in the consumption of fuels in general, it will be necessary to increase the fuel storage capacity in the country.

There is a series of measures that need to be taken to ensure the success of an undertaking in the biofuels area in Haiti. Many of these measures depend on effective actions by the Haitian government for the creation of laws and for assuring of their compliance; others also need gradual investments so that they can be done. Success in the execution of a project in this area, however, benefits the country as a whole: the population will have more access to energy, whether in the form of electricity, or in the forma of liquid fuels; the undertaking will create a significant amount of employment, both direct and indirect; the possibility of a replacement of charcoal by other cleaner and sustainable fuels and will contribute to the preservation of the environment and the health of the citizens who, currently, depend on this type of highly polluting fuel; the replacement of petroleum derivative fuels by biofuels produced within the country would have a major positive impact on the trade balance of the country, which has been in the red in latter years.

From the financial point of view, the investments in the production of biofuels in Haiti would have a relatively high risk, because the establishment of the business depends on the collaboration of the government and the adaptation to new products, both on the part of the farmers and the part of the consumers. However, in the same proportion as the risk is high, a high return (in percentage terms) may expected in a scenario in which the country achieves political stability, which would allow a fast acceleration in the growth of the Haitian economy.

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