Suitability Maps for Biofuels Crops in Saint Kitts and Nevis

General Secretariat of the Organization of American States

Final Report: Saint Kitts and Nevis

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Technical Sheet

Project: Suitability Maps for Biofuels Crops in Saint Kitts and Nevis

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Summary

Executive Summary

The present report brings a detailed study about biofuel crops considering its land suitability in Saint Kitts and Nevis. It is important to mention that agriculture is very sensitive to climate and weather conditions, which determines the suitable plant species or varieties for a given region, the agricultural systems to be adopted and the practices that are required to achieve high crop performance. For these reasons, agrometeorological information, mainly climatological data, is essential for agricultural planning, which in concert with soil information will define the potential of an area for a specific agricultural activity. Analysis of the 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.

The matching between the land capability information and the agroclimatic zoning was done using decision defines the Land suitability. The combination of these levels of information summarizes into one classification system the most important land and climatic variables that affect land uses in different locations. This simplification of the information into well-defined classes is important for land planners to assess the suitability of the land for different land uses. As for land capability, land suitability assessment was done on a qualitative base. Expert knowledge was the base for the definition of the suitability classes according to the matching of land capability classes and agroclimatic classes.

In this report a comprehensive study of land capability and suitability was done for Saint Kitts and Nevis. The land capability and suitability studies were done specifically for each of the three studied crops (sugarcane, sunflower and *Jatropha curcas*). Soil data was combined with landscape, environmental protection areas and inundation vulnerability data to produce five land capability classes (very high, high, moderate, low and very low). The combination of these land capability classes with the agroclimatic evaluation produced land suitability maps for each of the three crops. These land capability and suitability maps were produced with the objective of evaluating the potentialities of the crops cited above for biofuel production as well as defining potential areas for the development of biofuel producing industries.

At the analyzes of soil, climate and terrain, there were estimates of potential yields for sugar cane, as well was done comparisons to yield observed today. This analysis is the first step in evaluating the current potential production for culture, and to estimate possible improvements on the current yield.

As analyzed above, the territorial expression of the Land Capability classes for the three crops are not very different. Some similarities can be found in crops that have similar planting and harvesting characteristics, differences appear in crops with particular limitations or resistance to restrictive properties of the land. In all, the north and northwest part of the island which present larger areas for agriculture with less restriction would be the best areas for biofuel production, especially ethanol. The land characteristics show that this area has very few restrictions for sugarcane harvested manually. Mechanical harvesting of sugarcane presents higher limitations in relation to manual harvesting because of limitation in the slope and stoniness attributes. The alternative of using track harvesters increases the viable capability area for sugarcane (high and moderate) once that these machines can harvest in slopes higher than 12%. *Jatropha curcas* also showed few limitations in this area. But as indicated above, when analyzing the land, Jatropha could be planted in more restrictive areas that do not compete with the good lands for sugarcane or other crops. Sunflower for biofuel production showed lots of land limitations on this island, which restricts its use as a biofuel crop. No very high classes were found in any of the land capability maps due to the restriction of phosphorous fixation that occurs in volcanic soils.

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 higher. Sugarcane is suitable as a rainfed crop in 5,500 ha and with supplementary irrigation in 2,600 ha. For sunflower, 81.7% of the country is suitable for this crop, whereas for Jatropha, climate is not a limiting factor for crop growth and development; therefore, all the lands of the island are suitable for this crop, being soil and relief the main problems for their cultivation.

The Land Suitability analysis performed for three biofuel crops showed that important areas of Saint Kitts and Nevis have a good potential for their production. Sugarcane manually harvested presented large areas with good suitability classes, on the contrary when sugarcane is harvested mechanically with tire harvesters, which can only work up to 12 % slopes; the land with good suitability is reduced drastically. The option of working with track harvesters permits to extend the slope range to 20% this increases the land suitability classification for this crop making available larger areas with reasonable land suitability. Sunflower presents very low suitability classes and would not be a viable option. Jatropha on the contrary presents large areas (3,381 ha) with high land suitability being a viable option for biofuel production.

Considering the estimated potential yield and current observed yield for sugar cane, the analyzes done showed Potential productivity values with a mean of 70.69 ton/ha and the actual observed yield of 55.5 ton/ha. This shows that the correct exploitation of the land resources in the island of Saint Kitts can lead to higher yields and consequently a good potential for sugar-cane production.

1. Soils Study

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.

1.1 Data research and collection

1.1.1 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 of Saint Kitts and Nevis, as well as its quality. An intense search for this information was performed initially. Fortunately quite a lot of information was found for this country, provided by Saint Kitts and Nevis governmental agencies. Data related to soils, geology, geomorphology, land-use, etc, was found for this country 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: soils, slope, protected areas (environment, tourism, urban areas, beach and dumpsites), and inundated areas.

1.1.2 Soils

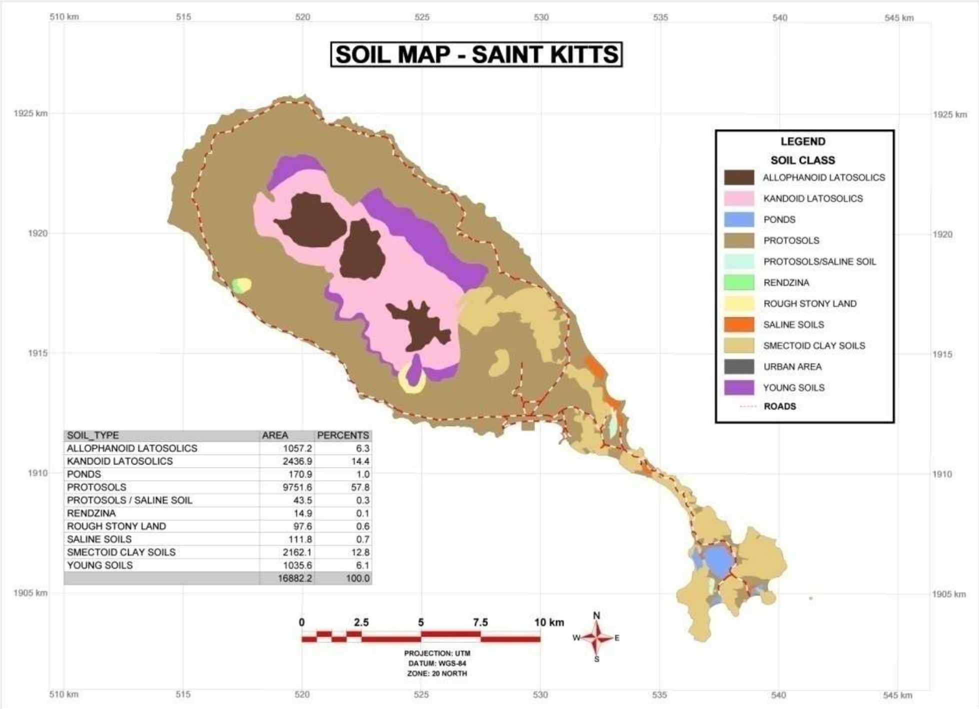
A soil map for Saint Kitts and Nevis was provided by the Ministry of Sustainable Development, Department of Physical Planning & Environment. The map was in a digital format, which enabled to process them in a GIS system (Geographic Information System). The soil data attached to these maps was quite complete for this country.

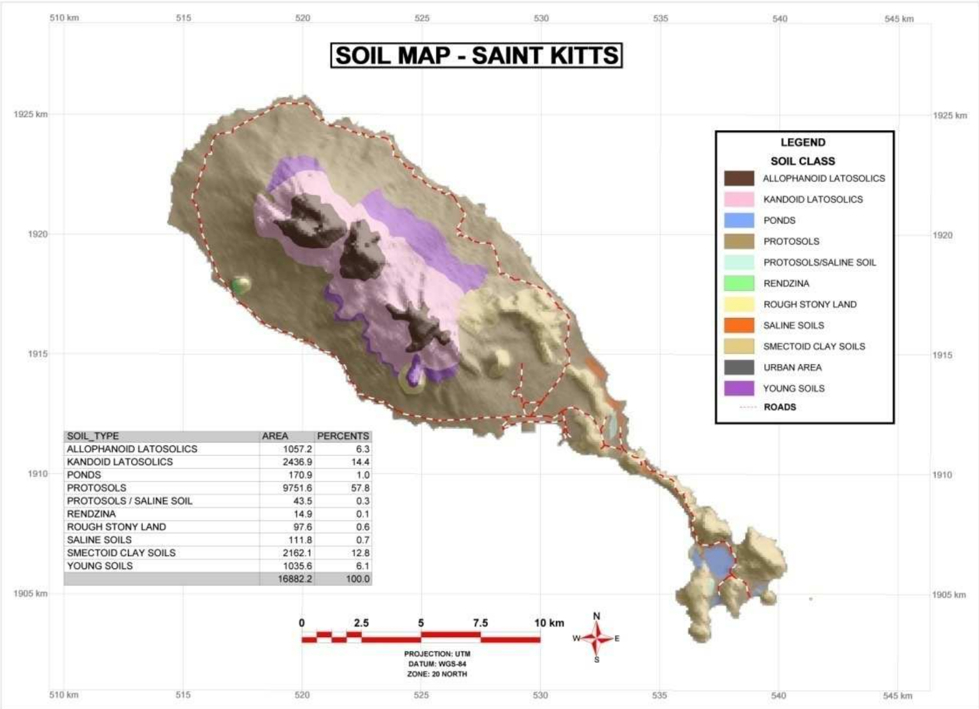
The soil map of Saint Kitts was prepared by GIS lab Physical Planning Division, Planning Unit. In this study 8 soil classes and a database for 38 mapping units were found. These soils are mostly originated from volcanic rocks and a few from materials as calcareous beach deposits. Soils on the island are young with moderate to low depths that present some degree of stoniness and boulders. Most of the soils present loamy and sandy textures. Soil fertility varies from moderately high to very low, with a predominance of moderate fertility soils. Figure1.1.2.1 presents the soil map of Saint Kitts Nevis, and Table 1.1.2.1 the main soils characteristics of the mapping units.

As mentioned above the soil database of Saint Kitts and Nevis was composed of 38 soil mapping units and quite detailed information for these units was furnished. Because of this, the procedure was first to define the soil aptitude for each crop according to the information in the database (Table 1.1.2.1) and then proceed to the definition of the land capability classes for each crop by matching the soil aptitude information with the slope, environmental protection and non-agricultural areas, and inundation maps. The tables defining the land capability classes for each crop will be presented in the specific sections for each crop.

Figure 1.1.2.1

Soil map of Saint Kitts and Nevis, without landscape (top) and with landscape (bottom)





SOIL MAP - SAINT KITTS
LEGEND
SOIL CLASS
ALLOPHANOID LATOSOLICS
KANDOID LATOSOLICS
PONDS
PROTOSOLS
PROTOSOLS/SALINE SOIL
RENDZINA
ROUGH STONY LAND
SALINE SOILS
SMECTOID CLAY SOILS
URBAN AREA
YOUNG SOILS
ROADS
SOIL_TYPE AREA PERCENTS
ALLOPHANOID LATOSOLICS 1057.2 6.3
KANDOID LATOSOLICS 2436.9 14.4
PONDS 170.9 1.0
PROTOSOLS 9751.6 57.8
PROTOSOLS / SALINE SOIL 43.5 0.3
RENDZINA 14.9 0.1
ROUGH STONY LAND 97.6 0.6
SALINE SOILS 111.8 0.7
SMECTOID CLAY SOILS 2162.1 12.8
YOUNG SOILS 1035.6 6.1
16882.2 100.0
0 2.5 5 7.5 10 km
PROJECTION: UTM
DATUM: WGS-84
ZONE: 20 NORTH

Table 1.1.2.1

Main soil characteristics found in Saint Kitts and Nevis soil map and their aptitude for biofuel crops

SOIL ID	SOIL TYPE	DRAINAGE	HIGH WATERTABLE	ROOT LIMIT	EROSION	FERTILITY	STONES-BOULDERS	SOIL APTITUDE			
								SUNFLOWER	JATROPHA	SUGARCANE MANUAL	SUGARCANE MECHANICAL
1	Protosols	Very rapid	Nil	Nil	Danger of wind erosion if clean cultivated	Low	Nil	Low	Moderate	Moderate	Moderate
2	Protosols	Very rapid	Nil	Nil	Danger of wind erosion if clean cultivated	Low	Nil	Low	Moderate	Moderate	Moderate
3	Protosols	Rapid	Nil	Nil	Gully on steeper slopes	Moderate	Generally stony and bouldery	Low	Moderate	Moderate	Low
4	Protosols	Rapid, but slight impedence below	Nil	Cemented sub-surface horizon	Very low	Moderately low	Few stones or boulders	Moderate	Moderate	Moderate	Moderate
5	Protosols	Rapid	Nil	Nil	Gully on steeper slopes	Moderately high	Variable, not very stony.	High	High	High	High
6	Protosols	Rapid, but often impeded in sub surface horizons	Nil	Usually a compact subsurface horizon	Low	Moderately high	Relatively few stones or boulders	High	High	High	High
7	Protosols	Rapid	Nil	Nil	Liable to both sheet wash and gullying	Moderately high	Some stones and boulders	Moderate	High	High	Moderate
8	Protosols	Rapid	Nil	Nil	Moderately low tends to gully	Moderately high	Very variable, often very bouldery	Low	High	High	Moderate
9	Protosols	Rapid	Nil	Nil	Much soil lost by creep	Moderately low	Stony and bouldery	Very low	Moderate	Low	Very low
10	Protosols	Rapid	Nil+	Very fine subsurface horizon often "pack"	Easily eroded due to light texture	Moderately high	Usually slightly stony and bouldery	High	High	High	High
11	Protosols	Very rapid	Nil	Nil	Low	Moderate	Usually not very stony	Moderate	Moderate	Moderate	Moderate

SOIL ID	SOIL TYPE	DRAINAGE	HIGH WATERTABLE	ROOT LIMIT	EROSION	FERTILITY	STONES-BOULDERS	SOIL APTITUDE			
								SUNFLOWER	JATROPHA	SUGARCANE MANUAL	SUGARCANE MECHANICAL
12	Protosols	Rapid	Nil	Nil	Low, an accumulating soil	Moderate	Relatively few stones or boulders	Moderate	Moderate	Moderate	Moderate
13	Protosols	Moderately rapid, often limited by impervious layer	Nil	Cemented sub-surface horizon	Easily deflated. Often severely gullied	Moderately high	Often stony	Very low	High	Moderate	Low
14	Young soils	Moderately rapid	Nil	Generally base of soil	Top soil usually lost by sheet erosion	Moderate	Usually few stones	Moderate	Moderate	Moderate	Moderate
15	Young soils	Moderately rapid	Nil	Generally base of soil	Top soil usually lost by sheet erosion	Moderate	Usually few stones	Moderate	Moderate	Moderate	Moderate
16	Young soils	Moderately rapid	Nil	Generally base of soil	Top soil usually lost by sheet erosion	Moderately high	Usually few stones	High	High	High	High
17	Young soils	Moderately rapid	Nil	Generally base of soil	Top soil usually lost by sheet erosion	Moderately high	Usually some stones or boulders	Moderate	High	High	Moderate
18	Young soils	Moderately rapid	Nil	Generally base of soil	Top soil usually lost by sheet erosion	Moderately high	Usually some stones or boulders	Moderate	High	High	Moderate
19	Kandoid latosolics	Moderately rapid	Nil	Increase lost of structure in deeper subsoil	Top soil usually lost by sheet erosion	Moderate	Not appreciably stony or bouldery	Moderate	Moderate	Moderate	Moderate
20	Kandoid latosolics	Moderately rapid	Nil	Increase lost of structure in deeper subsoil	Top soil usually lost by sheet erosion	Moderate	Not appreciably stony or bouldery	Moderate	Moderate	Moderate	Moderate
21	Kandoid latosolics	Moderate	Nil	Deeper subsoil is very compact	Top soil usually lost by sheet erosion	Moderate	Not appreciably stony or bouldery	Moderate	Moderate	Moderate	Moderate
22	Kandoid latosolics	Moderately rapid	Nil	Structure lost in deeper subsoil	Easily eroded if plant cover removed	Moderate	Not appreciably stony or bouldery	Moderate	Moderate	Moderate	Moderate
23	Kandoid latosolics	Rapid	Nil	Nil	Very liable to sheet erosion	Moderately low	Slightly stony	Low	Moderate	Low	Low
24	Allophanoid	Moderately	Nil	Generally base	Only moderate	Moderate	Some stones	Low	Moderate	Moderate	Moderate

SOIL ID	SOIL TYPE	DRAINAGE	HIGH WATERTABLE	ROOT LIMIT	EROSION	FERTILITY	STONES-BOULDERS	SOIL APTITUDE			
								SUNFLOWER	JATROPHA	SUGARCANE MANUAL	SUGARCANE MECHANICAL
	latosolic	rapid		of soil	under present vegetation		and boulders				
25	Smectoid clay soils	Moderately slow.fairly impervious clay horizon	Imperfect surface puddling	Heavy clay subsoil	Topsoil easily lost when clean cultivat	Moderate	Few stones or boulders	Very low	Low	Low	Low
26	Smectoid clay soils	Usually moderate may be impeded	Imperfect surface puddling	Often a sub-surface cemented horizon	Some sheet wash on slope over 5(degrees	Moderately high	Not very stony	Very low	Low	Low	Low
27	Smectoid clay soils	Moderate	Nil	Solid parent material	Moderately low	Moderately low	Generally stony and bouldery	Very low	Moderate	Low	Very low
28	Smectoid clay soils	Moderate	Nil	Solid parent material	Topsoil easily lost	Low	Stony and bouldery with rock outcrops	Very low	Low	Very low	Very low
29	Smectoid clay soils	Moderate	Nil	Usually base of soil	Very liable to sheetwash	Moderate	Stony and bouldery	Very low	Moderate	Low	Very low
30	Saline soils	Rapid	Usually below 2'-3'	Nil	Very low	Low	Nil	Low	Low	Low	Low
31	Saline soils	Slow	At 12"-18"	Poorly drained soil below 6"	Very low	Very low	Almost stone free	Very low	Very low	Very low	Very low
32	Saline soils	Very slow	Usually at 6"	Wet saline soil	Very low	Very low	Nil	Very low	Very low	Very low	Very low
33	Rendzina	Rapid									
PN	Protosols										
RS	Protosols	Moderate	Nil	Solid parent material	Topsoil easily lost	Low	Stony and bouldery with rock outcrops	Very low	Very low	Very low	Very low

1.1.3 Slope

The slope and landscape shading maps for were calculated based on the digital elevation models (DEM) [1]. After downloading the DEMs corresponding to each country, filters were applied using a SIG for elimination of noise and amelioration of the quality of the information obtained (Raster spatial filtering, Class: Noise reduction filter, Type: median). Six slope classes were calculated based on the DEMs of Saint Kitts and Nevis: 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

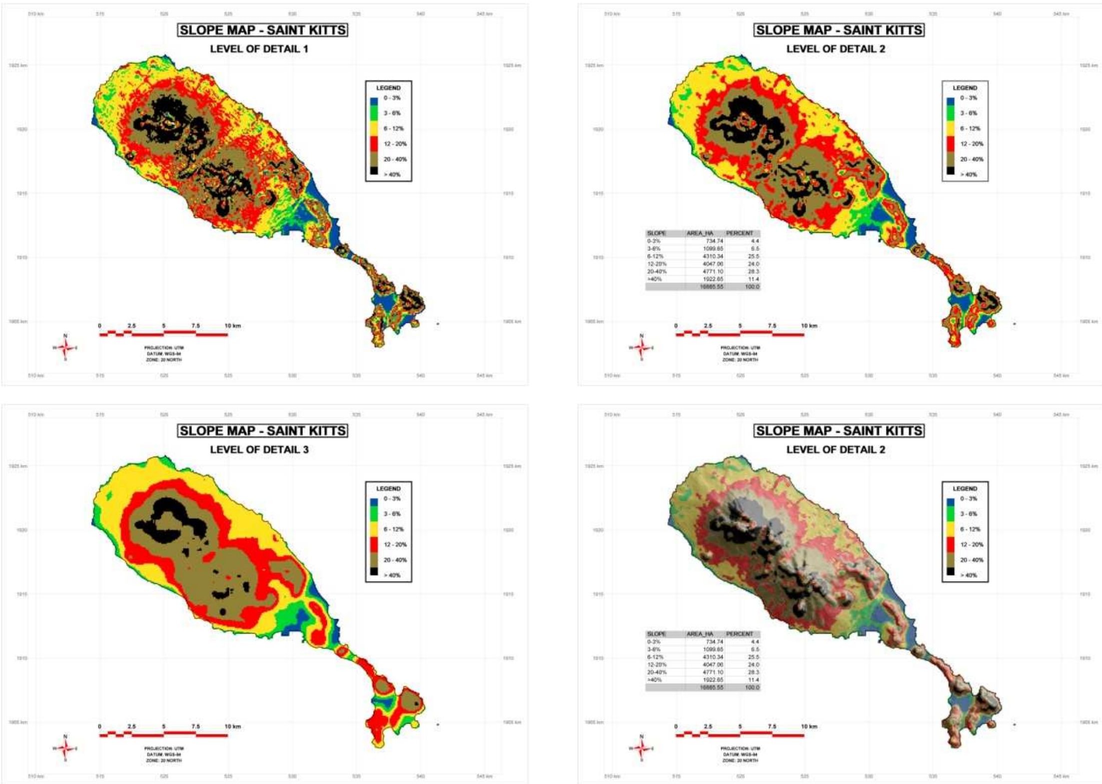
The detail of the slope classes was chosen based on the topography and on the chosen land uses for biofuel production.

For Saint Kitts and Nevis three different detail of slope calculations were performed. This was done to see which of the levels of detail better fitted the soil map of this country (Figure 1.1.3.1). The results of this fitting process showed that the level of detail 2 better fitted the soil data for matching in the GIS.

[1] Obtained from the website <http://seamless.usgs.gov/>

Figure 1.1.3.1

Three levels of detail of the slope map for Saint Kitts and Nevis and the landscape-shading map



Shading Map

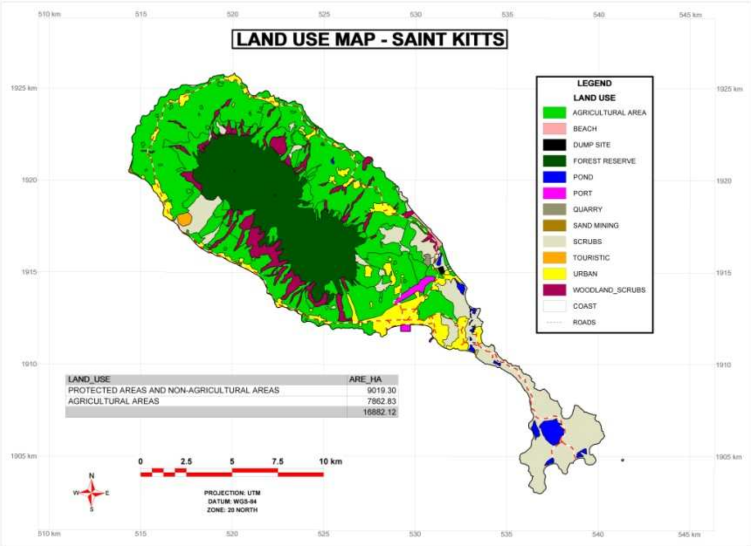
1.1.4 Protection areas and non agricultural areas

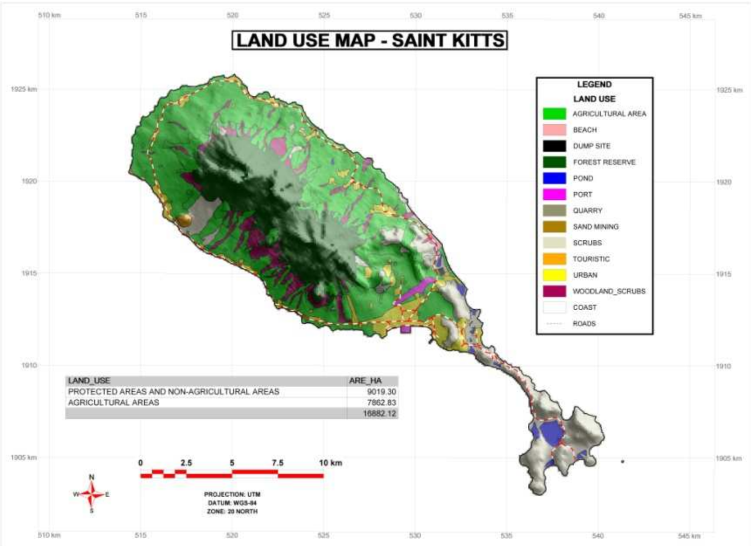
Protection areas include protected native forest areas or any other ecosystem that have been defined by the environmental protection agencies of Saint Kitts and Nevis as protected. This data was obtained from the Ministry of Sustainable Development, Department of Physical Planning & Environment. Other areas excluded from land capability analysis were beaches, dump sites, ponds, ports, quarries, sand mining, scrubs, tourist developments and urban areas. Figure 1.1.4.1 illustrates the environmental protected and non-agricultural areas for Saint Kitts and Nevis.

These areas should not be exploited.

Figure 1.1.4.1

Protection areas of Saint Kitts and Nevis, without landscape (top) and with landscape (bottom)



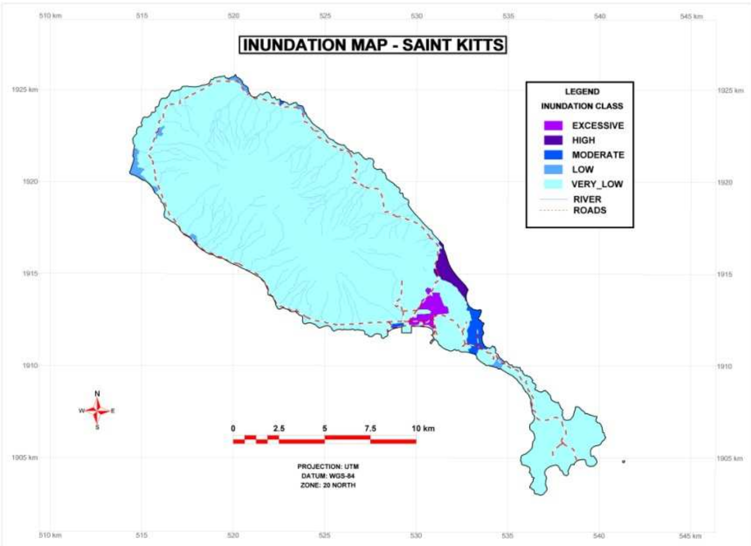


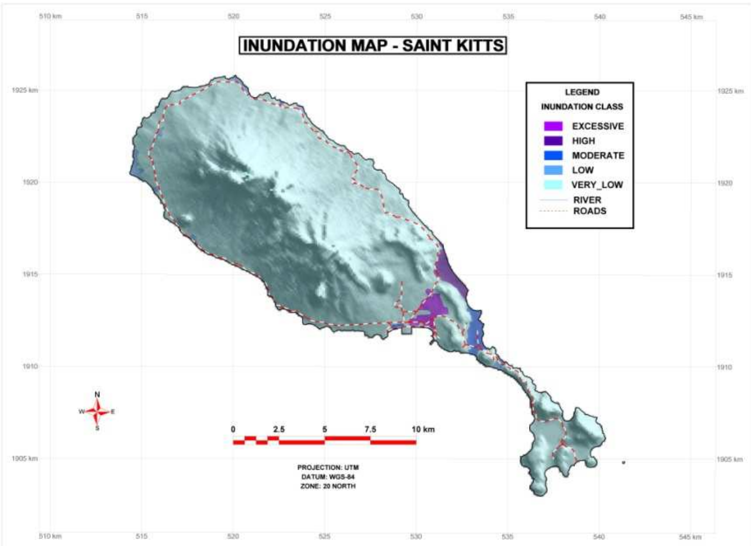
1.1.5 Inundated areas

For Saint Kitts and Nevis a map with the inundated areas was provided by the Ministry of Sustainable Development, Department of Physical Planning & Environment. This map help eliminating areas that may inundate sometimes and consequently should be classified as no capability for the crops evaluated in this project. Figure 1.1.5.1 illustrates the inundated classes for Saint Kitts and Nevis.

Figure 1.1.5.1

Inundation classes for the republic of Saint Kitts and Nevis, without landscape (top) and with landscape (bottom)





1.1.6 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, adequacy of the information for each specific crop according to its characteristics and elimination of any outliers and erroneous data found in the databases.

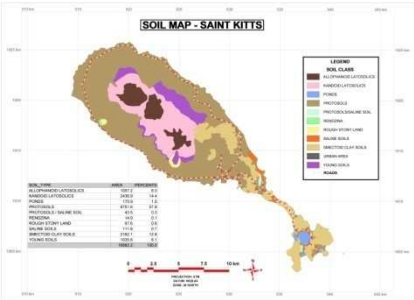
To simplify the information contained in the soil databases, these were re-classified according to their aptitude for each crop. This was done using expert knowledge on the soils and their characteristics and the features of the evaluated crops. Each soil-mapping unit was classified in to one of five aptitude classes according to their characteristics and their capacity to support the evaluated crops (this information will be shown in the following sections). The aptitude classes defined for this project are: very high aptitude, high aptitude, moderate aptitude, low aptitude and very low aptitude. The main soil attributes that were analyzed for defining the soil aptitude classes were soil drainage, depth to watertable, soil fertility, soil erosion, root growth limitations, soil texture, stoniness, and soil salinity. The soil aptitude was crossed with the terrain slope for defining the land capability class.

Using Boolean logic, a system that performs logical operations between some information and allows organizing concepts in sets, the information of the aptitude of the inherent soil characteristics for each country was crossed with the slope map. Slope, together with other soil attributes, is important mainly for defining soil erodibility potential and mechanization. Terrains that have higher slopes are more prone to suffer from erosion processes and consequently will have a lower land capability. Finally, the result of the matching between soils and slope crossed with the environment protection areas and inundation zones map produced the Land Capability map for each biofuel crop. Figure 1.1.6.1 illustrates the map matching for generating the Land Capability maps of Saint Kitts and Nevis. More detailed description of these class definitions will be given in forthcoming sections.

Figure 1.1.6.1

Data matching for the definition of the Land Capability of Saint Kitts and Nevis.

Soil map	Slope map	Environmental Protection and non-agricultural Areas	Zones of Inundation



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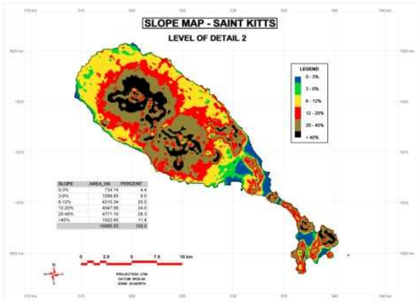

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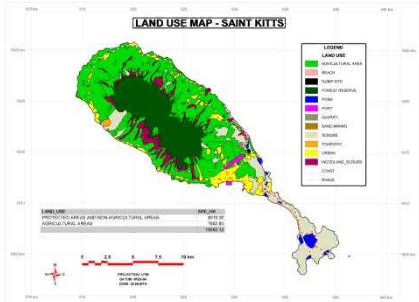

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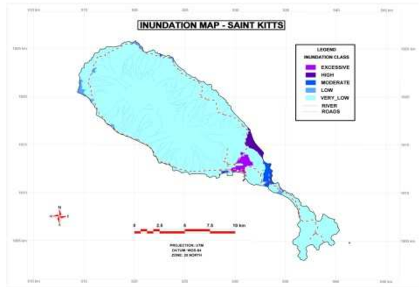
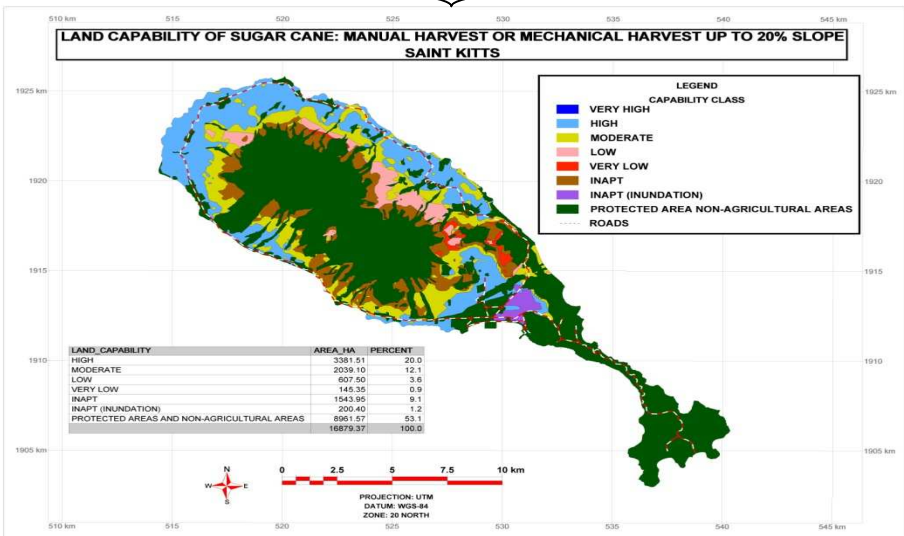




LAND_CAPABILITY	AREA_HA	PERCENT
HIGH	3381.51	20.0
MODERATE	2039.10	12.1
LOW	607.50	3.6
VERY LOW	145.35	0.9
INAPT	1543.95	9.1
INAPT (INUNDATION)	200.40	1.2
PROTECTED AREAS AND NON-AGRICULTURAL AREAS	8961.57	53.1
	16879.37	100.0

1.1.7 Land Capability for biofuel crops in Saint Kitts and Nevis

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 and *Jatropha curcas*).

The three biofuel-producing crops cited above were analyzed. Sugarcane was subdivided in to manually harvested and mechanically harvested sugarcane on 12% and 20% slopes. This was done to help future decision-making processes concerning what type of sugarcane harvesting system should be eventually implemented in this country. The choice is between a labor-intensive system with environmental restrictions if the sugarcane is burnt previous to harvest (manual harvest) and a high technological system with low labor demand that is environmentally friendly (mechanical harvest).

1.1.7.1 Annual crops (sunflower)

Table 1.1.7.1.1 presents the results of the land capability classes for sunflower. The main problems that limited land capability for these crops were slope, soil fertility, stoniness and soil drainage. Crops that need to be mechanically planted or harvested cannot occupy terrains with slopes higher that 12%, that is the slope limit in which a machine can work without danger of rolling over. Slope also increases soil erosion problems. Stoniness also hampers mechanical practices. Soil depth and drainage limits the exploration of roots for nutrients and water. Soil fertility affects plant nutrition.

Table 1.1.7.1.1

Land capability definition for sunflower

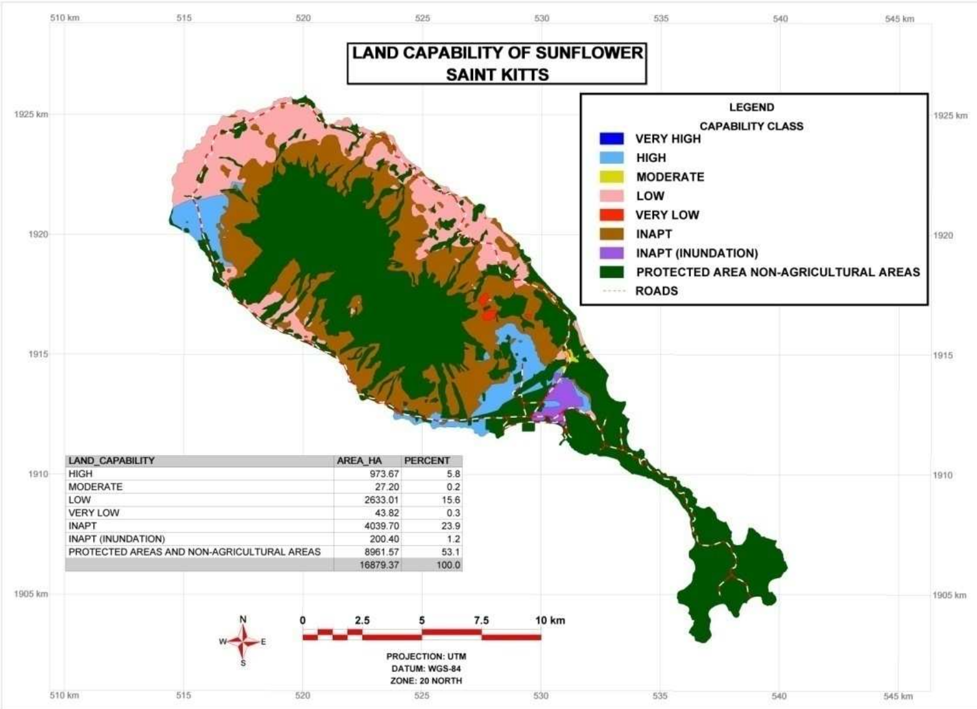
SOIL APTITUDE	SLOPE	LAND CAPABILITY
Low	0%-3%	Low
Low	3%-6%	Low
Low	6%-12%	Low
Low	12%-20%	Inapt
Low	20%-40%	Inapt
Low	>40%	Inapt
High	0%-3%	High
High	3%-6%	High

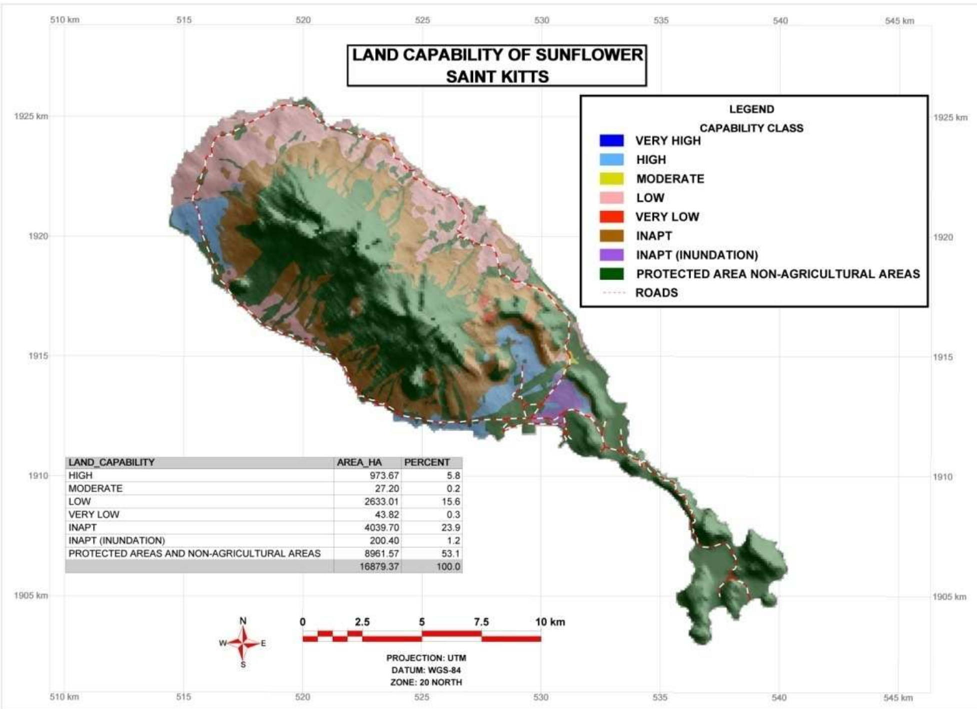
SOIL APTITUDE	SLOPE	LAND CAPABILITY
High	6%-12%	High
High	12%-20%	Inapt
High	20%-40%	Inapt
High	>40%	Inapt
Moderate	0%-3%	Moderate
Moderate	3%-6%	Moderate
Moderate	6%-12%	Low
Moderate	12%-20%	Inapt
Moderate	20%-40%	Inapt
Moderate	>40%	Inapt
Very low	0%-3%	Very low
Very low	3%-6%	Very low
Very low	6%-12%	Very low
Very low	12%-20%	Inapt
Very low	20%-40%	Inapt
Very low	>40%	Inapt
Very high	0%-3%	Very high
Very high	3%-6%	Very high
Very high	6%-12%	High
Very high	12%-20%	Inapt
Very high	20%-40%	Inapt
Very high	>40%	Inapt

Figure 1.1.7.1.1 illustrates the distribution of the land capability classes for sunflower in Saint Kitts and Nevis. These maps show that 5.8% of the area of the country, approximately 973 ha, presents very few restrictions for this crop, 0.2% moderate capability and the rest 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 capability, which occupy approximately 2,670 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. Due to mainly poor fertility, poor drainage, high slopes and stoniness 25% of the area of Saint Kitts and Nevis (4,300 ha) is inapt for annual crops.

Figure 1.1.7.1.1

Land capability map and area quantification for sunflower, without landscape (top) and with landscape (bottom)





1.1.7.2 Sugarcane: Manual harvest

Table 1.1.7.2.1 presents the land capability classification key for manually harvested sugarcane. 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 %. As for the rest of the soil and land attributes, the same can be said as for annual crops.

Table 1.1.7.2.1

Land capability definition for sugarcane manually harvested.

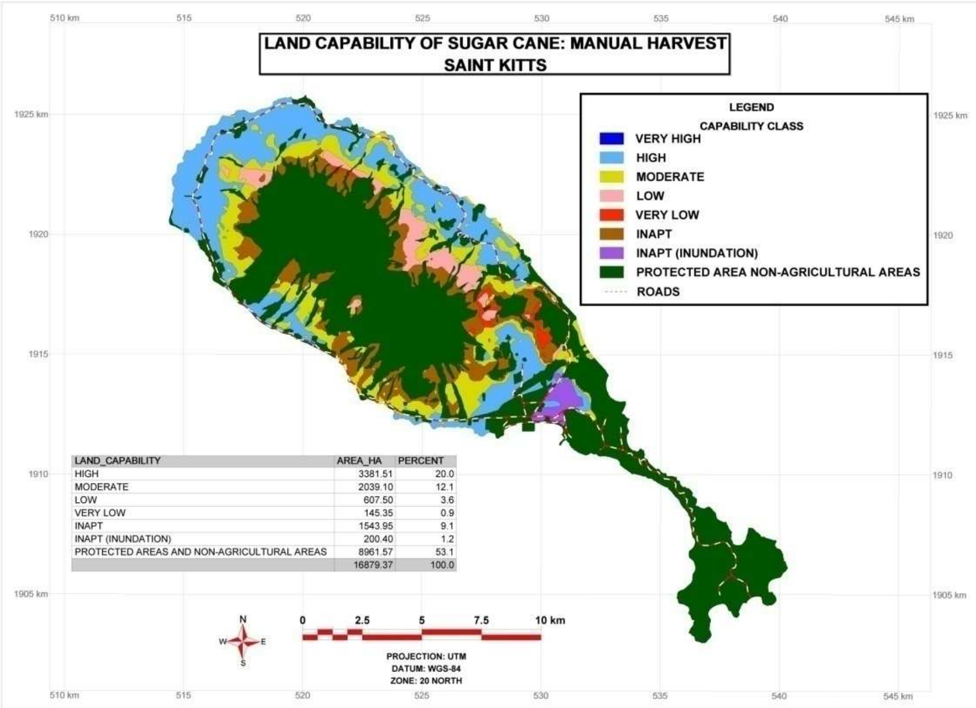
SOIL APTITUDE	SLOPE	LAND CAPABILITY
Low	0%-3%	Low
Low	3%-6%	Low
Low	6%-12%	Low
Low	12%-20%	Very low
Low	20%-40%	Inapt
Low	>40%	Inapt
High	0%-3%	High
High	3%-6%	High
High	6%-12%	High
High	12%-20%	Moderate
High	20%-40%	Inapt
High	>40%	Inapt
Moderate	0%-3%	Moderate
Moderate	3%-6%	Moderate
Moderate	6%-12%	Low
Moderate	12%-20%	Low
Moderate	20%-40%	Inapt
Moderate	>40%	Inapt
Very low	0%-3%	Very low
Very low	3%-6%	Very low
Very low	6%-12%	Very low
Very low	12%-20%	Very low
Very low	20%-40%	Inapt
Very low	>40%	Inapt
Very high	0%-3%	Very high
Very high	3%-6%	Very high
Very high	6%-12%	High
Very high	12%-20%	Moderate
Very high	20%-40%	Inapt
Very high	>40%	Inapt

The analysis of Figure 1.1.7.2.1 shows an increase in area of the high and moderate capability classes when compared to sunflower. These classes represent 32% of the agricultural area of Saint Kitts and Nevis and they can be used with good to reasonable potential for sugarcane harvested manually. This represents around 5,400 ha of which 3,381 ha have a high land capability and 2,039 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 5% of the agricultural areas were classified as low or very low for manually harvested sugarcane.

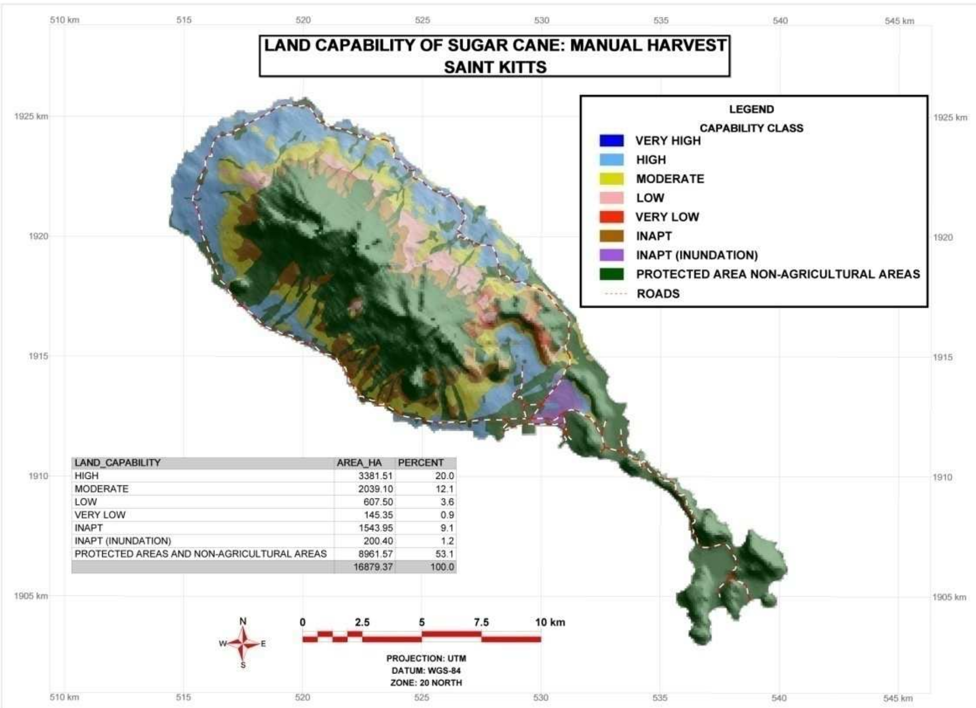
Although these classes represent high restrictions, mainly of slope or stoniness, they could be included in the sugarcane productive areas, if some investment were made. Probably more rustic varieties of sugarcane with lower productivities could be planted in these areas taking care chiefly of the erosion 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 1.1.7.2.1

Land capability map and area quantification for sugarcane manually harvested, without landscape (top) and with landscape (bottom)



LAND_CAPABILITY	AREA_HA	PERCENT
HIGH	3381.51	20.0
MODERATE	2039.10	12.1
LOW	607.50	3.6
VERY LOW	145.35	0.9
INAPT	1543.95	9.1
INAPT (INUNDATION)	200.40	1.2
PROTECTED AREAS AND NON-AGRICULTURAL AREAS	8961.57	53.1
	16879.37	100.0



LAND_CAPABILITY	AREA_HA	PERCENT
HIGH	3381.51	20.0
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INAPT	1543.95	9.1
INAPT (INUNDATION)	200.40	1.2
PROTECTED AREAS AND NON-AGRICULTURAL AREAS	8961.57	53.1
	16879.37	100.0

1.1.7.3 Sugarcane: Mechanical harvest up to 12% slope.

Table 1.1.7.3.1 presents the decision key that defines the land capability for sugarcane harvested with wheel harvesters. This type of harvester 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%. Apart from slope other soil attributes limited this crop in some areas, such as stoniness and presence of boulders. These were the main land and soil attributes that penalized this land use when compared to manually harvested sugarcane.

Table 1.1.7.3.1

Land capability definition for sugarcane mechanically harvested up to 12% slope.

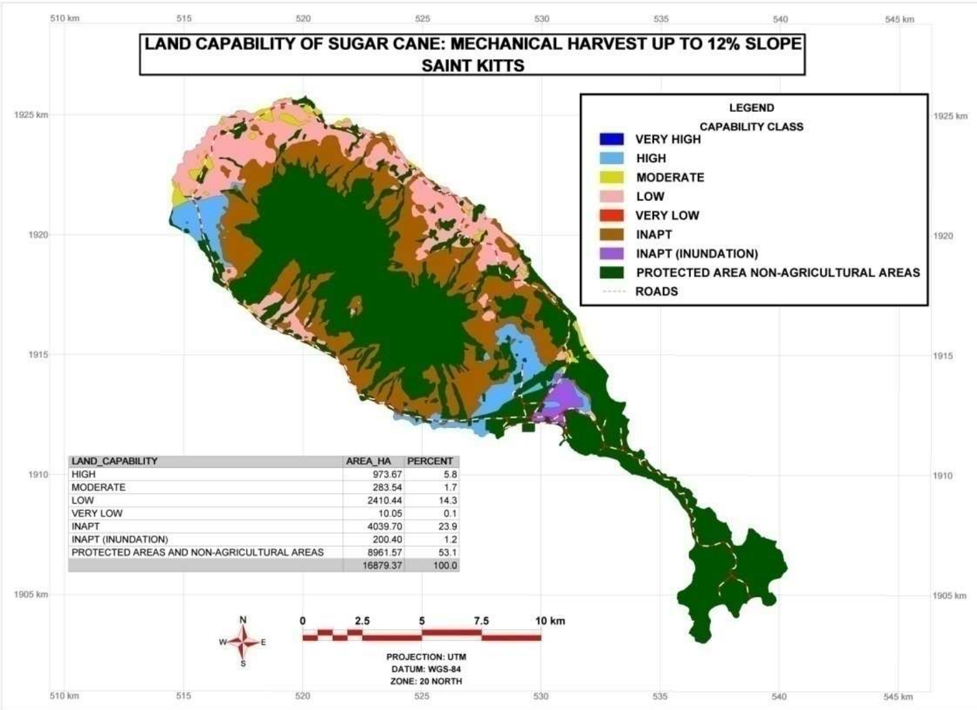
SOIL APTITUDE	SLOPE	LAND CAPABILITY
Low	0%-3%	Low
Low	3%-6%	Low
Low	6%-12%	Low
Low	12%-20%	Inapt
Low	20%-40%	Inapt
Low	>40%	Inapt
High	0%-3%	High
High	3%-6%	High
High	6%-12%	High
High	12%-20%	Inapt
High	20%-40%	Inapt
High	>40%	Inapt
Moderate	0%-3%	Moderate
Moderate	3%-6%	Moderate
Moderate	6%-12%	Low
Moderate	12%-20%	Inapt
Moderate	20%-40%	Inapt
Moderate	>40%	Inapt
Very low	0%-3%	Very low
Very low	3%-6%	Very low
Very low	6%-12%	Very low
Very low	12%-20%	Inapt
Very low	20%-40%	Inapt
Very low	>40%	Inapt
Very high	0%-3%	Very high
Very high	3%-6%	Very high
Very high	6%-12%	High
Very high	12%-20%	Inapt
Very high	20%-40%	Inapt

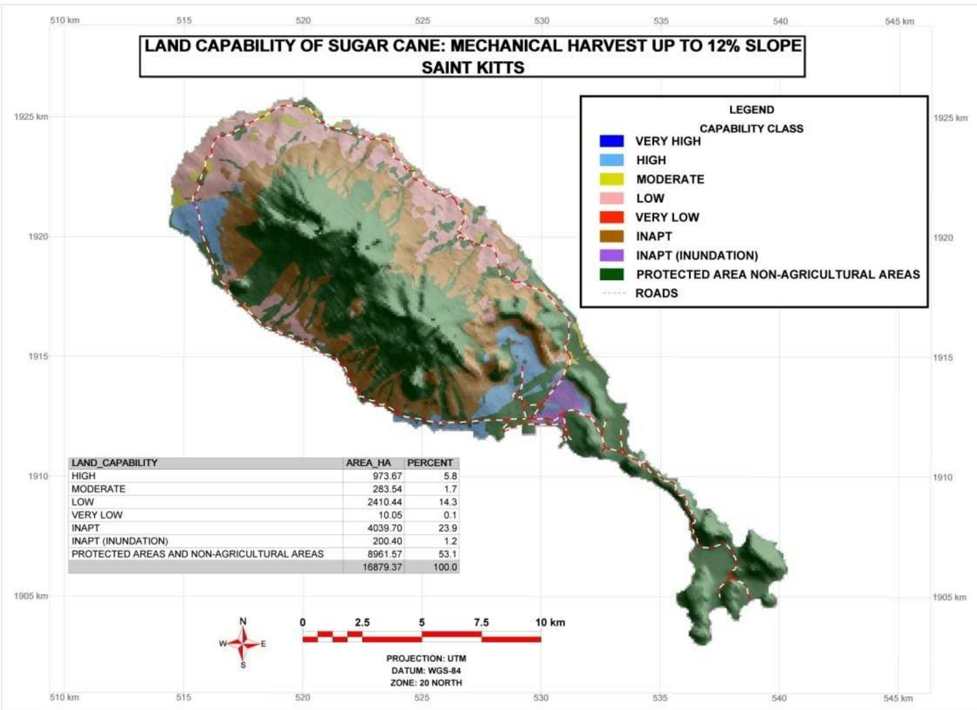
SOIL APTITUDE	SLOPE	LAND CAPABILITY
Very high	>40%	Inapt

Figure 1.1.7.3.1 illustrates the distribution of the land capability classes for mechanically harvested sugarcane up to slopes of 12% in Saint Kitts and Nevis. This map shows that 5.8% of the area of the country, approximately 973 ha, presents very few restrictions for this crop, 1.7% moderate capability and the rest would have low to very low capability presenting serious land restrictions that could affect sugarcane productivity. 14.3 % or 2.410 ha of the agricultural lands in Saint Kitts and Nevis are areas with low capability. These lands would need certain amount of investments to overcome the land restrictions. 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). Due to mainly soil limitations, high slopes, drainage and stoniness, 24% of the agricultural area of Saint Kitts and Nevis (4,040 ha) is inapt for mechanically harvested sugarcane up to 12% slopes.

Figure 1.1.7.3.1

Land capability map and area quantification for sugarcane mechanically harvested up to 12% slope, without landscape (top) and with landscape (bottom)





1.1.7.4 Sugarcane: Mechanical harvest up to 20% slope

If track harvesters are to be used for harvesting sugarcane, then higher slopes can be considered for defining the land capability of this land use. The use of track harvesters for mechanically harvesting sugarcane was cited by Mr. Conrad Kelly, former agriculture manager of the Saint Kitts and Nevis Sugarcane Manufacturing Corporation. According to Mr. Kelly's information, the use of this technology makes the mechanical harvesting of sugarcane viable above 12% slopes. Based on this information a land capability key (Table 1.1.7.4.1) and map (Figure 1.1.7.4.1) were produced for sugarcane harvested mechanically up to slopes of 20%.

Table 1.1.7.4.1

Land capability definition for sugarcane mechanically harvested up to 20% slope.

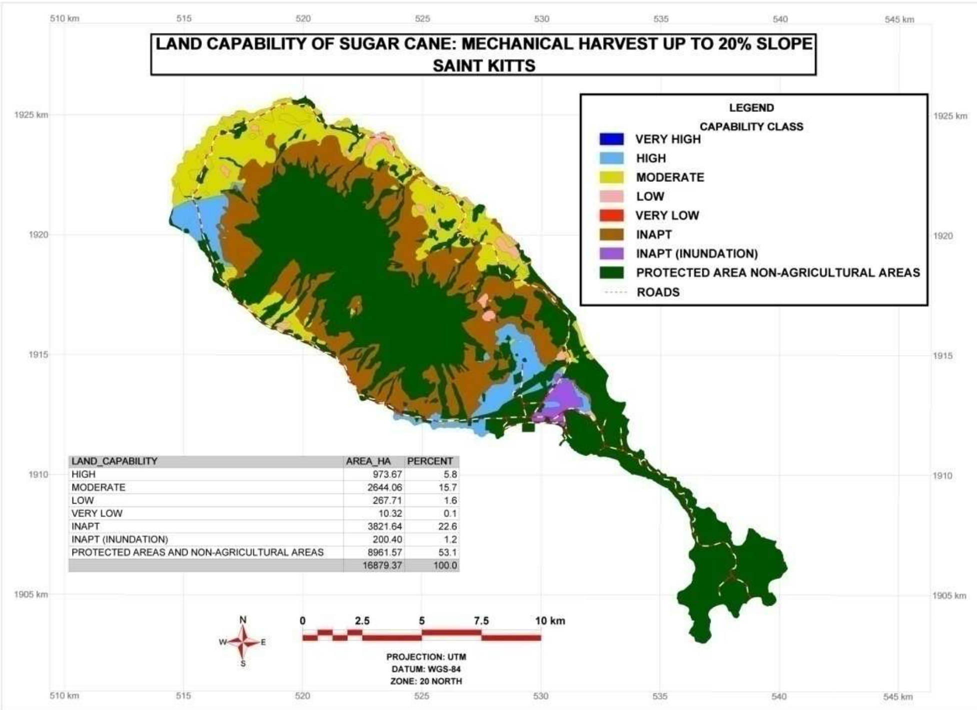
SOIL APTITUDE	SLOPE	LAND CAPABILITY
Low	0%-3%	Low
Low	3%-6%	Low
Low	6%-12%	Low
Low	12%-20%	Very low
Low	20%-40%	Inapt
Low	>40%	Inapt
High	0%-3%	High
High	3%-6%	High
High	6%-12%	High
High	12%-20%	Moderate
High	20%-40%	Inapt
High	>40%	Inapt
Moderate	0%-3%	Moderate
Moderate	3%-6%	Moderate
Moderate	6%-12%	Moderate
Moderate	12%-20%	Low
Moderate	20%-40%	Inapt
Moderate	>40%	Inapt
Very low	0%-3%	Very low
Very low	3%-6%	Very low
Very low	6%-12%	Very low
Very low	12%-20%	Very low
Very low	20%-40%	Inapt
Very low	>40%	Inapt
Very high	0%-3%	Very high

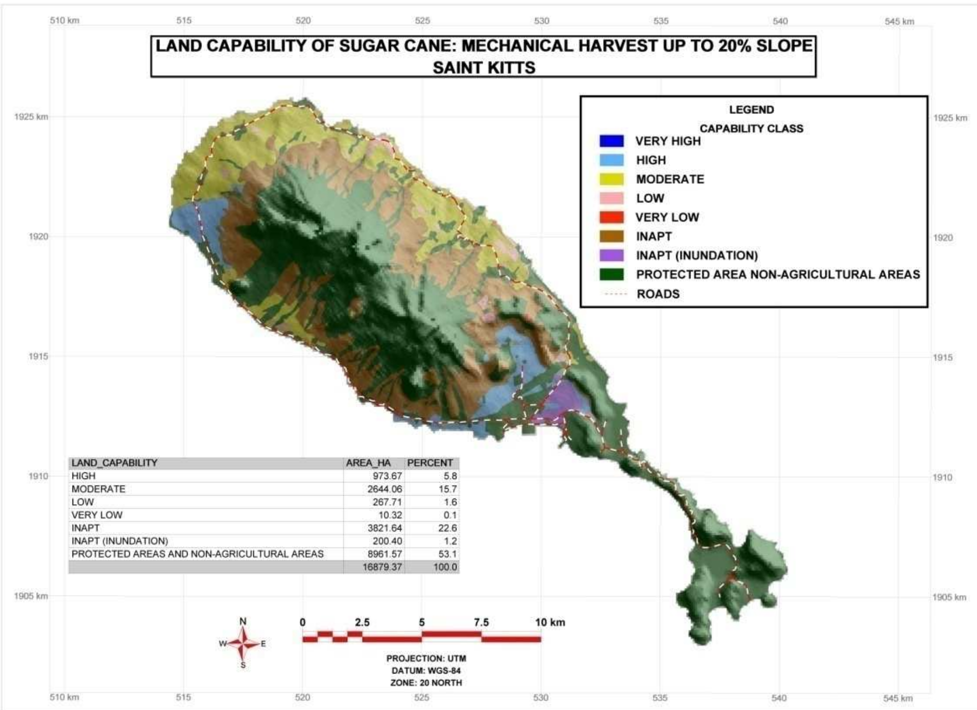
SOIL APTITUDE	SLOPE	LAND CAPABILITY
Very high	3%-6%	Very high
Very high	6%-12%	High
Very high	12%-20%	Moderate
Very high	20%-40%	Inapt
Very high	>40%	Inapt

The areas of land capability for sugarcane harvested up to 20% slopes are shown in Figure 1.1.7.4.1. The use of track harvesters permits the use of these machines up to a slope of 20%. Higher slopes can be attained but the risk of rolling over above 20% is very high. In Saint Kitts and Nevis 2,644 ha or 15.7% of the agricultural land presents a moderate capability for this use. The main land limitation is slope, which in this area varies from 6 to 12% and 12 to 20%. Some soil fertility and stoniness limitations exist that classify the aptitude of these soils as moderate. Soil fertility limitations can be corrected with fertilizers, which could improve the capability of the soils of this area. 973 ha present a high capability for sugarcane harvested with track harvesters. These areas coincide with those classified high for wheel harvesters. Probably if both types of harvesters are used, wheel harvester could be concentrated in these high capability areas whilst the track harvesters would be used in the moderate areas.

Figure 1.1.7.4.1

Land capability map and area quantification for sugarcane mechanically harvested up to 20% slope, without landscape (top) and with landscape (bottom)





1.1.7.5 Jatropha curcas

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 and when cultivated in good soils it will yield high productivities.

Table 1.1.7.5.1 presents the land capability classification key for *Jatropha curcas*. Due to the high adaptability of this crop the definition of the land capabilities penalized less the more marginal areas. Areas that presented the highest restrictions were those with high slopes and soils with drainage and salinity problems.

Table 1.1.7.5.1

Land capability definition for *Jatropha curcas.*

SOIL APTITUDE	SLOPE	LAND CAPABILITY
Low	0%-3%	Low
Low	3%-6%	Low
Low	6%-12%	Low
Low	12%-20%	Low
Low	20%-40%	Very low
Low	>40%	Very low
High	0%-3%	High
High	3%-6%	High
High	6%-12%	High
High	12%-20%	Moderate
High	20%-40%	Low
High	>40%	Very low
Moderate	0%-3%	Moderate
Moderate	3%-6%	Moderate
Moderate	6%-12%	Moderate
Moderate	12%-20%	Low
Moderate	20%-40%	Low
Moderate	>40%	Very low
Very low	0%-3%	Very low
Very low	3%-6%	Very low
Very low	6%-12%	Very low
Very low	12%-20%	Very low
Very low	20%-40%	Very low

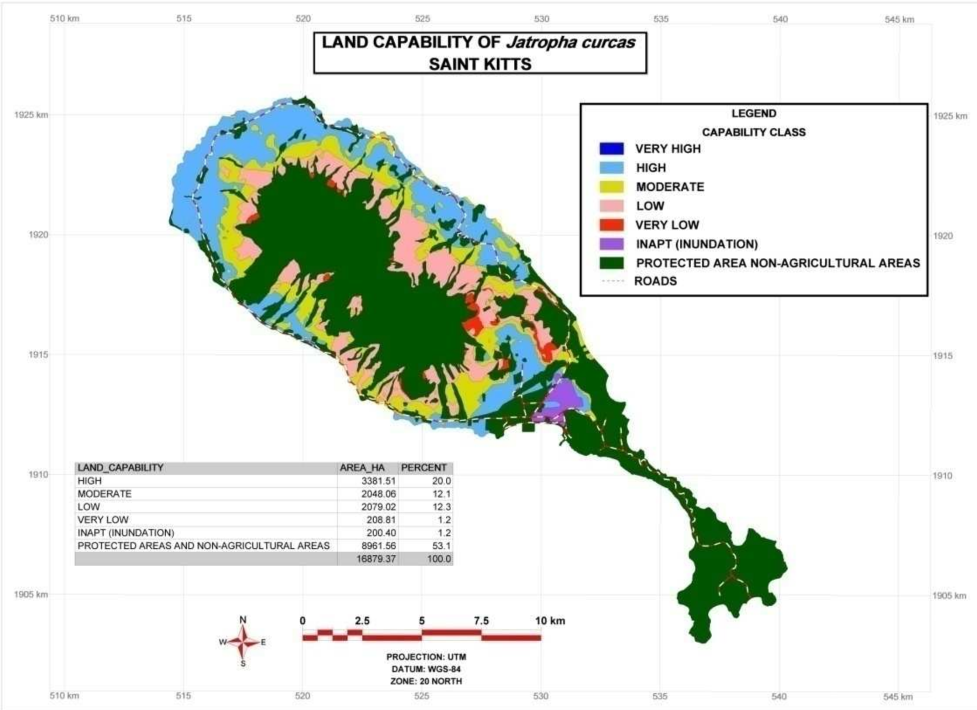
SOIL APTITUDE	SLOPE	LAND CAPABILITY
Very low	>40%	Very low
Very high	0%-3%	Very high
Very high	3%-6%	Very high
Very high	6%-12%	High
Very high	12%-20%	High
Very high	20%-40%	Low
Very high	>40%	Very low

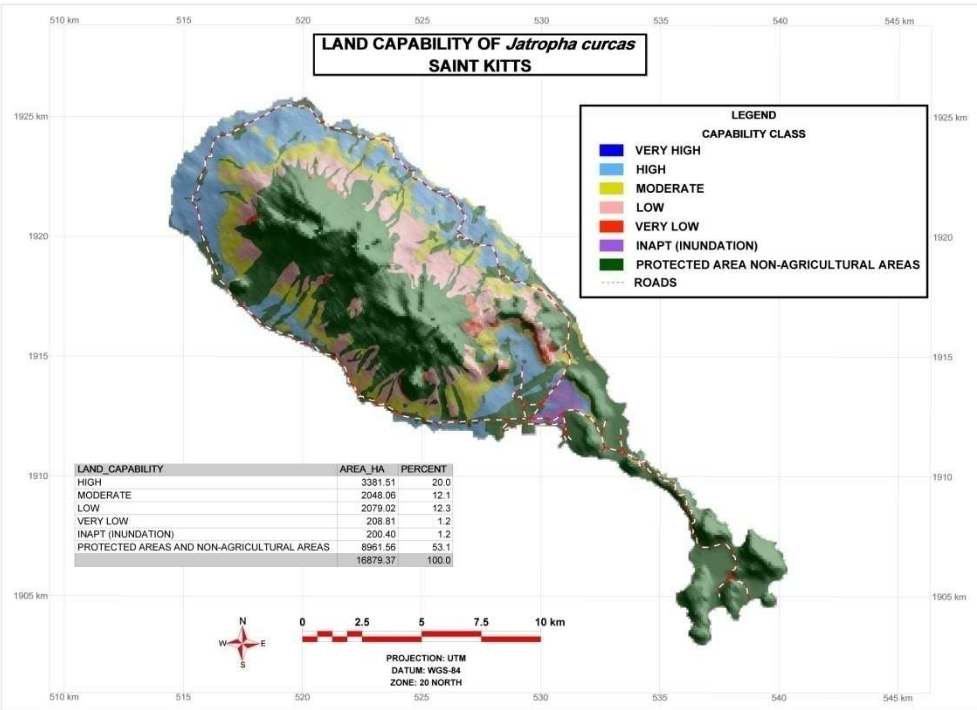
Saint Kitts and Nevis presents 5,430 ha of land with high to moderate land capability for Jatropha. This represents around 32% of the total area of the country (Figure 1.1.7.5.1). The valleys among the mountain chains and the footslopes of the escarpments were included in these areas. The most limited areas for Jatropha are those that, as cited above, presented the highest slopes or problems with highly restrictive soil attributes as salinity or drainage.

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 1.1.7.5.1

Land capability map and area quantification for *Jatropha curcas,* without landscape (top) and with landscape (bottom)





2. Agroclimatic Study

Agriculture is very sensitive to climate and weather conditions, which determines the suitable plant species or varieties for a given region, the agricultural systems to be adopted and the practices that are required to achieve high crop performance. So, agrometeorological information, mainly climatological data is essential for agricultural planning.

The agroclimatic zoning was based on climate information collected from different sources, mainly from “St Kitts Sugar Manufacturing Corporation” and from FAOCLIM2 system[2].. Climate data considered 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 20 years of data, since results from literature have shown that it is long enough to have good results[3]. A total of 45 rainfall stations (Figure 2.1) were used, with the data series from 1950-2000 for the majority of the stations.

Monthly rainfall and mean air temperature were the main variables used in this study. With these two variables was possible to estimate the other parameters required for the agroclimatic zoning. Potential evapotranspiration (ETP) was estimated with Thornthwaite method, based on an empirical relationship between data of evapotranspiration (considering latitude and month of the year) and mean air temperature[4]. Rainfall and ETP were used to run the climatological water balance[5] model, which allowed estimating monthly actual evapotranspiration (ETR), water deficiency (WD) and water surplus (WS). For running the water balance, the soil water holding capacities (SWHC) adopted was 125 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.

[2] Powered by FAO/UN

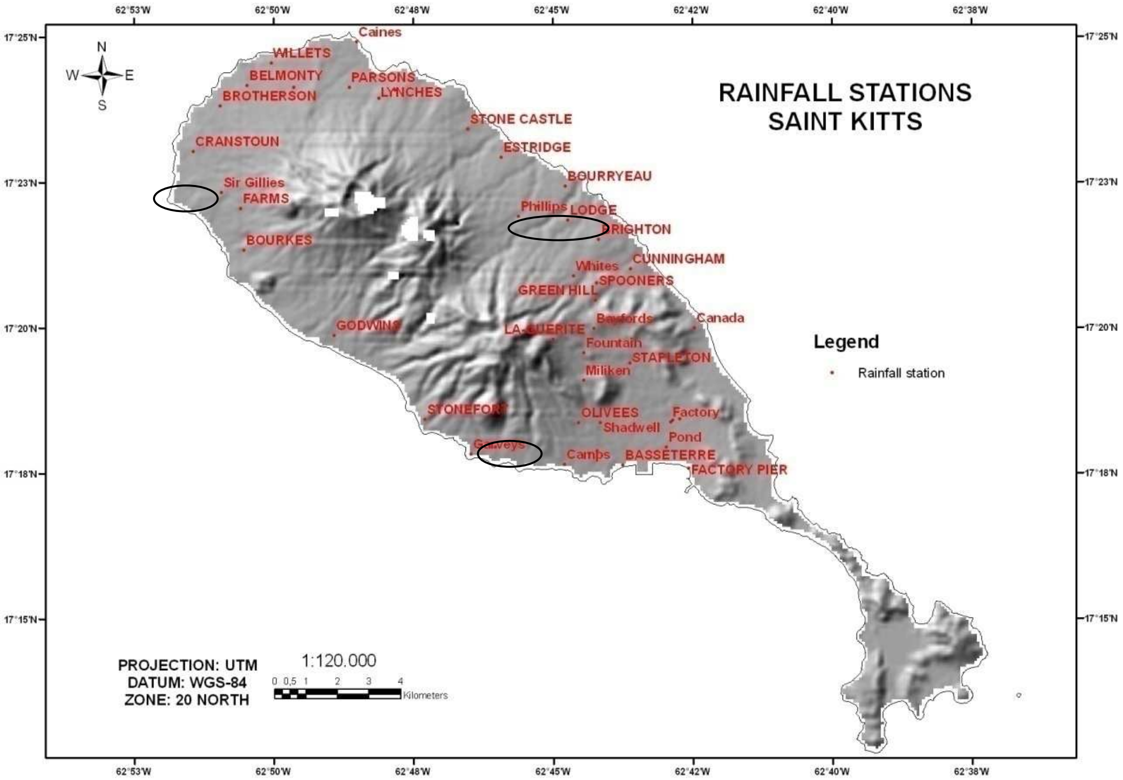
[3] Woltling et al., 2000; Marquinez et al., 2003

[4] Presented by Pereira et al. (2002)

[5] Accordingly to Thornthwaite and Mather (1955)

Figure 2.1

Rainfall stations in Saint Kitts and Nevis used in this project[6]



Source: Saint Kitts and Nevis Sugar Manufacturing Corporation and FAOCLIM2 networks

The climate requirements of each crop were obtained from 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; and annual total water deficiency. 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 using linear regression equations for each variable. These regression equations were converted into maps using map algebra with a geographical information system (ARGIS 9.2), as recommended by Rodríguez-Lado et al. (2007).

[6] Stations in evidence were used to represent the climatological water balance of their regions

2.1 Elaboration of climatic maps

Data from all bases were used to elaborate the climatic maps of Saint Kitts and Nevis. The maps for climate characterization of the country were 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 and WS were elaborated.

For temperature (average – Ta and of the coldest month – Tf), rainfall and ETP, the maps were made based on results from a multiple linear regression model adjusted for the country, which had as independent variables nominal latitude (LAT), longitude (LONG) and altitude (ALT) of the weather stations. For ETR, DEF and EXC, the maps were made based on results from a multiple linear regression model, which had geographical coordinates and rainfall as independent variables.

These regression equations were converted into variables maps using map algebra with a GIS (ARCGIS 9.2), processing the independent variables as map layers in raster format. Altitude raster layer, in meters, was obtained from digital elevation data (DEM), provided by NASA Shuttle Radar Topographic Mission (SRTM), which has a resolution of 90 m. Latitude and longitude raster layers, in decimal degrees, were computed using the central cell coordinates from the same DEM for each country.

2.1.1 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.

2.1.1.1 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. Regions with **Ta** greater than 24°C where classified as marginal, considering the lack of cool season for maturity process.

- **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 reducing 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:

    - suitable for rainfed crop – with WD between 10 and 200 mm;
    - suitable with supplementary irrigation or marginal as rainfed crop – with WD between 200 and 400 mm;
    - suitable with full irrigation or inapt as rainfed crop – with WD above 400 mm;
    - marginal for rainfed crop – with WD below 10 mm (lack of dry season for the maturity process).

2.1.1.2 Sunflower

The criteria adopted for delimiting the suitable zones for sunflower were based on the agroclimatic zoning for this crop made by Camargo et al. (1974). The following criteria were considered:

- **Annual average temperature (Ta)** – the lower limit of annual average temperature considered for crop development and growth was 15ºC. Based on that, all the regions with **Ta** greater than 15°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 deficiency (WD)** – as considered for soybean, WD is used as an index to represent the length of the dry season. For sunflower, considering a SWHC = 125 mm, regions with annual WD up to 300 mm were considered suitable for crop production, since the growing season is long enough to the crop finishes its cycle without too much water stress. Where WD was between 300 and 400 mm, dry periods during the growing season can damage the crop, making this region to be considered as marginal. Regions with annual WD above 400 mm were considered unsuitable for rainfed crops. In these last two cases irrigation could be a solution.

2.1.1.3 *Jatropha curcas*

Jatropha curcas is a drought-resistant perennial crop. It is easy to establish, grows relatively quickly and can stay producing seeds for 40 to 50 years. It is still uncertain where the center of origin is, but it is believed to be Mexico, Central America or Caribbean. It has been introduced to Africa and Asia and is now cultivated worldwide. 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 these references, the following criteria were adopted for Jatropha agroclimatic zoning in Saint Kitts and Nevis:

- **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 unsuitable for commercial production of rainfed crop. Regions with mean annual rainfall between 600 and 1000 mm were considered marginal and regions with more than 1000 mm suitable under rainfed conditions.

Even considering these references, there is little trustable information about the behavior of this crop in different climates and which is in fact the effect of water deficiency on crop yield. The criteria adopted in this project for agroclimatic zoning of Jatropha resulted in a map, which is just a ***preliminary approach***, therefore it must be ***considered with caution***.

2.1.2 Climate characterization of Saint Kitts and Nevis

The climate characterization of the studied countries will be presented in the following topics. To characterize the climate of Saint Kitts and Nevis, 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.

- Accordingly to "http://countrystudies.us/caribbean-islands" both Saint Kitts and Nevis have a hot tropical climate tempered by the northeast trade winds; there is little daily or seasonal variation. Temperatures generally range between 18℃ and 32℃ and average approximately 25℃ in the low lands; lower temperat ures prevail in the higher elevations. Humidity is generally about 70%. The driest period varies around the St Kitts Island, but in the majority is from February to August and there is increased rainfall in summer and towards the end of the year. The volume of rainfall varies according to altitude; rain showers can occur throughout the year. Annual precipitation varies from 1000 to 3000 mm. Neither island has the distinct rainy season characteristic of many other Caribbean islands. Winds are predominantly easterly and seldom exceed 19 km/h (5.3 $m.s^{-1}$) except during the islands' hurricane season, which occurs from July to September.

- The following maps (Figures 2.1.2.1 to 2.1.2.6) present the climate of the country in terms of the spatial distribution of annual average temperature, annual potential evapotranspiration, mean annual rainfall, and also of the variables related to the climatological water balance – water deficiency and water surplus.

Figure 2.1.2.1

Map of annual average air temperature

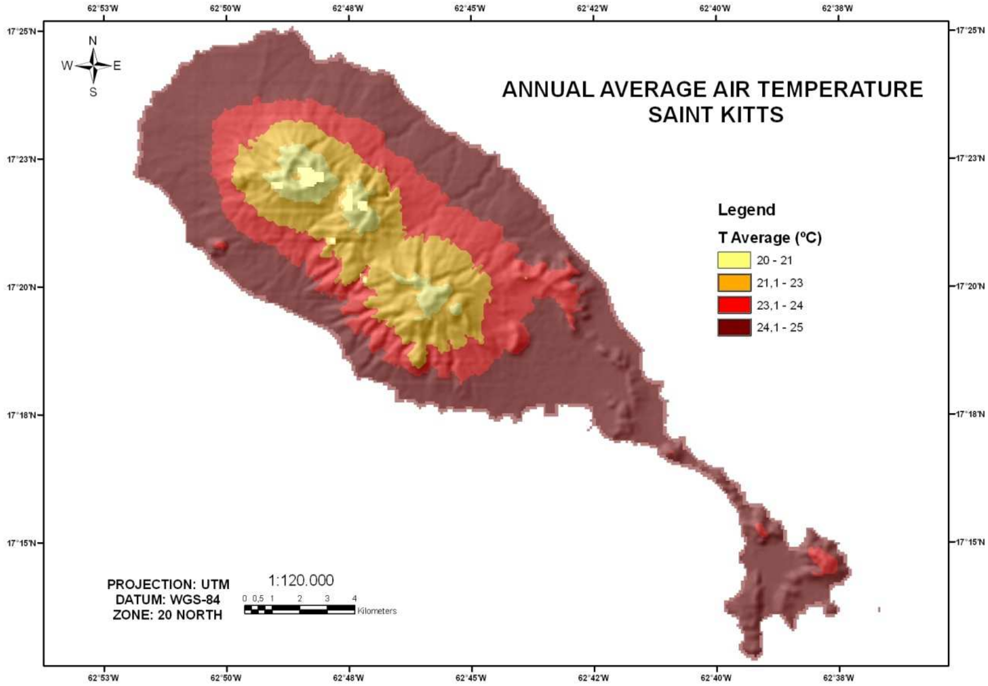


Figure 2.1.2.2

Map of average air temperature of the coldest month

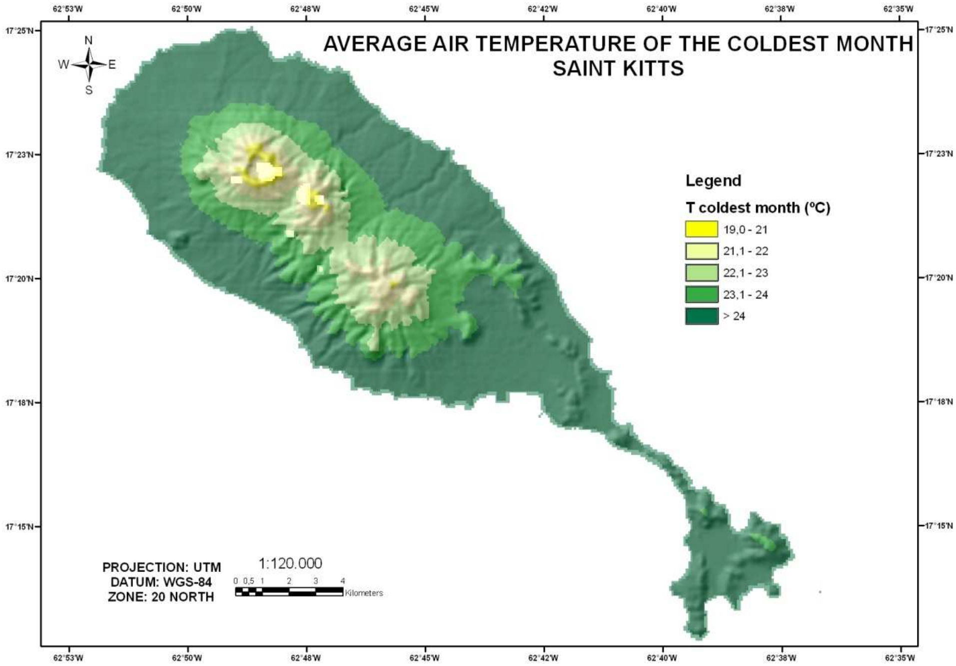


Figure 2.1.2.3

Map of mean annual rainfall based on the climatological average data from 1950 to 2000

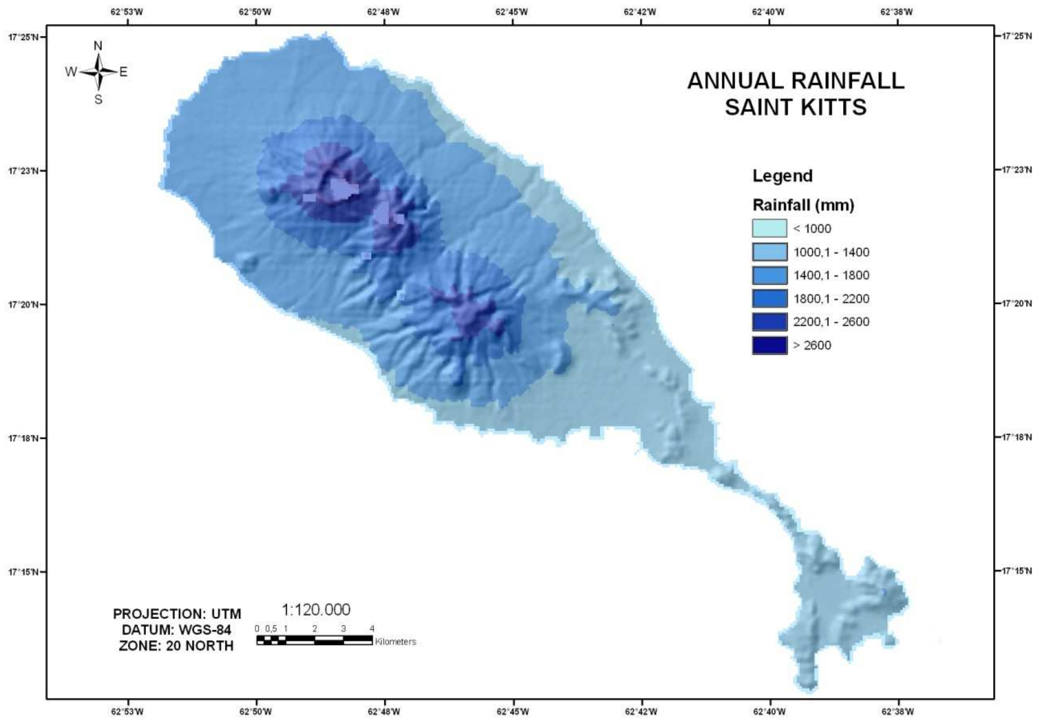


Figure 2.1.2.4

Map of annual potential evapotranspiration estimated by Thorthwaite (1948) method

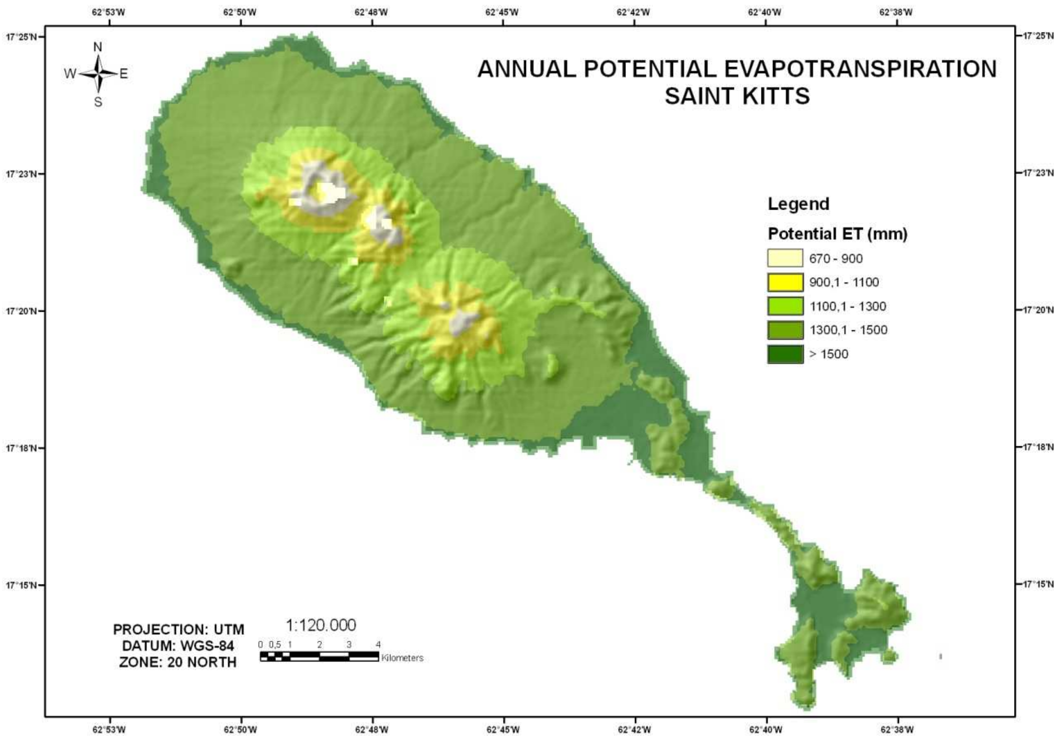


Figure 2.1.2.5

Map of annual water deficiency, obtained from the climatological water balance, considering a soil water holding capacity of 125 mm

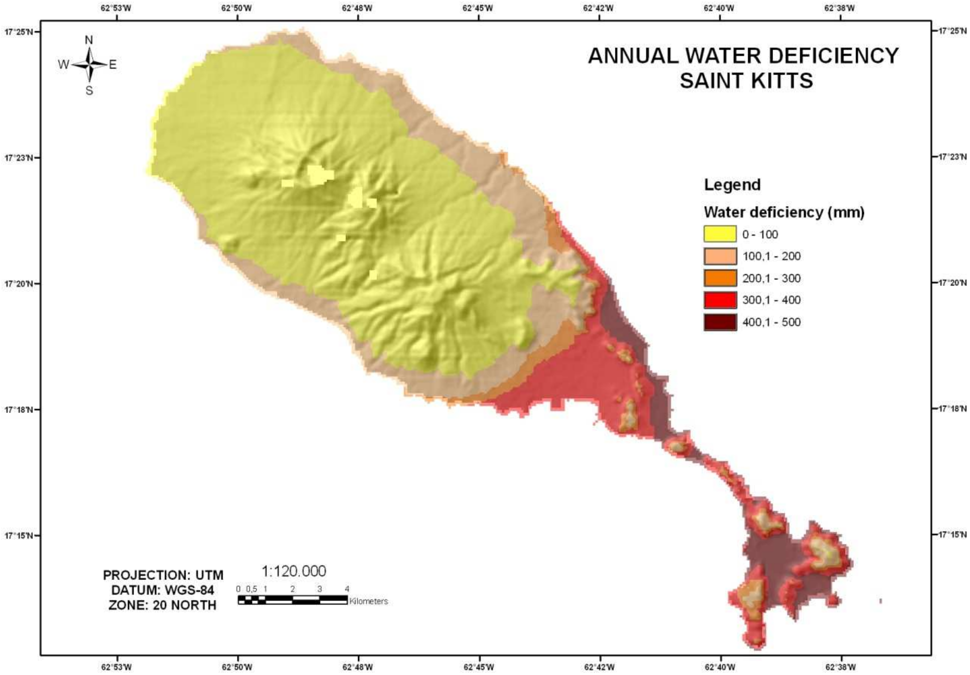
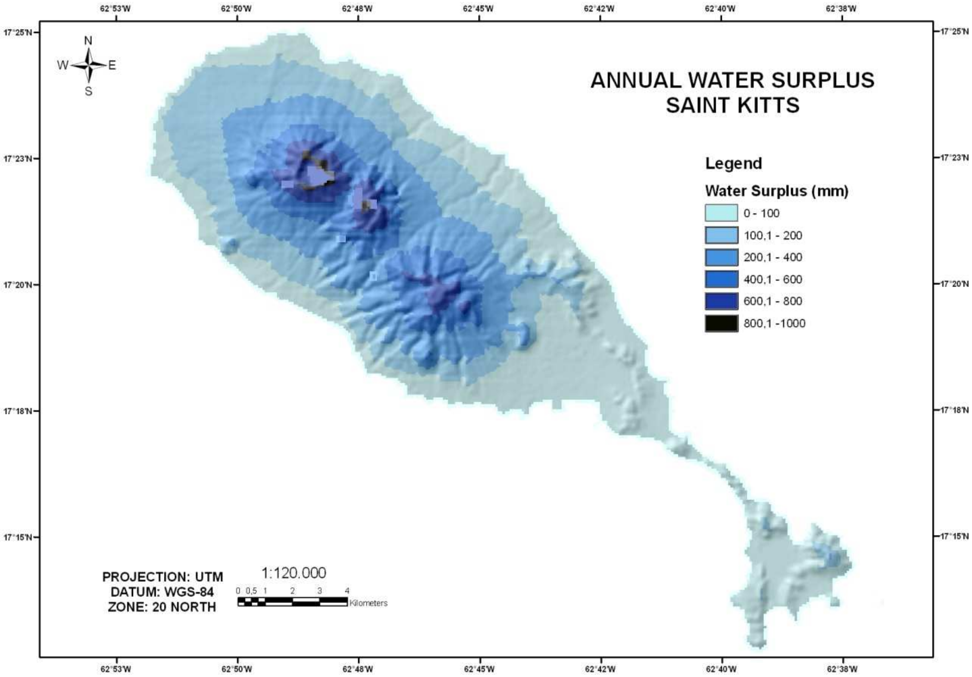


Figure 2.1.2.6

Map of annual water surplus, obtained from the climatological water balance, considering a soil water holding capacity of 125 mm

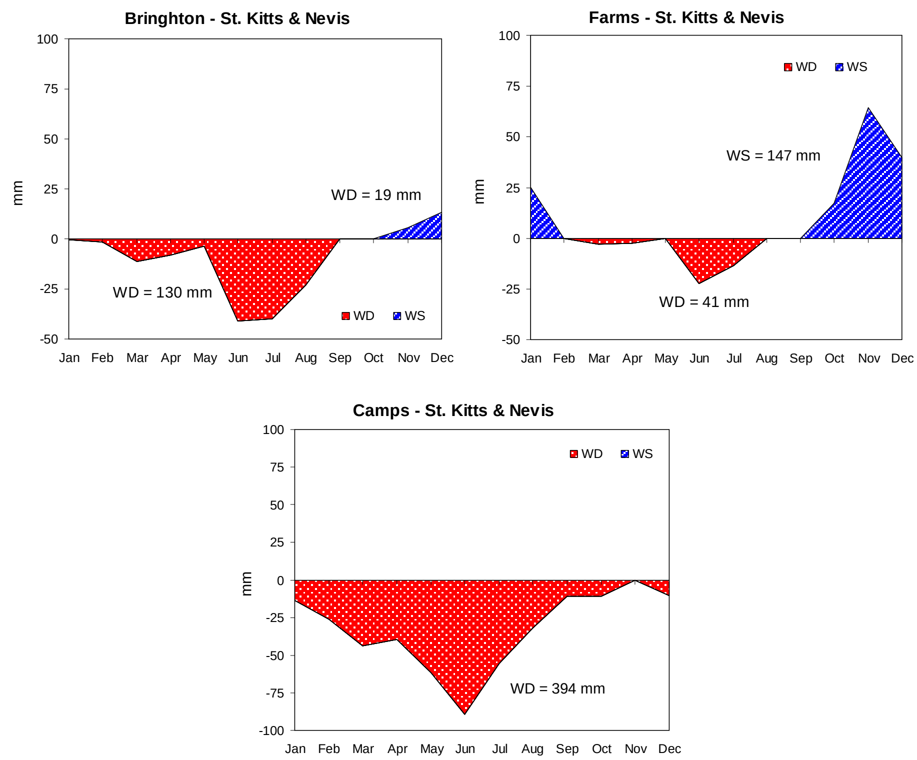


The seasonality of the water deficiency (WD) and water surplus (WS) and their variability in different regions of the country are presented in the Figure 2.1.2.7. Even considering that the island is not very large, there is a huge difference among the water availability of these areas. In Brighton station, the wet season lasts four months, from September to December, but with a very small WS (19 mm). The dry season is longer, from January to August, totaling a WD = 130 mm. For Farms station, the dry season starts in March and ends in July, with a total annual WD of 41 mm, whereas the wet season lasts six to seven months, totaling a WS of 147 mm. In Camps station, the water availability is critical and just water deficiencies are observed through out the year, with 394 mm of total WD.

In some places, where ETP decreases and rainfall increases because of altitude, WD falls to zero and WS can achieve 700 mm, however these lands are not suitable for agriculture. On the other hand, where rainfall is lower and ETP higher, like in the Basseterre region, where there is a rain shadow (annual rainfall < 1000 mm), WD raises to more than 400 mm.

Figure 2.1.2.7

Average water deficiency (WD) and water surplus (WS) for Brighton, Farms and Camps rainfall stations, obtained with the climatological water balance (SWHC = 125 mm)



2.1.3 Agroclimatic Crop Zoning

2.1.3.1 Sugarcane

According to FAO (2007), most of the rainfed and irrigated commercial sugarcane is grown between 35° N and S of the equator. The crop flouri shes 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.

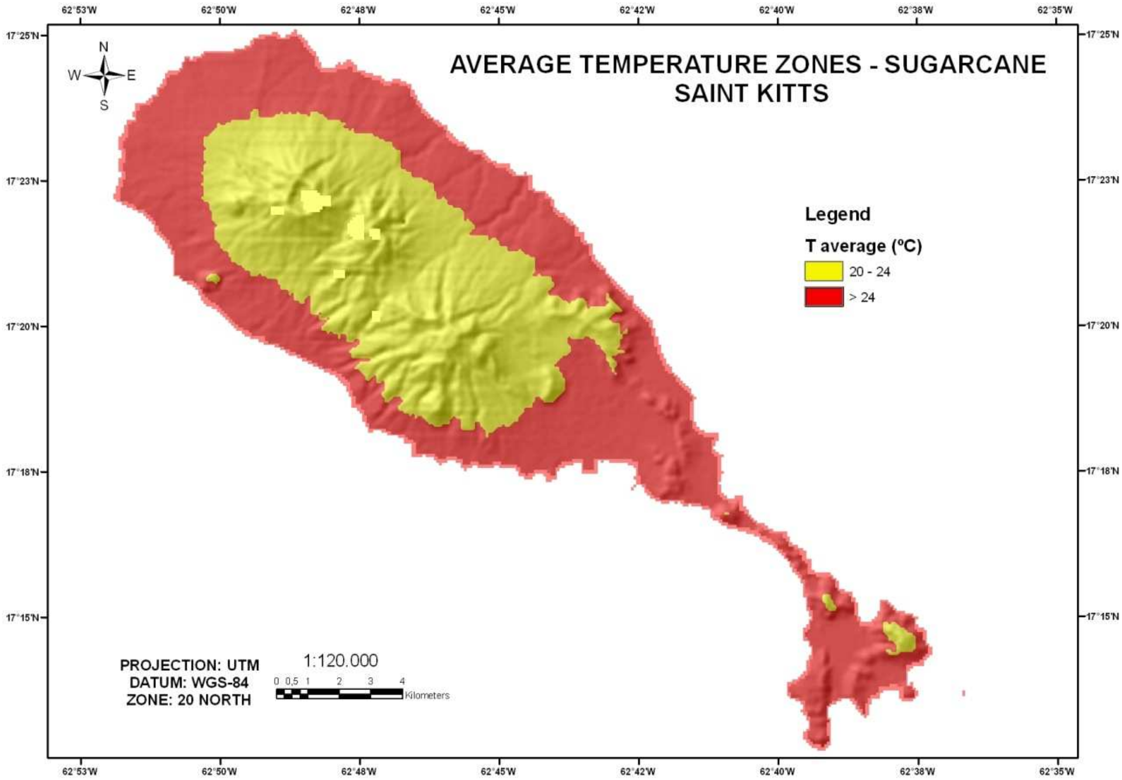
A long growing season is essential for high yields. The normal length of the total growing period varies between 9 months with harvest before winter to 24 months in Hawaii, but it is generally 15 to 16 months. Plant (first) crop is normally followed by 2 to 6 ratoon crops, and in specific conditions a maximum of 10 crops can be taken, each taking around one year to mature. Growth of the stool is slow at first, gradually increasing until the maximum growth rate is reached after which growth 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.

Saint Kitts and Nevis presents few limitations for sugarcane crop growth considering temperature conditions (Figure 2.1.3.1.1). Just few areas localized in high altitudes are considered as marginal, with annual average temperature around 20^{o}C. The great majority of the lands has **Ta** above 20^{o}C and is totally free of frosts, which make the conditions widely favorable for this crop.

However, when water deficiency is considered part of the country has marginal and inapt areas for rainfed crop (Figure 2.1.3.1.2). However, a very good portion of the lands is considered with aptitude. In the zones considered as marginal, supplementary irrigation can be used to make sugarcane crop suitable. In the areas considered as inapt, with more than 400 mm of water deficiency, full irrigation is required.

Figure 2.1.3.1.1

Map of average temperature zones for sugarcane crop in Saint Kitts and Nevis



Considering now temperature and water deficiencies as limiting factors for sugarcane, the country can be divided in 5 zones (Fig. 2.1.3.1.3). Around 33% of the lands or 5500 ha of the country are considered with aptitude for this crop with any restriction. Part of the lands, around 22% of the country (3,730 ha), is marginal considering limitations related to water deficiencies. In these areas, sugarcane fields will require supplementary or full irrigation to have good yield levels. However, in the majority of the lands, around 45% of the country or 7,650 ha, conditions for sugarcane growth are considered marginal due to the lack of dry or cool season for maturity process. In these areas, where altitude is higher, lower ETP and higher rainfall result in WD < 10 mm, which will require the use of chemicals to force the maturity process.

Figure 2.1.3.1.2

Map of water deficiency zones for sugarcane crop, considering a soil water holding capacity of 125 mm, in Saint Kitts and Nevis

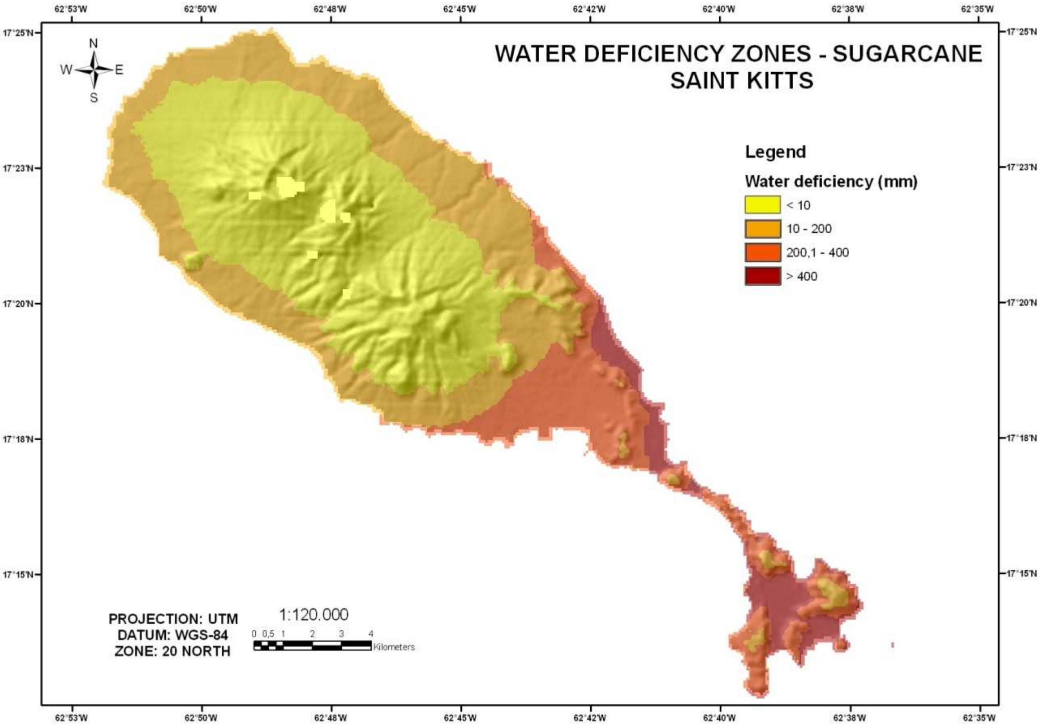
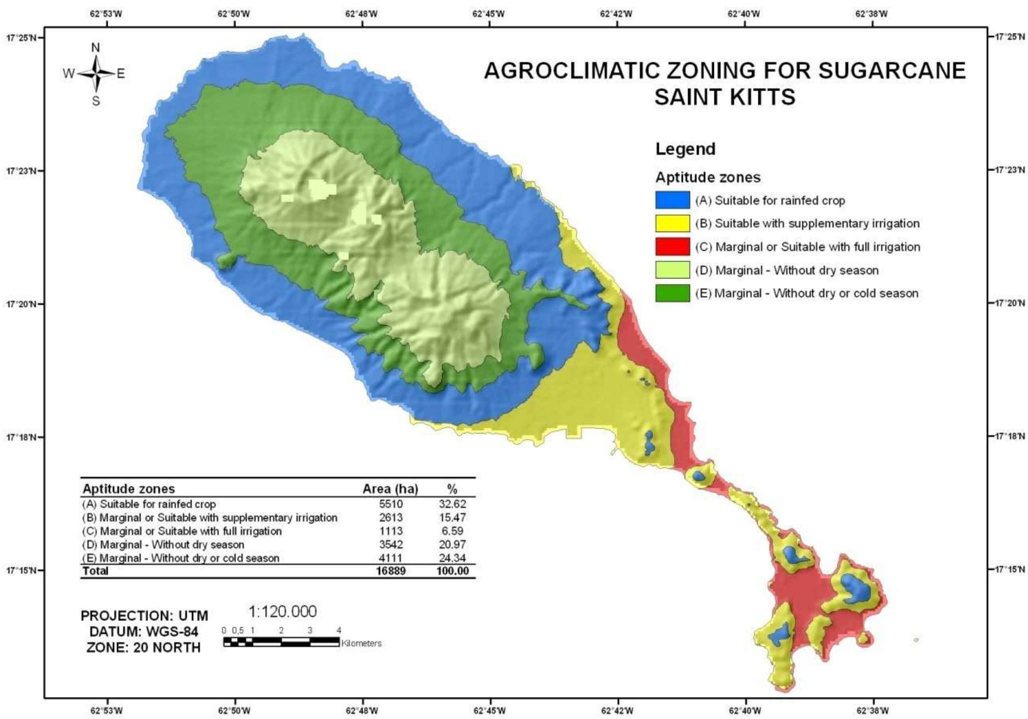


Figure 2.1.3.1.3

Agroclimatic zoning for sugarcane crop and the respective areas in hectares of each zone



2.1.3.2 Sunflower

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 70 d ays 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. Sunflower is a short-day plant with a variable response to daylength, but day-neutral varieties exist.

As observed in Figure 2.1.3.2.3, sunflower can be cultivated with very few restrictions in Saint Kitts and Nevis, regarding both temperature (Figure 2.1.3.2.1), always above 15^{o}C in all island, and water deficiency (Figure 2.1.3.2.2), below 300 mm in great part of the island. As can be seen in Figure 2.1.3.2.1, 81.7% of the country is suitable for sunflower growth, however this area will be reduced when soil, slope and conservation areas were considered.

Figure 2.1.3.2.1

Map of average temperature zones for sunflower in Saint Kitts and Nevis

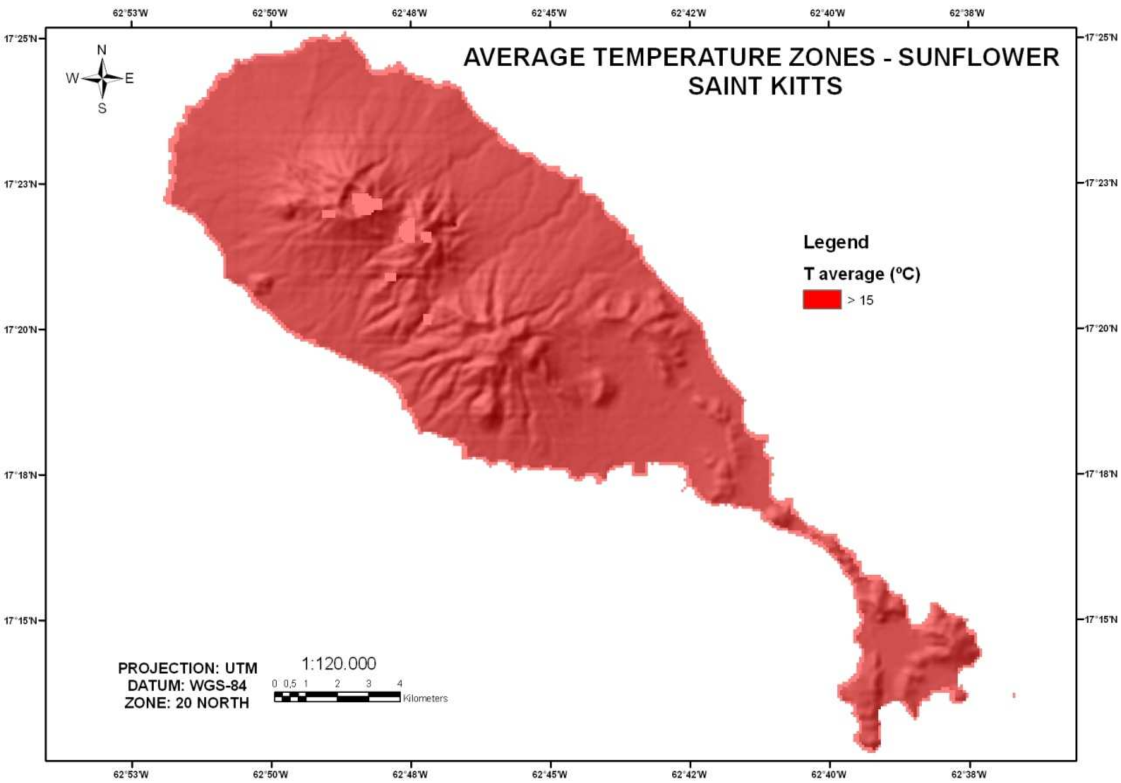


Figure 2.1.3.2.2

Map of water deficiency zones for sunflower, considering a soil water holding capacity of 125 mm, in Saint Kitts and Nevis

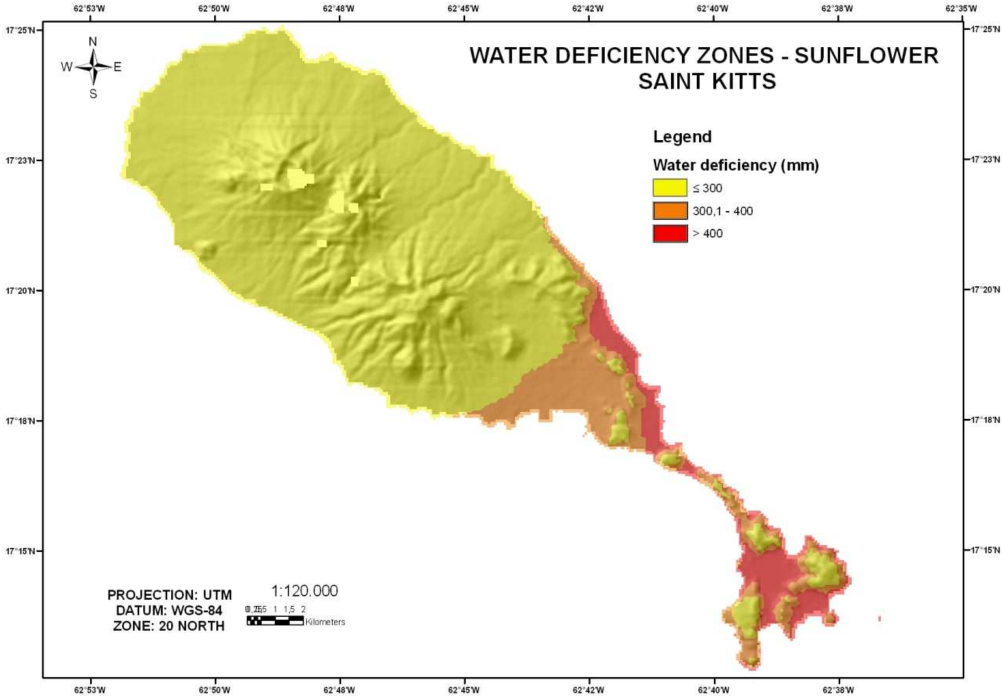
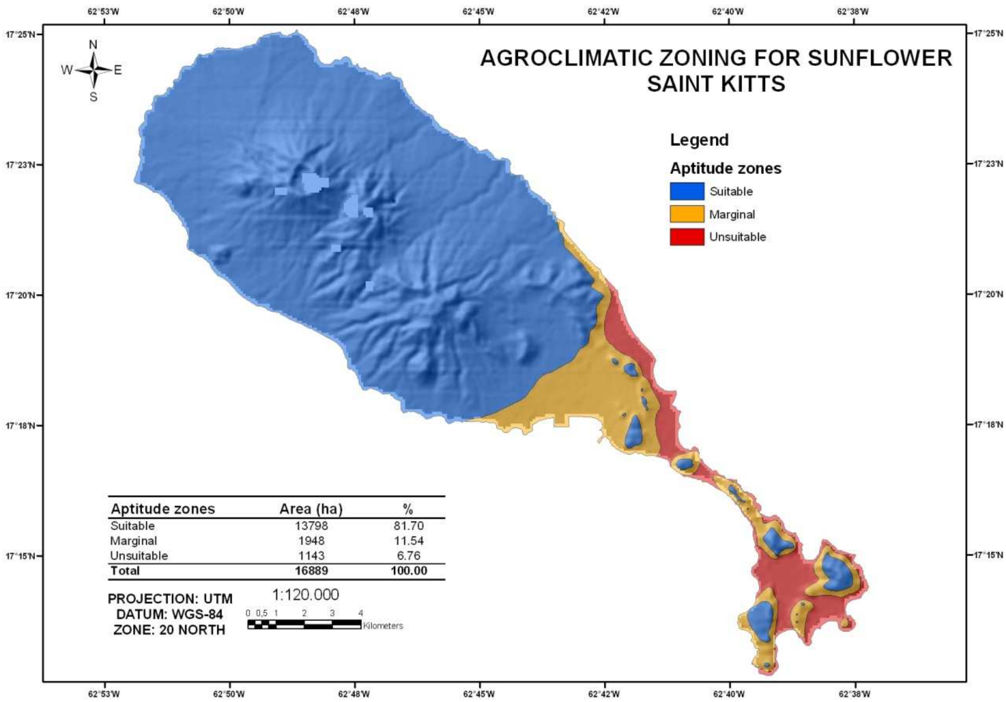


Figure 2.1.3.2.3

Agroclimatic zoning for sunflower and the respective areas in hectares of each zone in Saint Kitts and Nevis



2.1.3.3 *Jatropha curcas*

As Jatropha is originated from Caribbean, the climate of Saint Kitts and Nevis is normally favorable for this crop. According to Figures 2.1.3.3.1 and 2.1.3.3.2, temperature and rainfall conditions in Saint Kitts and Nevis are totally favorable for Jatropha in the great majority of the country. Based on this information, 99% of the country is considered favorable for Jatropha cultivation under rainfed condition (Figure 2.1.3.3.3). Therefore, as for sunflower, just soil and relief (slope) conditions will impose limitations for jatropha crop cultivation in St. Kitts and Nevis.

Figure 2.1.3.3.1

Map of average temperature zones for *Jatropha curcas* in Saint Kitts and Nevis

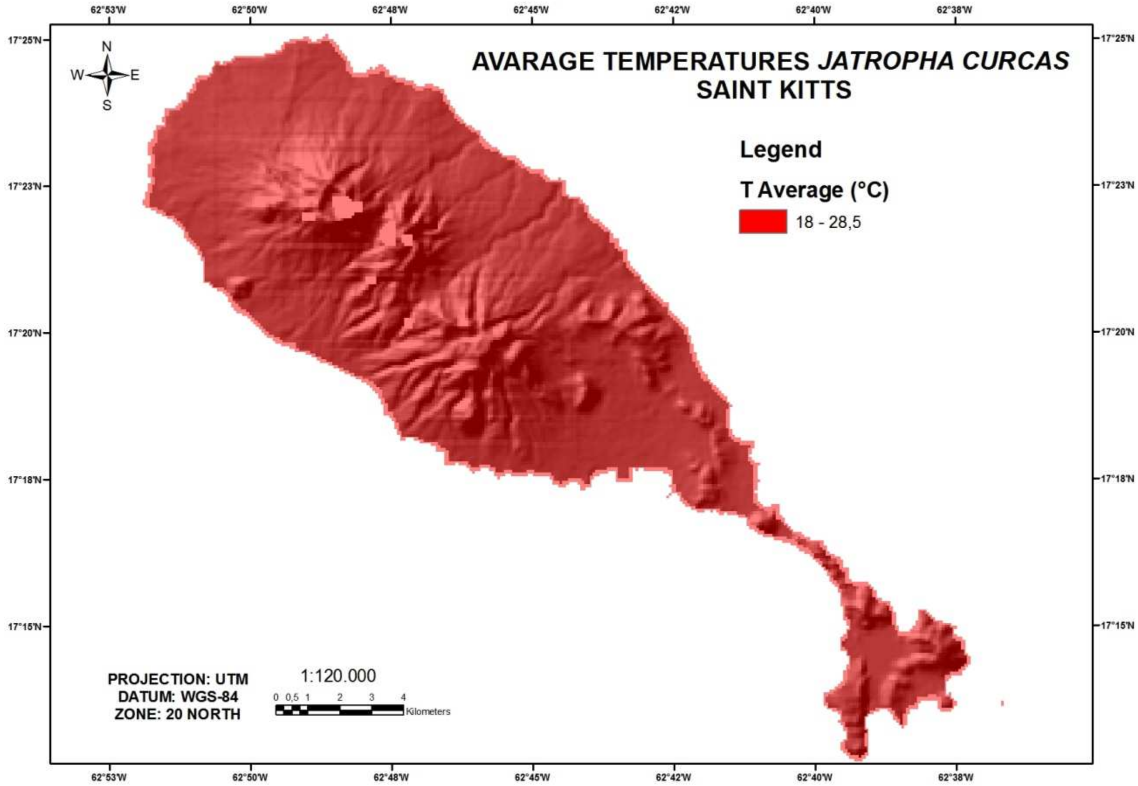


Figure 2.1.3.3.2

Map of annual rainfall zones for *Jatropha curcas* in Saint Kitts and Nevis

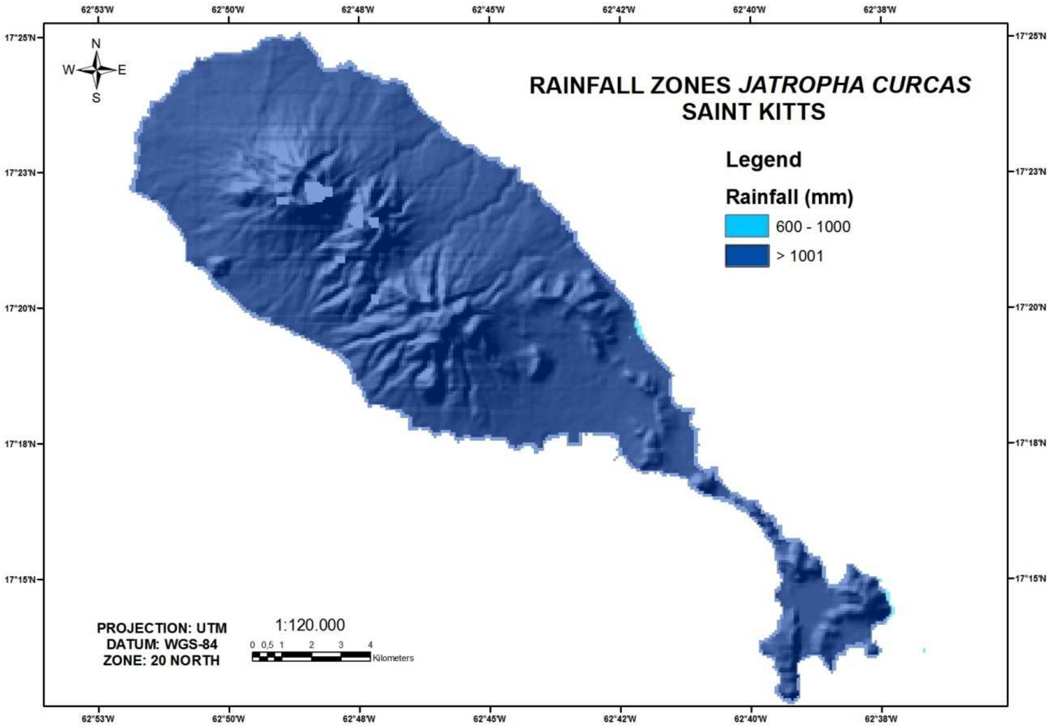
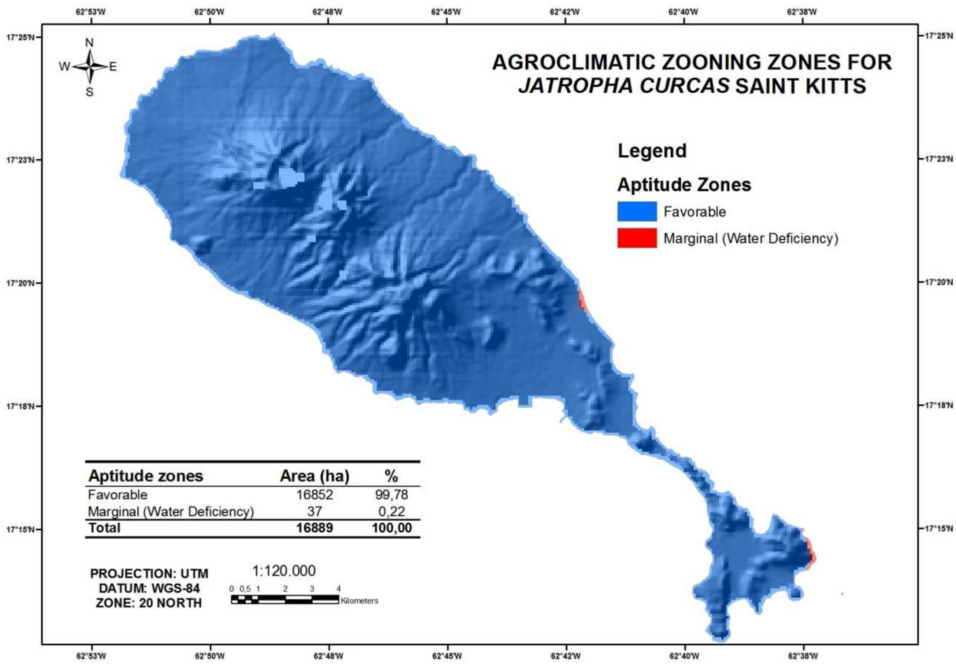


Figure 2.1.3.3.3

Agroclimatic zoning for *Jatropha curcas* and the respective areas in hectares of each zone in Saint Kitts and Nevis



3. Land Suitability

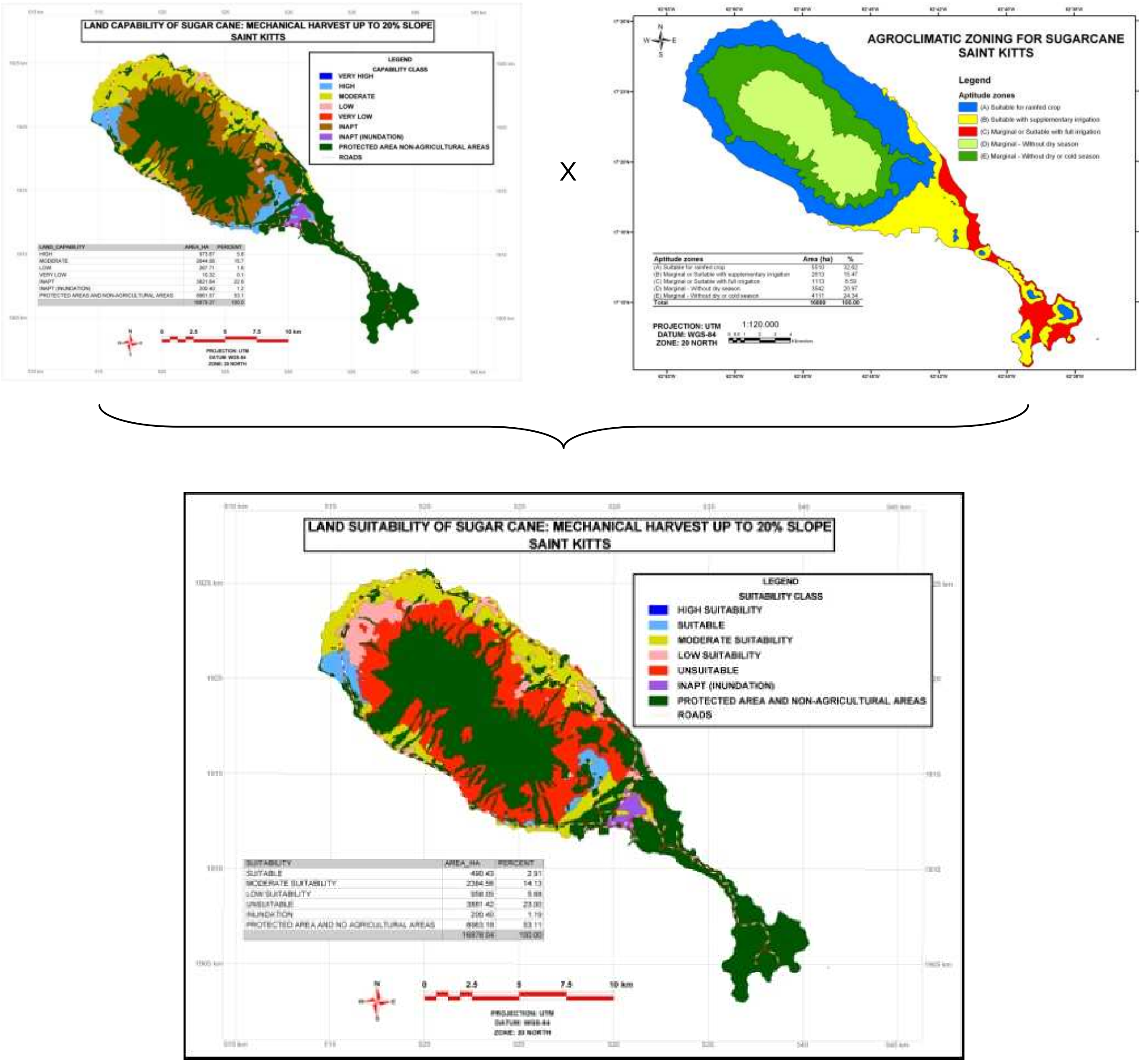
Land suitability is defined, in this project, as the result of the combination of the land capability and agroclimatic zoning maps. The combination of these levels of information summarizes into one classification system the most important land and climatic variables that affect land uses in different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

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 unsuitable (US) for totally inapt conditions of land capability and climate. For the classification of these classes not always the qualification between land capability and climate coincided. In some cases where the land capability or the climate was 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 3.1 illustrates the matching process between the land capability data and the agroclimatic zoning for the Republic of Saint Kitts and Nevis.

Figure 3.1

Map matching process for generation of the land suitability map



3.1 Land Suitability for biofuel crops

This section presents the results of the data matching explained in the previous section that defined the land suitability classes. Land suitability was defined for each of the evaluated biofuel crops (sugarcane, sunflower and *Jatropha curcas*) in Saint Kitts and Nevis.

The three biofuel-producing crops cited above were analyzed. Sugarcane was subdivided in manually harvested, mechanically harvested sugarcane up to 12% slope and mechanically harvested sugarcane up to 20% slope. This was done to help future decision-making processes concerning what type of sugarcane harvesting system is going to be eventually implemented in this country. The choice being between a labor-intensive system with environmental restrictions (manual harvest) and a high technological system with low labor demand that is environmentally friendly (mechanical harvest).

3.1.1 Sugarcane: manual and mechanical harvest

Table 3.1.1.1 presents the decision key for defining the suitability classes of sugarcane harvested manually and mechanically in Saint Kitts and Nevis. The six land capability classes were defined in the land capability report for this crop. In the agroclimatic zoning report, the five agroclimatic classes for sugarcane were: rainfed, supplementary irrigation, marginal – full irrigation, marginal – without dry season and marginal – without dry or cold season.

Table 3.1.1.1

Land suitability definition for sugarcane manually and mechanically harvested

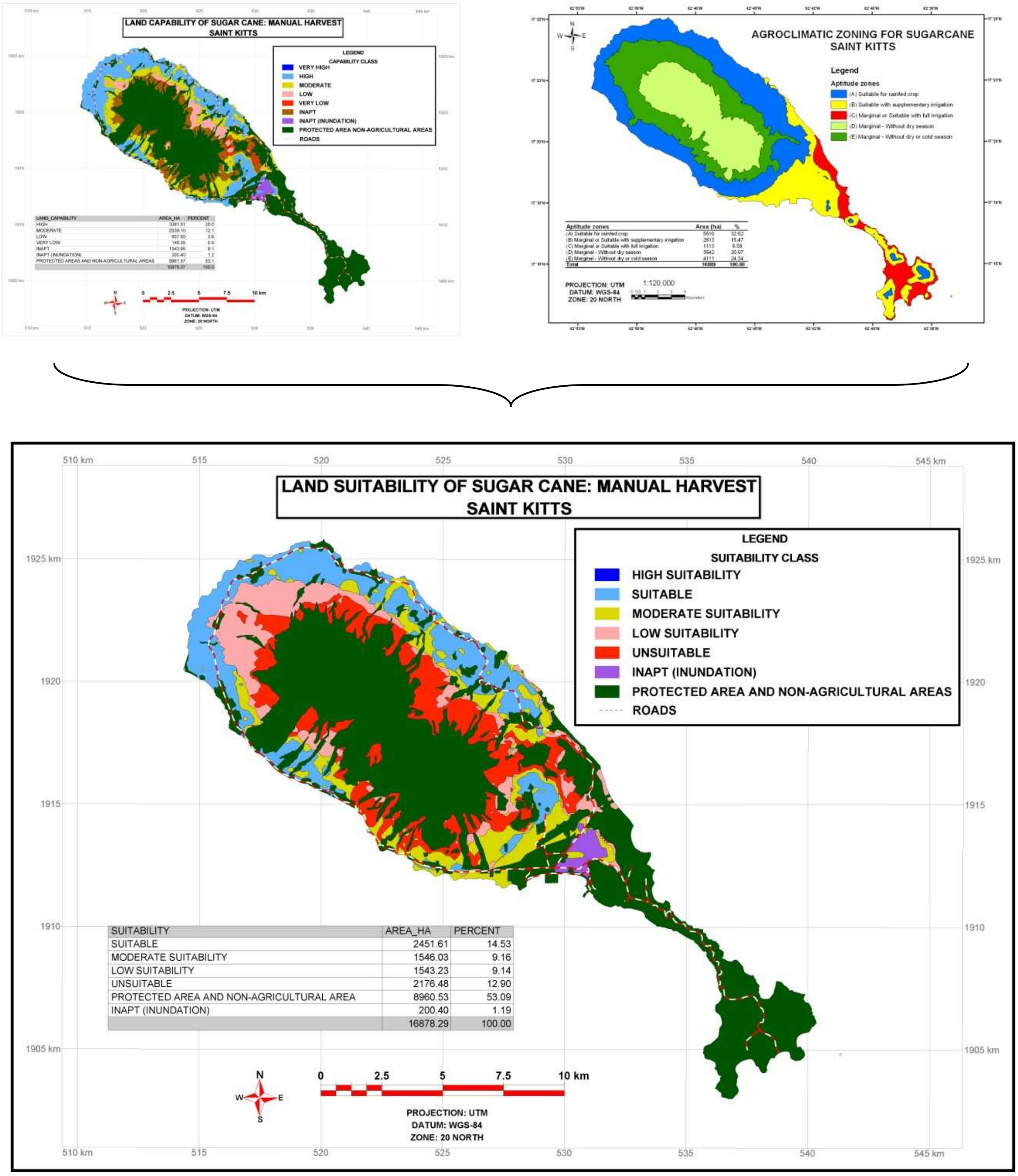
CLIMATE CATEGORIES	SOIL CATEGORIES	CLIMATE x SOIL	LAND SUITABILITY CATEGORIES
Rainfed	High	SU/H	S
Supplementary irrigation	High	SI/H	MS
Marginal – full irrigation	High	MFI/H	LS
Marginal – without dry season	High	MD/H	US
Marginal – without dry or cold season	High	MDC/H	US
Rainfed	Inapt	SU/H	US
Supplementary irrigation	Inapt	SI/H	US
Marginal – full irrigation	Inapt	MFI/H	US
Marginal – without dry season	Inapt	MD/H	US
Marginal – without dry or cold season	Inapt	MDC/H	US
Rainfed	Low	SU/H	LS
Supplementary irrigation	Low	SI/H	US
Marginal – full irrigation	Low	MFI/H	US
Marginal – without dry season	Low	MD/H	US
Marginal – without dry or cold season	Low	MDC/H	US
Rainfed	Moderate	SU/H	MS

Supplementary irrigation	Moderate	SI/H	LS
Marginal – full irrigation	Moderate	MFI/H	US
Marginal – without dry season	Moderate	MD/H	US
Marginal – without dry or cold season	Moderate	MDC/H	US
Rainfed	Very High	SU/H	HS
Supplementary irrigation	Very High	SI/H	S
Marginal – full irrigation	Very High	MFI/H	MS
Marginal – without dry season	Very High	MD/H	LS
Marginal – without dry or cold season	Very High	MDC/H	US
Rainfed	Very Low	SU/H	US
Supplementary irrigation	Very Low	SI/H	US
Marginal – full irrigation	Very Low	MFI/H	US
Marginal – without dry season	Very Low	MD/H	US
Marginal – without dry or cold season	Very Low	MDC/H	US

Figures 3.1.1.2 to 3.1.1.4 show the distribution of the land suitability classes for manually and mechanically harvested sugarcane in Saint Kitts and Nevis. Suitable areas occupy 2,451 ha which represents 14.53% of the total land of the island whereas 1,546 ha or 9.16% of the island is occupied by moderate suitability areas. No land with high suitability was found in Saint Kitts and Nevis, this could be explained mainly by soil restrictions due to moderate and low soil fertility (refer to Land Capability report). Areas with low and very low suitability present both soil and climatic restrictions. These areas are associated with higher slopes found on the sides of the volcanoes that occupy the middle of the island which affect the quality of the soil and the climatic conditions.

Figure 3.1.1.2

Land suitability, land capability and agroclimatic zoning maps for sugarcane manual harvest for Saint Kitts and Nevis



SUITABILITY	AREA_HA	PERCENT
SUITABLE	2451.61	14.53
MODERATE SUITABILITY	1546.03	9.16
LOW SUITABILITY	1543.23	9.14
UNSUITABLE	2176.48	12.90
PROTECTED AREA AND NON-AGRICULTURAL AREA	8960.53	53.09
INAPT (INUNDATION)	200.40	1.19
	16878.29	100.00

Figure 3.1.1.3 represents the Land Suitability for sugarcane harvested mechanically up to 12% slopes. Low suitability and unsuitable areas increase when compared to the manually harvested sugarcane. This decrease in suitability is explained by the slope limitations of the island for harvesting with tire harvesters as well as stoniness and presence of boulders, which also affects this type of harvest. The climatic conditions are not affected by the harvesting technique so no differences in the agroclimatic map were observed. The main limitations in this suitability map are referred to soil conditions. Unfortunately the soil limiting factors (slope and stoniness) that affect this type of harvesting technique are not easily resolved from the soil point of view but can be ameliorated if technology is developed so that the tire harvesting machines present a higher stability at slopes above 12%.

Figure 3.1.1.3

Land suitability, land capability and agroclimatic zoning maps for sugarcane mechanical harvest up to 12% slopes for Saint Kitts and Nevis

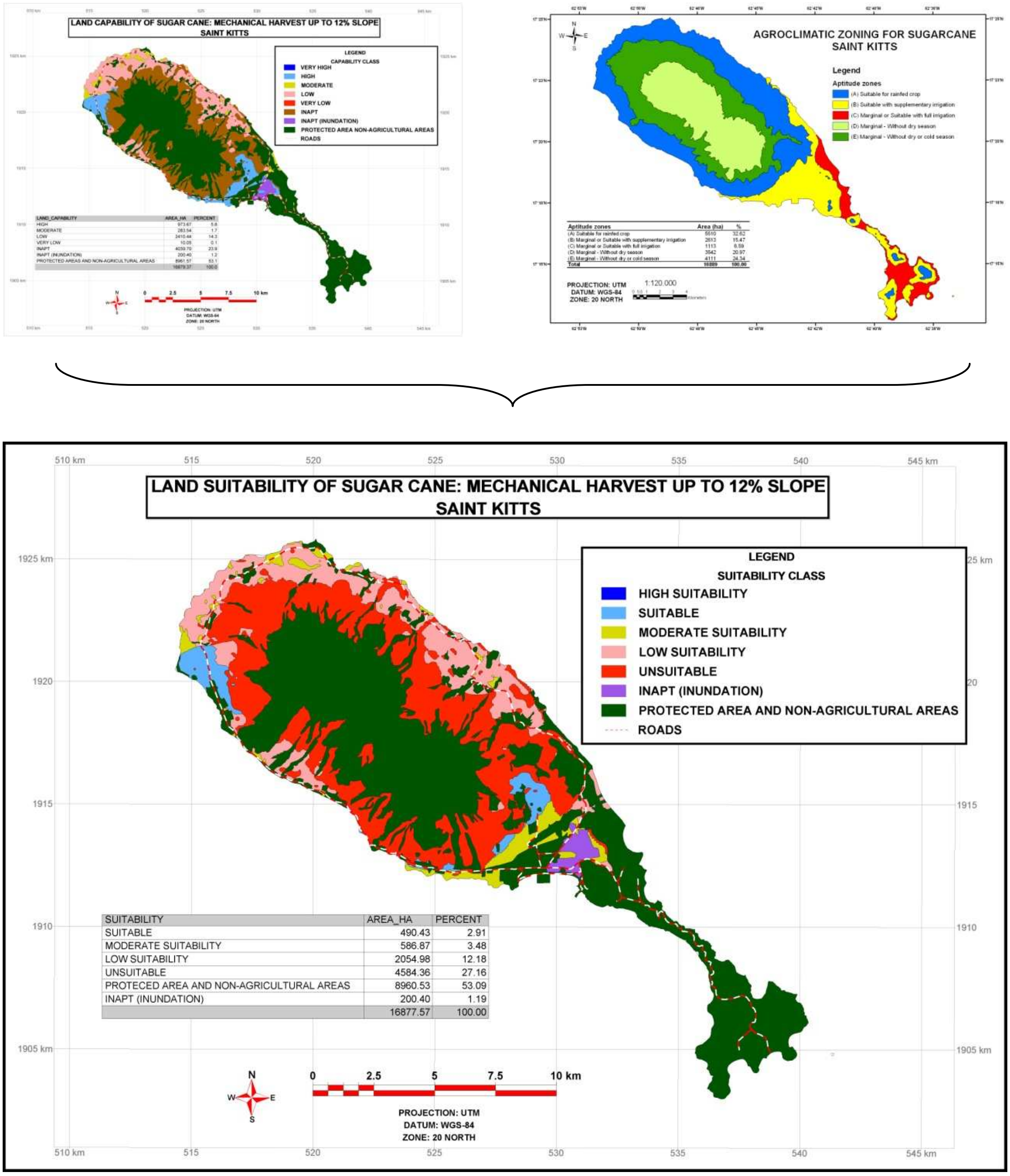
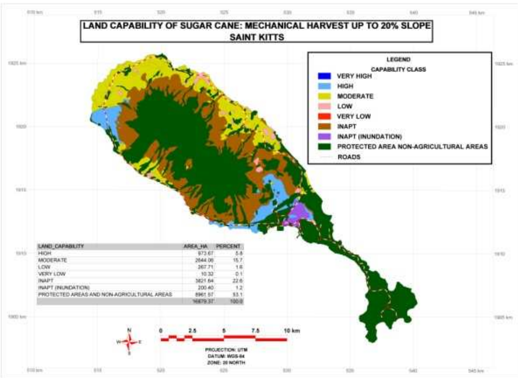
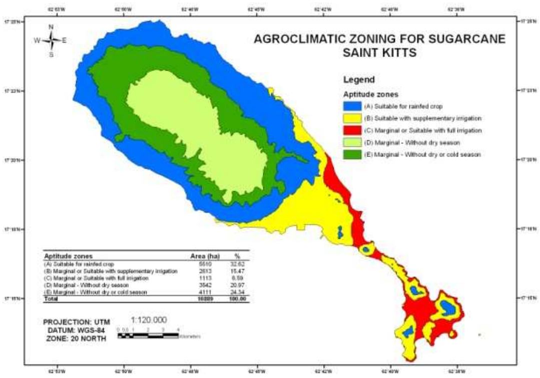


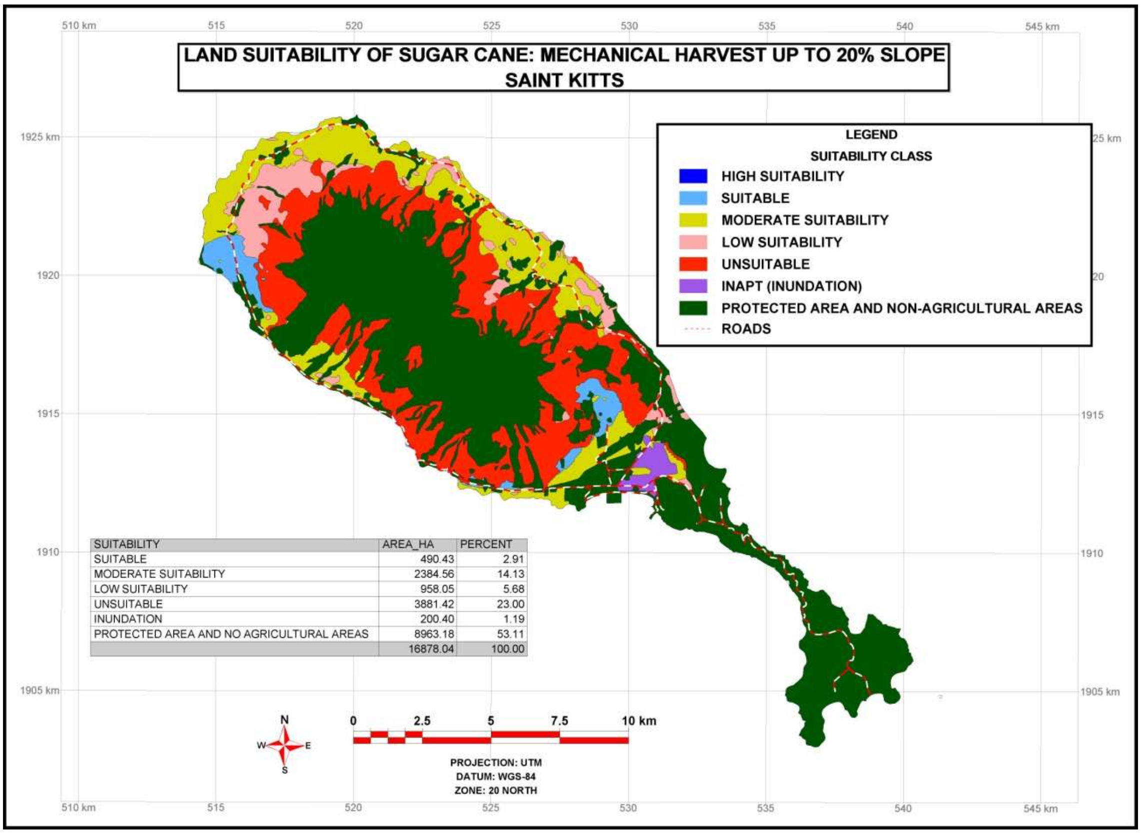
Figure 3.1.1.4 shows the suitability conditions of Saint Kitts and Nevis for sugarcane harvested at slopes up to 20%. As explained in the land capability report this extension of slope percentage for harvesting evaluation purposes is due to information obtained from Mr. Conrad Kelly, former agriculture manager of the Saint Kitts and Nevis Sugarcane Manufacturing Corporation, which informed us that track harvesters could work up to slopes of 20%. In this case suitability conditions in some areas increased, when compared to the 12% slope analysis, due to the inclusion of areas with slope percentages above this value. This means that slope is not such a limitation anymore and stoniness and presence of boulders becomes the main soil attribute affecting the areas suitable for this harvesting technique. The soil fertility and physical restrictions that were observed and affected the manually harvested sugarcane, also affect the mechanically harvested sugarcane up to 12 and 20% slopes.

Figure 3.1.1.4

Land suitability, land capability and agroclimatic zoning maps for sugarcane mechanical harvest up to 20% slopes for Saint Kitts and Nevis







3.1.2 Sunflower

According to Table 3.1.2.1, the land suitability for sunflower crop, integrating climate and soil information, was divided in five categories, from high suitable (HS) to unsuitable (US).

Table 3.1.2.1

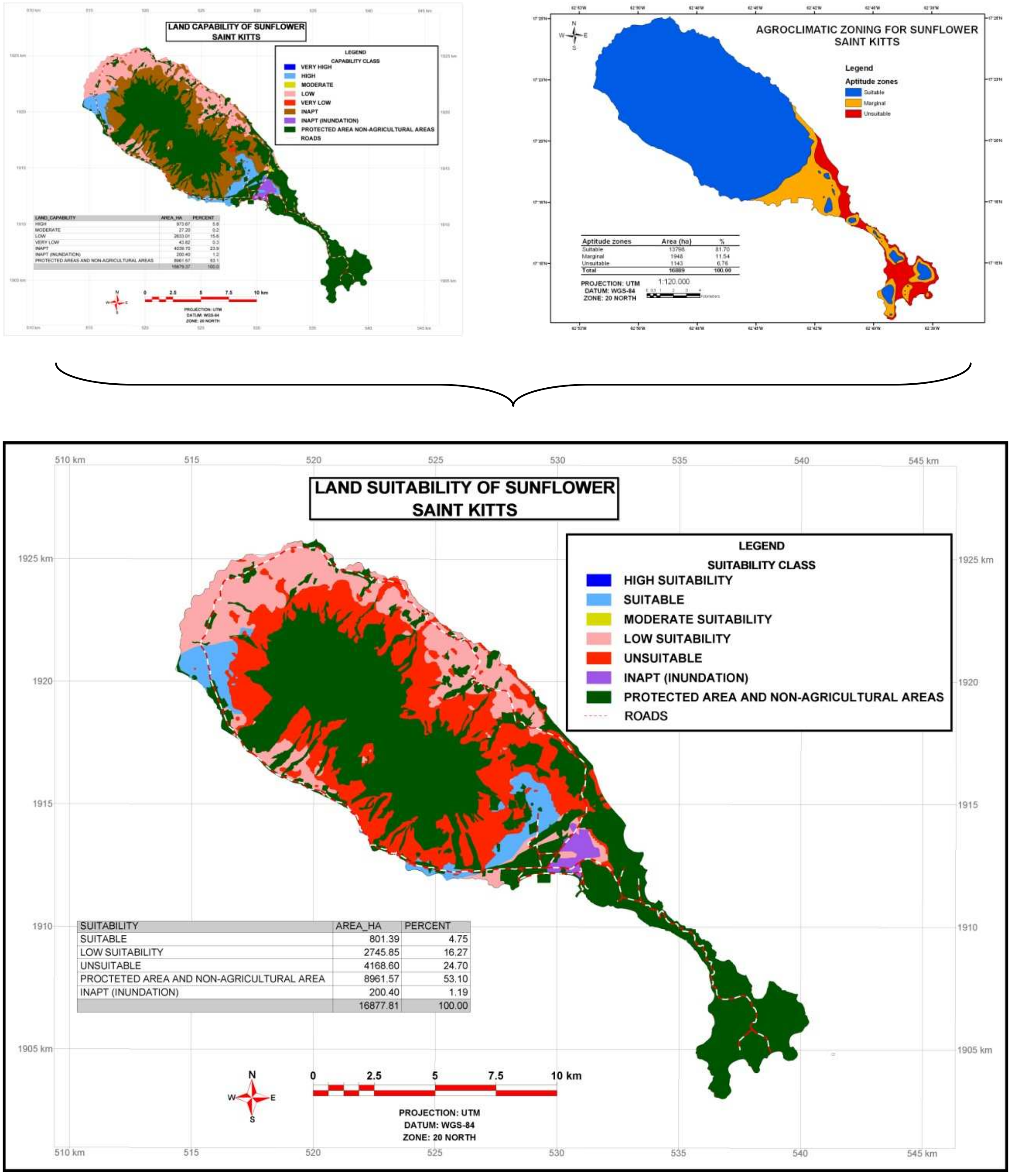
Suitability categories adopted for sunflower crop, according to climate and soil information

CLIMATE CATEGORIES	SOIL CATEGORIES	CLIMATE SOIL	LAND SUITABILITY CATEGORIES
Suitable	High	SU/H	S
Marginal	High	M/H	LS
Unsuitable	High	UN/H	US
Suitable	Inapt	SU/IN	US
Marginal	Inapt	M/IN	US
Unsuitable	Inapt	UN/IN	US
Suitable	Low	SU/L	LS
Marginal	Low	M/L	US
Unsuitable	Low	UN/L	US
Suitable	Moderate	SU/M	MS
Marginal	Moderate	M/M	LS
Unsuitable	Moderate	UN/M	US
Suitable	Very High	SU/VH	HS
Marginal	Very High	M/VH	S
Unsuitable	Very High	UN/VH	US
Suitable	Very Low	SU/VL	US
Marginal	Very Low	M/VL	US
Unsuitable	Very Low	UN/VL	US

In Saint Kitts and Nevis, sunflower is basically limited by soil conditions, since climate is favorable for this crop in most of the island (Figure 3.1.2.1). Soil limitations limit the areas classified as suitable (S) for sunflower crop to 4.75% of the country, totaling approximately 801.39 hectares. No areas considered of moderate suitability (MS) were found and low suitability (LS) totalizing 16.27% of the island (2,745.85 ha), whereas unsuitable (US) zones comprise 24.7% of the lands. Soil limitations that affect sunflower in Saint Kitts and Nevis are poor fertility, poor drainage, high slopes and stoniness (refer to Land Capability report).

Figure 3.1.2.1

Land suitability, land capability and agroclimatic zoning maps for sunflower crop in Saint Kitts and Nevis



3.1.3 Jatropha curcas

According to Table 3.1.3.1, the land suitability for *Jatropha*, integrating climate and soil information, was divided into five categories, from high suitability (HS) to unsuitable (US).

Table 3.1.3.1

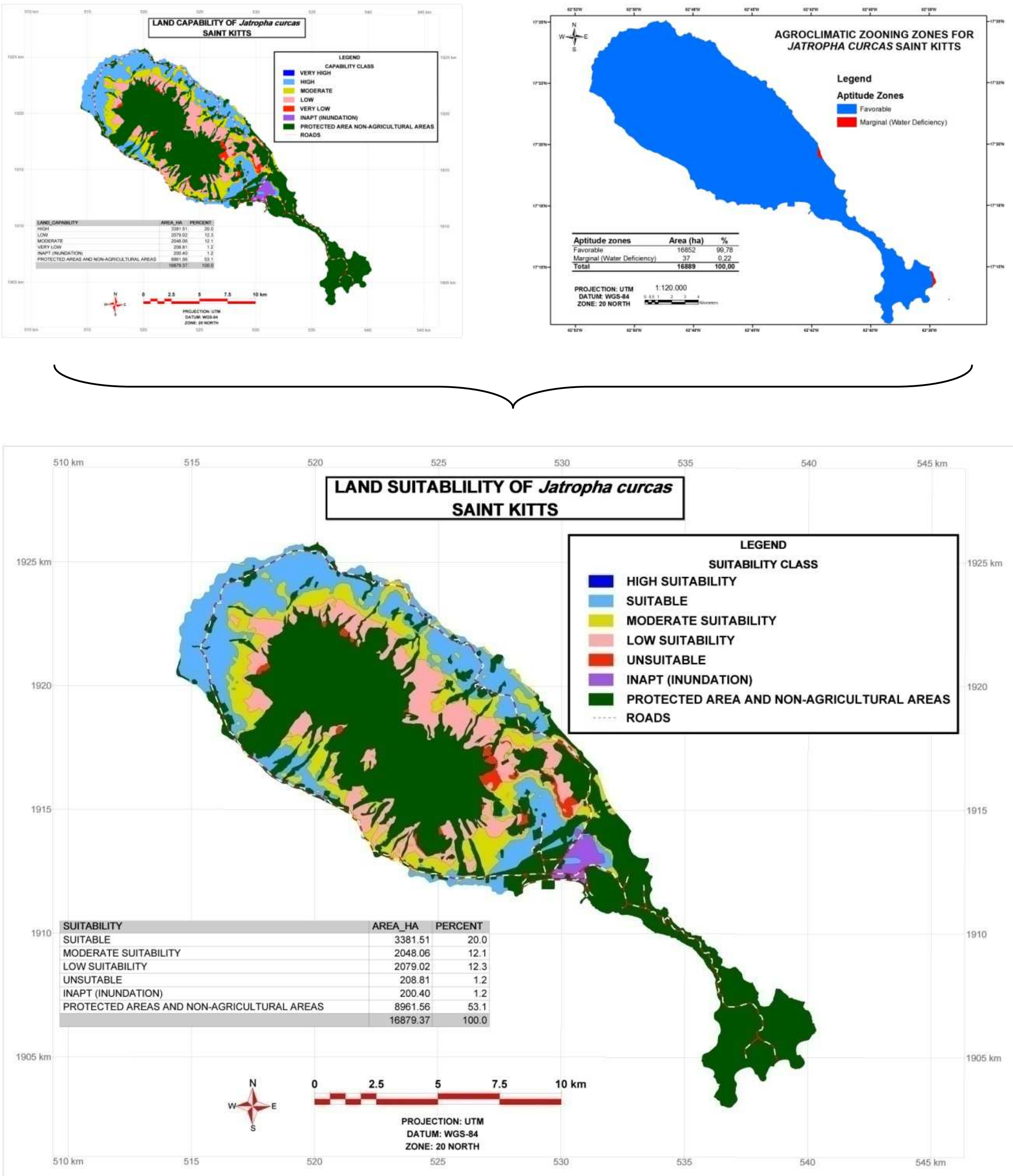
Categories of suitability adopted for *Jatropha curcas*, according to climate and soil information

CLIMATE CATEGORIES	SOIL CATEGORIES	CLIMATE SOIL	LAND SUITABILITY CATEGORIES
Suitable	High	SU/H	S
Marginal – Water Deficiency	High	WD/H	LS
Suitable	Inapt	SU/IN	US
Marginal – Water Deficiency	Inapt	WD/IN	US
Suitable	Low	SU/L	LS
Marginal – Water Deficiency	Low	WD/L	US
Suitable	Moderate	SU/M	MS
Marginal – Water Deficiency	Moderate	WD/M	US
Suitable	Very High	SU/VH	HS
Marginal – Water Deficiency	Very High	WD/VH	MS
Suitable	Very Low	SU/VL	US
Marginal – Water Deficiency	Very Low	WD/VL	US
Unsuitable	Very High	UN/VH	US
Suitable	Very Low	SU/VL	US
Marginal	Very Low	M/VL	US
Unsuitable	Very Low	UN/VL	US

Even considering that jatropha is a native crop from Central America and Caribbean, having a high suitability under the climate point of view – 98% of the island has a very good climate for its growth and development – Saint Kitts and Nevis presents just four categories of land suitability. The area of suitable (S) and moderate suitability for jatropha in Saint Kitts and Nevis corresponds to 32% of the lands, totaling 5.429 ha. The remaining available areas are unsuitable (US) or with low suitability (LS), totaling 2.287 ha or 13.5% of the island (Figure 3.1.3.1). Main restrictions are due to soil attributes, which for jatropha present low limitations except when slope and stoniness increase due to the islands' geomorphology or problems arise due to salinity or drainage (refer to Land Capability report).

Figure 3.1.3.1

Land suitability, land capability and agroclimatic zoning for *Jatropha curcas* in Saint Kitts and Nevis



4. Estimated yields for sugar cane

Table 4.1 presents the values of the potential productivity for sugar cane in the island of Saint Kitts estimated using a modified version of Teramoto’s (2003) model. Potential productivity values range between 39 ton.ha^{-1} to 99 ton.ha^{-1} with a mean of 70.69 ton.ha^{-1}. These values were estimated considering a maximum productivity of 120 ton.ha^{-1} for sugar cane. Comparing the information in Table 4.1 with the real mean yield of sugar cane of 55.5 ton.ha^{-1} obtained from FAOSTAT, one can observe that most of the sampled areas presented an estimated potential, which is superior to this mean. This shows that the correct exploitation of the land resources in the island of Saint Kitts can lead to higher yields and consequently a major enhancement for sugar-cane production.

Table 4.1

Potential productivity of sugar cane for each soil class calculated the soil databank of Saint Kitts and Nevis

	Factor for (Soil Fert)	Factor for Drainage	Factor for Slope		Maximum productivity observed (t.ha^{-1})	
Weighing factor	3	2	2		120	
	Soil and landscape attribute punctuations					
Soil_ID	**Soil fertility**	**Drainage**	**Slope**	**Soil punctuation**	**Relative productivity (%)**	**Potential productivity (t.ha^{-1})**
01	0.300	1.000	0.600	4.400	55.00	66.00
02	0.300	1.000	0.600	4.400	55.00	66.00
03	0.500	0.900	0.400	4.600	57.50	69.00
04	0.400	0.900	1.000	5.400	67.50	81.00
05	0.700	0.700	0.400	5.000	62.50	75.00
06	0.700	0.900	1.000	6.600	82.50	99.00
07	0.700	0.900	0.500	5.600	70.00	84.00
08	0.700	0.900	0.600	5.800	72.50	87.00
09	0.400	0.900	0.700	4.800	60.00	72.00
10	0.700	0.900	0.600	5.800	72.50	87.00
11	0.500	1.000	1.000	6.000	75.00	90.00
12	0.500	0.900	0.900	5.600	70.00	84.00
13	0.700	0.600	0.300	4.600	57.50	69.00
14	0.500	0.600	0.700	4.600	57.50	69.00
15	0.500	0.600	0.700	4.600	57.50	69.00
16	0.700	0.600	0.700	5.400	67.50	81.00
17	0.700	0.000	0.700	4.200	52.50	63.00
18	0.700	0.600	0.700	5.400	67.50	81.00
19	0.500	0.600	0.700	4.600	57.50	69.00
20	0.500	0.600	0.700	4.600	57.50	69.00
21	0.500	0.600	0.700	4.600	57.50	69.00
22	0.500	0.600	0.500	4.200	52.50	63.00

	Factor for (Soil Fert)	Factor for Drainage	Factor for Slope		Maximum productivity observed ($t.ha^{-1}$)	
Weighing factor	3	2	2		120	
	Soil and landscape attribute punctuations					
Soil_ID	Soil fertility	Drainage	Slope	Soil punctuation	Relative productivity (%)	Potential productivity ($t.ha^{-1}$)
23	0.400	0.900	0.500	4.400	55.00	66.00
24	0.500	0.600	0.600	4.400	55.00	66.00
25	0.500	0.400	0.600	4.000	50.00	60.00
26	0.700	0.400	0.600	4.800	60.00	72.00
27	0.400	0.500	0.800	4.200	52.50	63.00
28	0.300	0.500	0.700	3.600	45.00	54.00
29	0.500	0.500	0.700	4.400	55.00	66.00
30	0.300	0.200	1.000	3.600	45.00	54.00
31	0.100	0.100	1.000	2.600	32.50	39.00
32	0.100	0.800	1.000	4.000	50.00	60.00
Means	**0.50**	**0.6625**	**0.69375**	**4.71**	**58.91**	**70.69**

Legend for Soil_ID: 1) Protosols, 2) Protosols, 3) Protosols, 4) Protosols, 5) Protosols, 6) Protosols, 7) Protosols, 8) Protosols, 9) Protosols, 10) Protosols, 11) Protosols, 12) Protosols, 13) Protosols, 14) Young Soils, 15) Young Soils, 16) Young Soils, 17) Young Soils, 18) Young Soils, 19) Kandoid Latosolics, 20) Kandoid Latosolics, 21) Kandoid Latosolics, 22) Kandoid Latosolics, 23) Kandoid Latosolics, 24) Allophanoid Latosolic, 25) Smectoid Clay Soils, 26) Smectoid Clay Soils, 27) Smectoid Clay Soils, 28) Smectoid Clay Soils, 29) Smectoid Clay Soils, 30) Saline Soils, 31) Saline Soils, 32) Saline Soils, 33) Rendzina

5. Final Remarks

The Land Suitability analysis performed for three biofuel crops showed that important areas of Saint Kitts and Nevis have good potential for their production. Sugarcane manually harvested presented large areas with good suitability classes, on the contrary when sugarcane is harvested mechanically with tire harvesters that can only work up to 12% slopes; the land with good suitability is drastically reduced. The option of working with track harvesters permits to extend the slope range to 20% – this increases the land suitability classification for this crop, making available larger areas with reasonable land suitability. Sunflower presents very low suitability classes and would not be a viable option. Jatropha on the contrary presents large areas (3,381 ha) with high land suitability being a viable option for biofuel production.

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 higher.

The Land Suitability analysis performed for three biofuel crops showed that important areas of Saint Kitts and Nevis have a good potential for their production. Sugar-cane manually harvested presented large areas with good suitability class (suitable: 2,551.16 ha), on the contrary when sugar-cane is harvested mechanically with tyre harvesters which can only work up to 12 % slopes, the land with good suitability is reduced drastically. The option of working with track harvesters permits to extend the slope range to 20% - this increases the land suitability classification for this crop making available larger areas with reasonable land suitability. Sunflower presents very low suitability classes and would not be a viable option (suitable: 801.39). *Jatropha* on the contrary presents 3,381 ha with suitable areas, being a viable option for biofuel production.

Finally, the correct exploitation of the land resources in the island of Saint Kitts can lead to higher yields and consequently a for sugar-cane production.

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