Identifying Areas for Cultivating Industrial Hemp in Puerto Rico Using Geospatial Technologies

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Abstract *— This investigation focuses on determining areas that are optimal for growing industrial hemp in Puerto Rico. Using a multi-criteria decision-making model, weights were calculated and assigned to each variable. Weights help establish a hierarchy between the criteria of precipitation, temperature, slope, organic carbon, and pH. These criteria are then combined to create a suitability map. The results of the analysis found that the most suitable lands are in the south and center-east parts of the island. A sensitivity analysis demonstrated that the model is considered highly sensitive to the organic carbon data, meaning that changing its parameters alters drastically suitability map results.*

Key Terms *— Analytical Hierarchy Process, Geographical Information Systems, Hemp, Suitability Analysis.*

INTRODUCTION

Hemp is the non-intoxicant variant of the cannabis plant, which produces fiber, seeds, and flowers. These are extracted from the plant to create hemp-based products for commercial and industrial use. Countries around the world are competing to become major exporters in a currently billion-dollar industry. Recent legislation has given the opportunity to Puerto Rico to participate in this emerging market; but for this to become a reality hemp must be cultivated on the island.

This research is focused on the use of geographic information systems (GIS) as a tool to analyze and identify suitable areas for hemp cultivation in Puerto Rico. The goal of this investigation is to highlight fields of land that meet optimal criteria that produces the best yields. The analysis takes into consideration that some criteria have parameters that are more ideal than others. Using a multi-criteria decision-making model such as an analytical hierarchy process helps add weights to rank each criterion; this method is known to produce accurate and logical results [1]. This investigation is crucial because of the lack of information on the subject matter of hemp in Puerto Rico and could be of benefit to entities that are interested on investing in this new industry.

Research Description

This project aims to analyze multiple factors that affect hemp growth utilizing geographical information systems as the main tool to identify the best suitable locations in Puerto Rico. A site selection process will be conducted using existing available data on the island's temperature, precipitation, soil type, slope, and land use. A sensitivity analysis will be done to determine the effect of the models' assumptions on the results; this will be evaluated by modifying one parameter at a time.

Research Objectives

The objective of this research is to highlight functionality of a suitability analysis when selecting lots of land for hemp growth. This research could help achieve optimum utilization of the available land for sustainable agricultural production. Another objective of this research is to establish the use of GIS technology in the industrial hemp market in Puerto Rico, by developing an important methodology to improve mapping technology for finding cultivation sites.

Research Contributions

The main contribution of this research is understanding the optimal areas for hemp growth. Maps and data tables will be used in the GIS analysis, dedicated to comprehending potential cultivation sites in Puerto Rico. Because of the lack of formal research on this area in the Caribbean, this research seeks to encourage the common practice of site selection that occurs around the world. To persuade the industry to implement the use of geospatial technologies as a part of their agricultural business operations.

LITERATURE REVIEW

This part elaborates on the historical context and the subject matter to be investigated, based on the limited available literature.

Background

The cultivation of cannabis started in eastern China around twelve thousand years ago, when farmers dedicated their lands to produce hempseeds and fiber, later to be used in a spiritual or recreational context [2]. As trade routes began connecting civilizations from around the world, cannabis was introduced to new cultures in Europe, which then introduced it to the Americas. By 1753, botanists gave the plant its taxonomic identification and physicians were reporting its medicinal qualities [2]. When its popularity soared as a recreational drug, a negative perception of the plant developed in the twentieth century. Many countries began to ban the substance; the United States of America, motivated by racial prejudice, also forbade the cultivation of cannabis, making it illegal to produce hemp [3].

In modern times, the Agriculture Improvement Act of 2018 removed low THC cannabis plants from the Schedule One Controlled Substance list, thus making industrial hemp an ordinary agricultural crop. This allowed farmers to seek out water rights and cultivation grants, and introduced them to the national banking system, giving the industry opportunities in marketing, agronomy research, and insurance [4]. That legislative decision opened opportunities in Puerto Rico to produce a new agricultural product.

Hemp Products

Industrial hemp is mostly grown for three purposes: the CBD that can be obtained from the flower, the fiber that comes from the stems, and the grain (seeds) that it creates to reproduce. The flower produces CBD, which is associated with the medicinal properties of cannabis. Conclusive or substantial evidence that cannabis or cannabinoids are effective is limited to only three domains: "(i) alleviation of chronic pain in adults (cannabis); (ii) as antiemetics in the treatment of chemotherapy induced nausea and vomiting (oral cannabinoids); and (iii) the improvement in patient-reported multiple sclerosis spasticity symptoms (oral cannabinoids)" [5]. Fiber has been used in the past to create rope, linens, and paper. Modern technological advances have brought hemp fiber as fabric alternatives for wood in construction materials, strengthening of concrete to generate hempcrete, and the creation of composite materials like molded plastics. There are even promising results showing that supercapacitors with electrodes made from hemp-based carbon nanosheets outperform standard supercapacitors [2]. Hempseed can be used as a dietary supplement, as it contains high concentrations of omega-3 and omega-6 fatty acids [3]. Across Canada, this grain is used to create all kinds of products, including toasted hemp seed, hemp seed oil, hemp flour, and hemp coffee. Birds and livestock are being fed hempseed as an alternative, much like other grains today [4]. Hemp is incredibly versatile; all these products may be used for a myriad of applications. "The global market for industrial hemp has more than 25,000 products in nine main submarkets: textiles, agriculture, automotive, food and beverages, paper, furniture, construction, recycling, and personal care [6]."

Agricultural Requirements

To be able to rely on a stable crop, it is important to find the best lands for cultivation. *Cannabis sativa* has multiple hemp genotypes that can survive in different climates. As part of a study conducted in Malaysia, a suitability assessment found hemp an adaptable crop for tropical environments [7]. Other studies have shown that the best conditions for industrial hemp are "comparable to corn-growing soils… well-aerated loams with high fertility and high organic matter" [8]. Since the objective for any economically sustainable agricultural product is to maximize yields, it is advised to select good corn (maize) lands to grow hemp [9]. In Puerto Rico, corn has been grown for nearly a hundred years, with studies determining the viability of specific corn species in the tropical climate, with groups like the Caribbean Crops Society concluding in 1987 that the best yields were obtained by planting before the beginning of long days [10]. The General Administration for Development Cooperation published a list of crop requirements for land evaluation and mentions corn (maize) to have a tolerance to wide range of environmental conditions, but still details the best parameters for optimal growth cycles [11]. Table 1 shows these parameters, with 1 being the best possible condition and 5 being the absolute worst conditions.

Table 1
Maize Criteria Requirements

Climate and Land	5	4	3	2	1
Precipitation mm per year	900-600	1200-900, 600-500	1600-1200, 500-400	1900-1600, 400-300	>1900 <300
Mean Temperature °C	26-24	32-26, 22-18	35-32, 18-16	40-35, 16-14	>40, <14
Topography Slope %	0-4	4-8	8-16	16-35	> 35
Organic Carbon %	>1.2	1.2-0.8	0.8-0.5	0.5-0.2	< 0.2
pH	7.0-6.2	7.8-7.0 6.2-5.8	8.2-7.8 5.8-5.5	8.5-8.2 5.5-5.2	> 8.5 < 5.2

*Data not used in this research withheld.

Suitability Analysis

A suitability analysis is a spatial multi-criteria decision-making method that assists in selecting the best option from several alternatives. This is accomplished by assigning a weight to each criterion; a value assigned to the criterion to indicate its importance relative to the other criteria. Weights are calculated through an Analytical Hierarchy Analysis (AHA); when it becomes challenging to establish a clear relationship between a significant number of criteria, this method can be helpful [12]. The larger the weight, the more important is that criterion overall. It is recommended by the Food and Agricultural Organization (FAO) to evaluate the suitability of an agricultural site by ratings from highly suitable to not suitable, based on climate, soil, and terrain data [12]. Geographic information systems help with adding the spatial component to this process, which will be needed to identify areas of interest. By implementing GIS and remote sensing for land evaluation and crop suitability analysis, farmers can make more informed decisions about land use. In recent years, there have been many studies regarding land suitability [13]. In Iran, scholars found appropriate parcels of land to cultivate rice using a fuzzy multi-criteria decision-making approach [14]. Others have used a suitability analysis to identify land for citrus cultivation utilizing ArcGIS software as their main tool [15]. In Turkey, researchers analyzed a whole province to assess the agricultural productivity of the land [16]. It was revealed that 65% was suitable for grain production, primarily in areas that were further away from industrial activity. Most studies found that a geostatistical approach is the best solution for identifying areas of interest. Researchers in Croatia used GIS-based multicriteria analysis to determine cropland suitability for maize [17]. The main selected criteria used were temperature, precipitation, and soil type.

The Croatian study applied an analytical hierarchy process and was able to locate areas for cultivation that benefit farmers with better yields and crop quality. The researchers implemented a sensitivity analysis and found that the precipitation data was particularly impactful to the results, while the temperature data was not. This investigation attempts to do something analogous with a similar crop: industrial hemp.

Methodology

The focus of this section is on the methods employed to examine the data for the investigation. The chosen methodology was based on prior research and an understanding of similar cases.

Data Sources

The data acquired for this investigation was downloaded directly from the ArcGIS Living Atlas, a collection of geographical information from around the world. A total of six raster data layers are used to obtain the results of the suitability analysis:

- **Annual Mean Precipitation:** The WorldClim 2.1 produced this layer from GeoTIF datasets to estimate a rainfall climate variable millimeter (figure 1). It was first published in the International Journal of Climatology in 2017, with the support of a grant from Feed the Future to the Geospatial and Farming Systems Consortium of the Sustainable Intensification Innovation Lab.

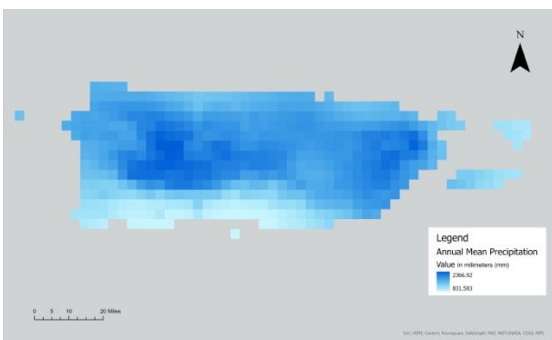

Figure 1
Annual Mean Precipitation

- **Annual Mean Temperature:** The WorldClim, a database of high spatial resolution global weather and climate data, produced this data with the help of the United States Geological Survey (USGS). The unit of measurement valued in the data is in Celsius degrees (figure 2).

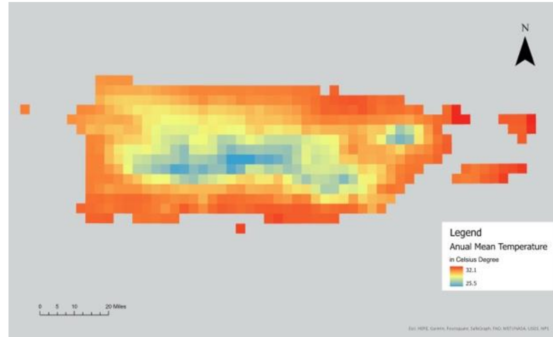

Figure 2
Annual Mean Temperature

- **Topography Slope:** A multi-resolution world layer that offers elevation data from which slope was calculated. This digital terrain model was put together by the National Geospatial Intelligence Agency (NGA), the National Aeronautics and Space Administration (NASA), and the USGS, and is available to download from the ESRI ArcGIS online platform. The slope values are set in percentage functions (figure 3).

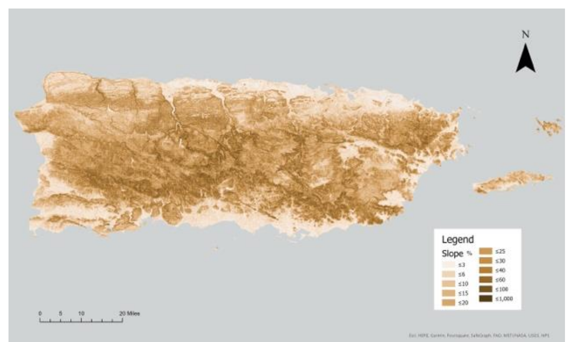

Figure 3
Topography Slope

- **Organic Carbon in Soil:** The organic carbon data layer was derived from the World Soils Harmonized Database. It contains information related to soil chemistry provided by the Food and Agricultural Organization, an agency of the United Nations. The organic carbon is measured in percentage weight (figure 4).

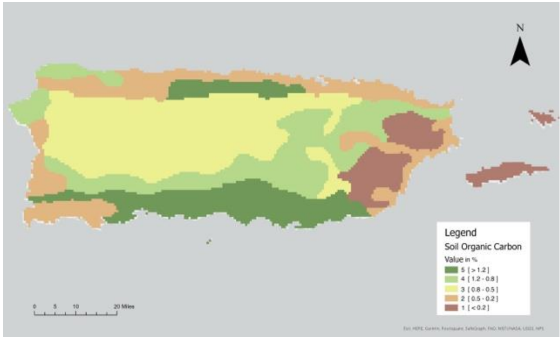

Figure 4
Organic Carbon in Soil

- **Soil pH Levels:** The layer that displays the acidity or alkalinity of the soil was also derived from the World Soils Harmonized Database. Known as pH, it has a range of 0 to 14, with 0 being the most acidic and 14 being the most basic (figure 5).

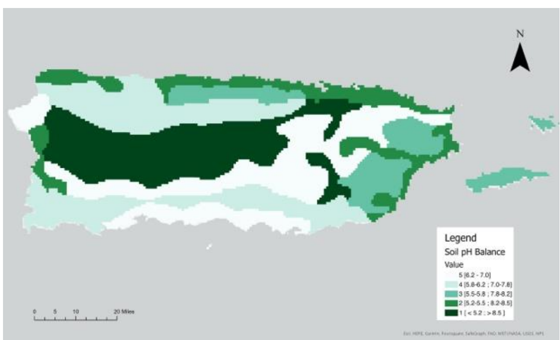

Figure 5
Soil pH Levels

- **Farmland Class:** The layer showcases farmlands that are prime and of local and statewide importance (figure 6). Created by the Natural Resources Conservation Service under the Farm Protection Policy Act, this data is divided into multiple classes of farmland, from which all were used as the extent of the investigation. All the research will fall within the boundaries of theses classes.

As part of the quality control, every raster dataset was modified to have the same cell size and data projection, except for the Farmland class, for the abovementioned reasons.

Figure 6
Farmland Class

Analytical Hierarchy Process

By using a multi-criteria decision-making method is possible to identify the relationship between the criteria of a complex problem. Due to its versatility and comprehensiveness, the analytic hierarchy process is considered dependable [18]. Weights can be determined through the AHP [19]. Researchers generated a decision matrix and performed a pairwise comparison (table 2). These calculations are made to obtain the weights that will be used in the suitability analysis.

Table 2
Pairwise Comparison Matrix

	P	T	S	OC	pH	CW
P	1	2	5	2	5	0.3750
T	0.50	1	5	2	5	0.2736
S	0.20	0.20	1	0.25	3	0.0773
OC	0.50	0.50	4	1	7	0.2232
pH	0.20	0.20	0.33	0.14	1	0.0459

P: Precipitation, T: Temperature, S: Slope, OC: Organic Carbon, pH: pH Balance, CW: Criteria Weight

To determine the relative importance of selected factors, a pairwise comparison matrix was conducted for all possible combinations, assigning values, according to their relative importance, from 1 (equally important) to 9 (extremely important). The coherence of the pairwise matrix was verified using the Consistency Ratio (CR), which was determined based on the Consistency Index (CI) and the number of criteria being compared, applying the Random Consistency Index (RI).

$$CI = \frac{\lambda_{Max} - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

Equations (1) and (2) were used to calculate CR, where λ (lambda max) is the value representing consistency vectors and *n* is the number of criteria.

Suitability Analysis Framework

The investigation was done using ArcGIS Pro, an Esri GIS platform, to conduct a suitability analysis helping to find the best location for cultivating hemp in Puerto Rico. Specifically, the suitability modeler tool which provides an ease of use to represent each criterion and combining the rasters into a single surface that meets the model goal. For this investigation a weighted model was chosen; the suitability scale in a weighted model ranges from 1, the lowest preference, to 5, the highest preference. Table 1 shows the parameters of each criterion and their suitability value. A mask was applied to define the spatial extent using the Farmland Class data (Figure 6). The values of each dataset that represents a criterion was then transformed into a 1-to-5 suitability scale. Weights, as a percentage, were assigned to enable the relative importance of each criterion to the overall goal. As a percentage, the total weight must add up to 100. Each criterion was given its calculated weight from the abovementioned step, and the data layers were then combined to create a suitability map that considers each criterion and weights assigned.

Sensitivity Analysis

The purpose of a sensitivity analysis is to assess how the outcome of the model is influenced by its underlying assumptions, to understand how much the value of each variable affects the results. This was applied by modifying a weight in the original model. Since the soil criteria has two datasets of evaluation, it was chosen to change its weight percentages by only 5%. Every data layer was re-combined to create a new suitability map and observe the changes.

RESULTS AND DISCUSSION

In this section, the results obtained from the investigation are presented and discussed in detail. The discussion highlights the mayor findings of the study and their significance.

Analytical Hierarchy Process

The pairwise comparison matrix (table 2) was normalized; then, mean values were calculated for each row that belongs to the normalized pairwise comparison matrix values. The multi-criteria decision-making model provided the following weights for each variable: precipitation: 0.3750; temperature: 0.2736; slope: 0.0773; organic carbon: 0.2232; and pH: 0.0459. The consistency ratio was checked. The lambda max is 5.2761, which helped determine the consistency index. CI equals 0.0690. RI is the consistency index of randomly generated pairwise matrix; for the number of criteria used in this research (five in total), the RI is 1.12. With the results of CI and RI, the consistency ratio was calculated to be 0.0616. Due to the fact that the consistency ratio is less than 0.10, it is not necessary to generate a pairwise matrix again [19]. Thus, the calculated weights for each criterion will be used.

Suitability Analysis Results

The amalgamation of every criterion resulted in a raster detailing the ideal locations for hemp cultivation (figure 7), where the value of 5 is expressed as the most suitable and 1 as the least suitable. Visually, it is illustrated in a color gradient ranging from green to red. The most suitable areas are displayed in green and the least suitable areas are displayed in red, with the intermediate values in yellow.

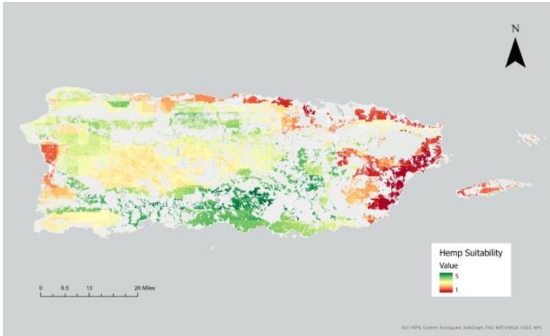

Figure 7
Hemp Suitability Results

Most of the island of Puerto Rico is shown to have medium to low suitability for hemp growth. The absolute best locations are found in the center-south of the island, heading in-land. These areas are in the coastal municipalities of Ponce, Juana Díaz, Santa Isabel, and Salinas; and the interior municipalities of Coamo, Cayey, Cidra, and Aguas Buenas. The lands that are or near the value of 4 (light green color) are located around the central mountainous region. These areas are the south-western municipalities like San Germán, Sabana Grande, and Yauco; and the northern municipalities of Florida, Manatí, and Vega Baja. These two latter also have territory with a value of or near 1. The zones that are less suitable are all around the coast, except for the south of the island. Most of these lands are in the east, in the municipalities of Vieques, Culebra, Naguabo, Maunabo, Ceiba, Humacao, Las Piedras, Yabucoa, Juncos, and Gurabo. The center of Puerto Rico, where the highest peaks are located, have medium values of suitability. The municipalities in this region are Utuado, Jayuya, Ciales, Adjuntas, and Lares.

Sensitivity Analysis Results

This investigation has two data layers in the category of soil chemical characteristics. Past research mentions high organic carbon as an important factor for agricultural cultivation, which led for it to have a higher weight percentage than pH. These data layers were used to conduct a sensitivity analysis. The original weights per data sets are 22.32% for organic carbon and 4.59% for pH. A 5% change was made, for a new total weight percentage of 17.32% for organic carbon and 9.59% for pH. A new suitability map was created using the adjusted weight percentages (figure 8).

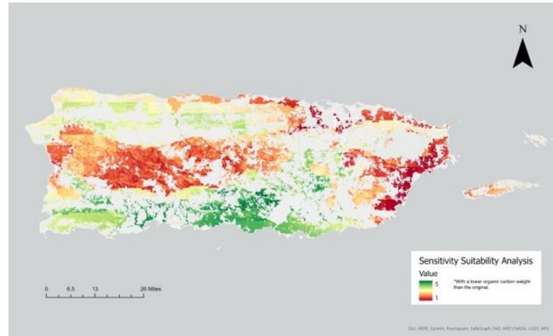

Figure 8
Sensitivity Map Results

The difference in results, from the original Hemp Suitability Map (figure 7) are distinguishable in the center region of the island of Puerto Rico. All the medium values in that area have turned into less suitable zones, with new values of 2 and 1 on a scale from 5 to 1, where 5 is the most suitable and 1 the least. There also seems to be a change in the far-left corner of the island, where the municipalities of Guánica, Lajas, and Cabo Rojo are located; these are now higher in the suitability scale than before.

CONCLUSIONS

This investigation has shown how the use of Suitability Analysis can be implemented to improve site selection in the agricultural industry. Using weights can work to model real-world conditions more accurately. A suitability analysis during the initial phases of planning could be a powerful tool for determining the ideal location for a specific crop.

During the process of investigation, instead of clipping each raster to our desired study area, the farmland data layer was used as a mask. The use of a binary mask in this type of model improves the processing of the analysis and accuracy of the results. To validate the suitability map generated from the available data, it may be beneficial to collect ground truth data by visiting the areas identified as most suitable. This will help confirm that the locations identified in the Hemp Suitability

Map with a value of 5 are indeed the most appropriate sites.

The aim of a sensitivity analysis is to investigate the impact of model assumption on the outcome by changing a single parameter. The results changed drastically when reducing the weight of organic carbon and increasing the weight of pH. This means that the model is considered highly sensitive to that assumption. Places, where organic carbon has moderate values, are being taken into consideration less in the sensitivity map. This is to be expected because every data layer has a major overlap with respect to their most unsuitable zones, the center of the island, as opposed to the organic carbon data set, where its least suitable area is in the eastern part of the island. Thus, when changing the weight of organic carbon, the output is more amounts of land to be unfit for cultivating hemp.

The use of geographical information systems, with the aid of an analytical hierarchy process, helps identify the areas that are ideal for hemp growth. The ease of use of these applications made it possible to understand that not all lands in Puerto Rico are preferable for cultivating this crop. Hemp is a robust product that can grow in many environments, but for it to be commercially available it needs to be in optimal conditions. The most suitable places appear to be in the south and center-east leaning parts of the island. Hopefully, the next investments in this market target real estate in the most suitable locations illustrated in the results (figure 7). Better yet, existing entities should conduct their own investigation by implementing the widely available GIS tools. This research provides an example of a strategy that should be considered when introducing an emerging agricultural product in Puerto Rico.

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