Agave lechuguilla as a Potential Biomass Source in Arid Areas

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ABSTRACT

Biomass productivity presents a challenging problem in arid and semi-arid areas. Despite a large need for energy in the form of solid biomass, liquid fuel or needs for animal feed, these regions remain largely unproductive. A convenient way to overcome this challenge is to utilize plants with high water-use efficiency. *Agave lechuguilla* is an example of a highly productive (3.8 tons ha^{-1} yr^{-1}) desert plant that holds the potential for producing biomass with minimal water resources. For this purpose, a global suitability map has been developed showing areas where this plant can be planted, and its productivity was assessed. A Maxent model was used and was further refined by excluding protected areas and used lands (urban, agriculture, etc.). Productivity assessment provides a good way forward for prioritizing the regional utilization of this plant. This study provides an initial analysis for the use of arid and semi-arid regions for biomass production. Results indicate the potential generation of 93.8 million tons per year of dry biomass if the suitable areas were fully utilized. The analytical method can be readily applied to other potential plant species to optimize the use of certain areas.

KEYWORDS

GIS, Maxent, Suitability analysis, Productivity, Arid, Semi-arid.

INTRODUCTION

Biomass productivity presents a challenging problem in arid and semi-arid areas. Despite a large need for energy in the form of solid biomass, liquid fuel or the need for animal feed, these regions remain largely unproductive. A convenient way to overcome this challenge is to utilize Crassulacean Acid Metabolism (CAM) plants with high water-use efficiency that are highly productive [1, 2]. These plants have been well documented in reference works by Nobel and coworkers [3-6]. Their efficiency is derived from their ability to close their stomata during the hot days and opening them during the cool nighttime which tends to decrease water transpiration while maximizing CO_2 absorption. Some studies have attempted to develop a global perspective of the potential for Agave to provide biomass in arid areas [7] while others assessed fiber content of others [8]. Some authors have also revised the reported productivities [9] but the global productivity potential of *Agave lechuguilla* has not been studied. *Agave lechuguilla* is an example of a highly productive desert plant that holds the potential for producing biomass with minimal water resources. This plant has been thoroughly studied as far as gas exchange [10], germination response [11], reproductive biology [12], productivity indices [13], field productivity [14] is involved by academics and

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government entities [15] and previous studies indicated a productivity of 3.8 tons ha^{-1} yr^{-1} [13, 16]. The plant's productivity is not as high as other Agave or CAM species but it is more drought tolerant than many. The introduction of this plant globally is limited by several factors including rainfall, freezing temperatures and solar insolation. Various productivity indicators have been analyzed taking into account water, sunlight and day/night temperature variations in order to optimize plant productivity [13]. Unfortunately, and in order to insure global adoption, *Agave lechuguilla* needs to be adopted under natural rain-fed conditions with a predicted productivity similar to that observed under natural rather than artificial conditions.

Agave lechuguilla does not seem to suffer from extremely high temperatures but is rather killed by subfreezing temperature below -16 °C. It has a high tolerance for dry spells although its productivity drops to zero after 14 dry days [13].

Agave lechuguilla has many other uses besides biomass (like soap and fiber) that could help provide a good income source for poor communities. *Agave lechuguilla* has the potential to be a source of steroid drug precursors but other species are more easily processed. It is also a source of saponin which is a potent toxin making the plant parts toxic for foraging animals. Domestic animals have died when fed 1% of their body weight of *Agave lechuguilla* [15, 17, 18]. Toxicity was not a major concern for wild animals of the area. The plant's toxic juices have been used on tips of arrows. Traditional uses have included using the leaves as soap after crushing them and putting them in water.

Agave lechuguilla has already been determined not to be an economically feasible agricultural crop and that is why it cannot compete in agricultural lands. Its potential lies mainly in abandoned or unproductive dry lands. This study presents a methodology for the suitability analysis and prediction of productivity for *Agave lechuguilla* resulting in a global prediction map for both usable areas and their productivities. GIS and the Maxent suitability model is utilized in addition to available land use databases.

METHODS

The coordinates of *Agave lechuguilla*'s presence points' were sourced from GBIF [19] and Gentry [17]. These points were combined with historical synthetic weather data obtained from WorldClim [20] and used as inputs for a suitability analysis using Maxent Model [21]. The rendered map was then classified into four different suitability categories:

- Not suitable for bottom quarter of Maxent values;
- Moderately suitable for 3rd quarter;
- Suitable for 2nd quarter;
- Highly suitable for 1st quarter.

The generated map was then refined within GIS (QGIS and ArcGIS) by eliminating all protected areas as obtained from World Database on Protected Areas [22] and all other areas with human use, such as urban and agricultural areas as obtained from the World Land Cover maps [23].

The presence points of reported productivity were then overlaid with the obtained classes to determine potential productivity for each class. The areas of the obtained classes were then quantified.

Productivity was estimated based on a linear relationship between the reported literature for the Highly Suitable class and zero for the Not suitable class. Total annual productivity was thus determined on a class level and global level by multiplying the suitability factor with the indicated area. It is to be kept in mind that all productivities are based on dry mass weight.

RESULTS

The generated model predicts a high potential for planting *Agave lechuguilla* in a variety of arid and semi-arid areas, specifically in its natural habitat in Mexico, but also interestingly in South Africa, Ethiopia, Yemen and Australia (Figure 1). Several other countries have the potential to successfully grow *Agave lechuguilla*.

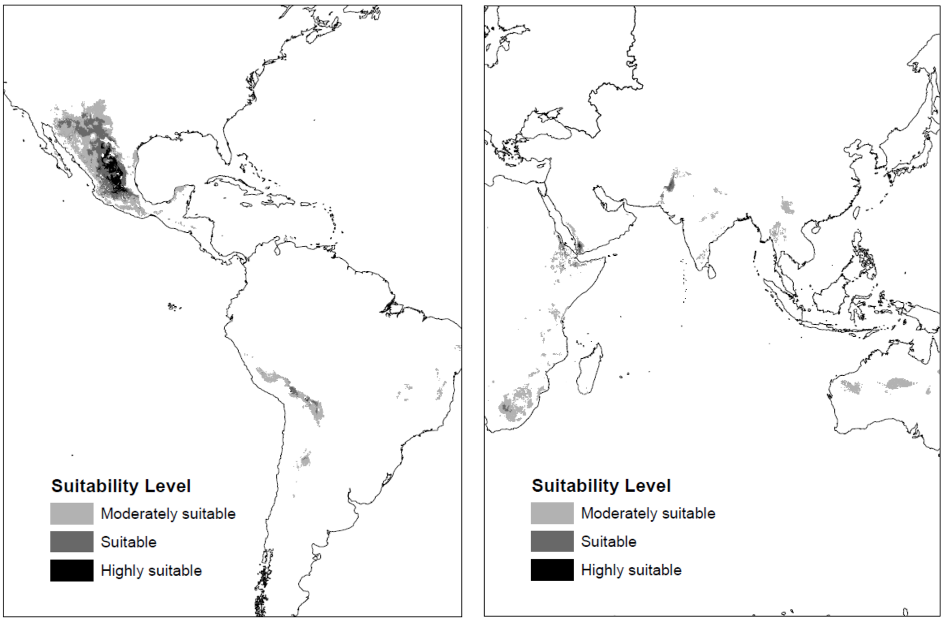

Figure 1. Suitable regions for *Agave lechuguilla*: western and eastern hemispheres

The area of each suitability category was then calculated. The highly suitable area was 32,030 km^2, the suitable area was 135,807 km^2 while the moderately suitable area was 372,716 km^2 (Table 1). The most comprehensive productivity study [16] was used and the location of the studied plants was determined to be in the highly suitable category. The significantly larger area of the moderately suitable region resulted in higher total productivity despite a lower per-square-km productivity. The overall potential area was 540,553 km^2 with an estimated annual productivity of 93.8 million tons.

Table 1. Areas and potential productivity of *Agave lechuguilla*

Class	Area [km^2]	Classification	Expected productivity [tons/km^2 yr]	Total productivity [tons/yr]
0	N/A	Not suitable	0	-
1	372,716	Moderately suitable	127	47,210,693
2	135,807	Suitable	253	34,404,440
3	32,030	Highly suitable	380	12,171,400
Total	540,553			93,786,533

DISCUSSION AND CONCLUSION

A methodology for the prediction of the potential use of *Agave lechuguilla* as a biomass resource has been presented. Areas of high suitability have been identified and their potential productivity quantified. *Agave lechuguilla* can be planted on 541 thousand square km with a potential total annual productivity of 93.8 million tons. Further "zoom-in" analysis will serve to identify specific locations for countries that are interested in introducing this plant as a biomass source. The approach should naturally be towards planting area that are "highly suitable" first. However, some countries may only have "suitable" areas and they should be motivated to initiate planting programs to make their lands more productive.

The suitable lands are arid or semi-arid unused lands, lying mainly in poor areas. The utilization of CAM plant agriculture will provide work for locals in addition to biomass which can then be used either locally for heating needs or sold for biofuel manufacturing. Additionally, these plantations may help initiate a biomass related industry in these areas providing skilled jobs for locals and a decent income. The use of the obtained biomass should be directed to generate the best economic outcome for the locals and the country. Satisfaction of local needs should precede attempts at more complex processing of biomass.

Introduction of *Agave lechugilla* or any other non-native plant to a given area must be preceded by a thorough environmental impact assessment. The potential for invasiveness should be taken seriously and whenever present, such plans for introduction should be re-analysed. In addition, the threat of these plants to the local way of life should be addressed. For example, *Agave lechuguilla* may not serve as a good fodder source for local grazing animals and may even be toxic. Additionally, the impact on local wild animals should also be considered.

It is very important that the methodology presented is applicable to other Agave and non-Agave plants for determination of biomass potential. To that end, further studies on other Agave species are underway to determine the most effective use of a given plot of land by comparing the productivity of various species in that area. The most productive plant can then be selected.

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