Mapping sugar cane yield for bioethanol production in Veracruz, México

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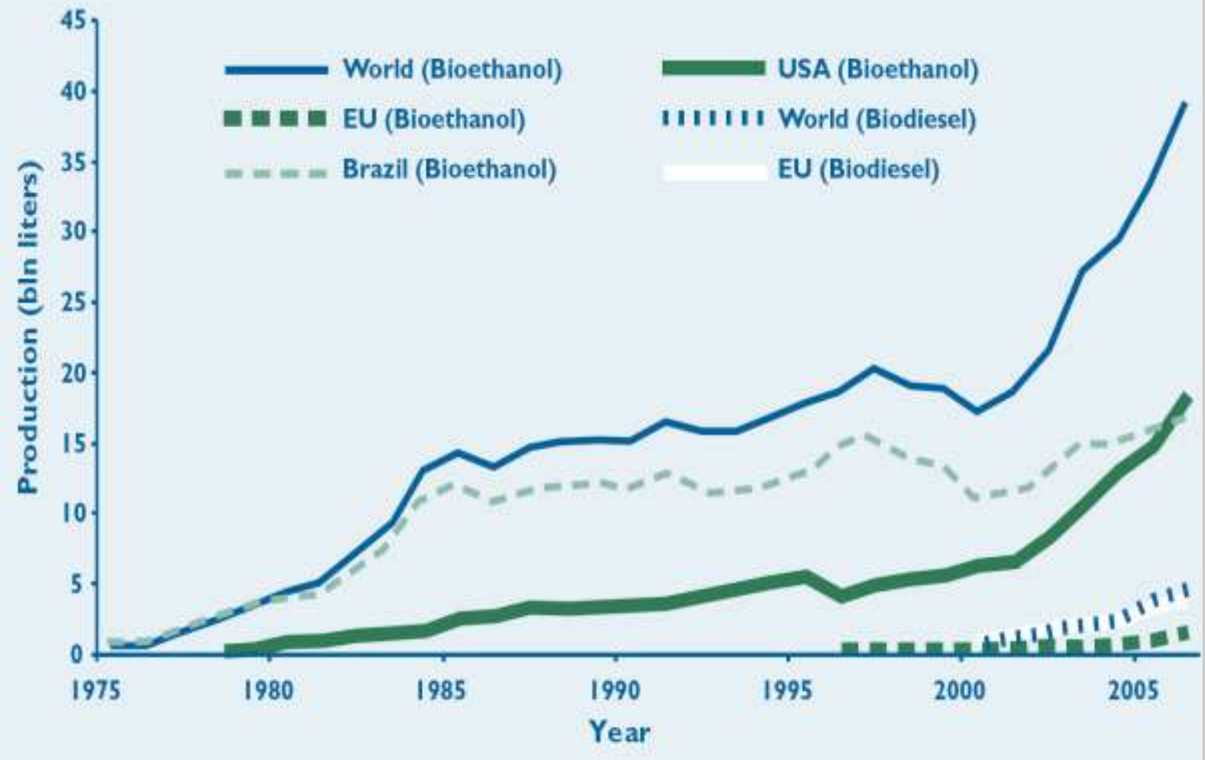
World Bioethanol production



Source: *F. O. Licht's World Ethanol and Biofuels Report*, Vol. 4, No. 16, p. 365 and Vol. 4, No. 17, p. 391 (Tunbridge Wells, U.K.: F. O. Licht, 2006).

<u>In México</u>, bioethanol production from sugar cane is incipient; however, recently, many public and private instances are strongly promoting its production and use.

(SAGARPA, 2007; SENER, 2007; DOF-SENER, 2009)

Some reasons why the sugar cane crop is promoted as a bioenergy crop (Average figures)

Issue	Sugar cane	Sugar beet	Corn
Ethanol yield L ha^{-1}	6,500	5,500	4,500
Net Energy Ratio	8	2	1.5
GHG reduction (%)	80	40	30
Production cost USD $liter^{-1}$	0.22	0.38	0.80

Source: Goldemberg and Guardabasi, 2010

Objectives

- To simulate and map the sugar cane yield.
- To estimate theoretical bioethanol yield (from sugar, cellulose and hemicellulose) in the state of Veracruz, México.

In order to:

- Identify both, highly and marginally productive areas.
- Develop a data set to assist decision makers in planning rural development and bioethanol refineries establishment.

The SWAT model was used to simulate and map the sugar cane biomass yield throughout the 7.2 million hectares of the state of Veracruz, México.

Climate (Köppen classification) and soil types (FAO soil classification) in Veracruz, México.
Total area: 7.2 million hectares.

Type of Climate	% of area	Type of soil	% of area
Warm, humid: Am[1]	38	Heavy, Clayey (VR, GL)[2]	34
Warm, sub-humid: Aw	48	Medium, Loamy (PH, FL, KS, CM, LV, O)	33
Semi-warm, humid and sub-humid: (A)C(m) and (A)C(w)	7	Light, Sandy (RG, AR, CL, SC)	12
Temperate, humid and sub-humid: C(m) and C(w)	6	Acid (AC, AN, NT, PL)	15
Temperate, semi-arid: Bs	1	Shallow (LP)	6
Total	100	Total	100

[1]Köppen climate classification keys. [2] FAO soil classification Keys.

Land slope and land use in Veracruz, México.
Total area: 7.2 million hectares.

Land slope category (%)	% of area	Land use category	% of area
0 – 5	70	Forest	18.0
5 -15	16	Grassland	53.0
15-30	8	Cropland	24.6
>30	6	Water bodies and urban	3.6
Total	100	Total	100

In México, sugar cane is cropped mainly for the sugar market; production of bioethanol is incipient.

Average (1997-2007) planted and harvested area (X1000 has) and yield (t ha^{-1}) of sugar cane (fresh stem) in México and Veracruz (SIAP, 2011).

Sugar cane item	In México	In Veracruz
Planted area (has)	689	253 (37%)
Harvested area (has)	645	248
Cane (fresh stem) yield (t ha^{-1})	73.4	72.2
Sugar yield (kg t^{-1} of fresh stem)	112	112

SWAT modeling procedure

The entire area of the state of Veracruz was considered as the basin.

Watershed delineation

Done from a DEM with pixel size of 90x90 meters,

Flow direction and accumulation was carried out based on DEM.

The stream network was created using the minimum mapping area.

Watershed was delineated by selecting all the outlets available.

90 sub-basins were created.

Hydrological Response Units Analysis (HRU's).

Four slope categories (0-5, 5-15, 15-30 and >30%),

46 soil sub-units (FAO soil classification) and

One land use Class. It was assumed all area was cropped to cane.

6,204 HRU's were created.

Database Inputs

Soils

Typical soil profile for each of the 46 soils was characterized from 829 soil description data sets.

Typical soil profile of the Acrisol humico

Horizon	Depth (mm)	Clay (%)	Silt (%)	Sand (%)	pH	O.C. (%)	albedo	K ($mmhr^{-1}$)	AWC	BD ($g\ cm^{-3}$)
A	157	28	27	45	4.80	3.55	0.05	3.7	0.12	1.37
B1	202	39	24	37	4.75	1.58	0.11	2.0	0.12	1.30
B2t	856	44	22	34	4.79	0.66	0.18	1.7	0.12	1.28

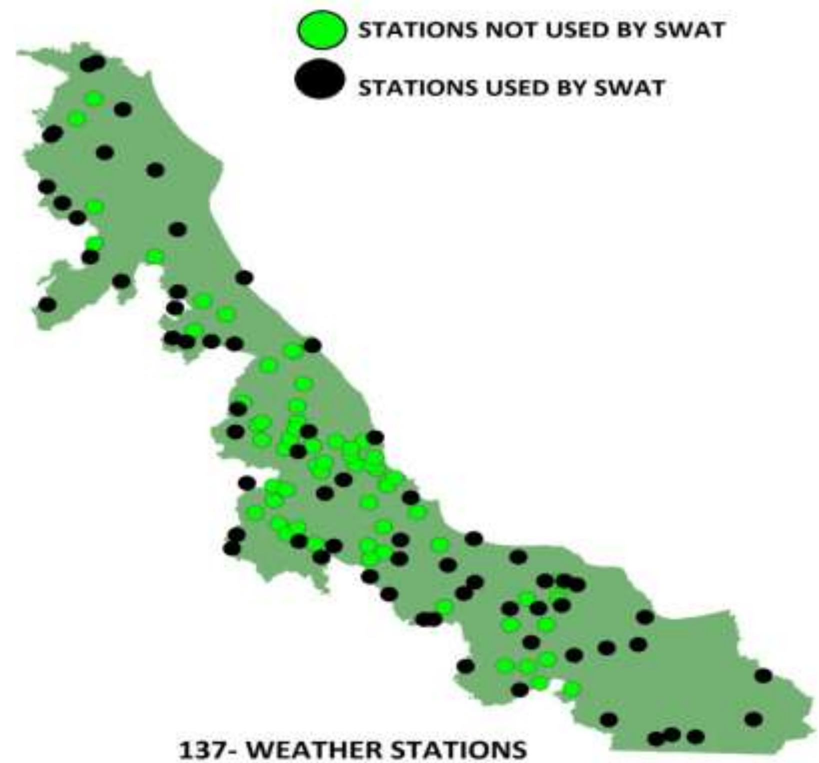
O.C.: Organic carbon, K: Saturated hydraulic conductivity, AWC: Available Water Capacity, BD: Bulk density.

Sugar cane physiological parameters fed to SWAT.

Species	RUE ($Kgha^{-1}/Mjm^{-2}$)	2nd point RUE	LAI	HI	Canopy Height (m)	Root depth (m)	Optimum temp. ^0C	Base temp. ^0C
Sugar cane	35	42	8	0.7	3.0	2.0	25	11

Weather stations

- Weather data was taken from 66 weather stations. (Taken from a loaded 137-weather stations network).
- Each station has at least 20 years of records between1960-2000.
- Weather statistics were worked out using the EPIC weather generator.
- Daily maximum and minimum temperature and rainfall data from 1990 to 2000 were fed to SWAT.
- Solar radiation was left to be estimated by SWAT.



137- WEATHER STATIONS NETWORK IN THE STATE OF VERACRUZ, MEXICO.

General Sugar Cane Management Schedule

Activity	Operation	Input rate (kg ha^{-1})	Date
Land preparation	Slash-blading		2nd may
	Sub-soiling		12th may
	Plowing		20th may
	Harrowing		29th may
	Cross harrowing		30th may
	Furrowing		31st may
Cane establishment	Planting	12,000 (0.60m cane stems)	1st June
Fertilization	1st fertilization	130-65-90 NPK	30th June
	2nd fertilization	130-00-90 NPK	31st August
Weed control	1st Chemical control	1.528+1.528 (Ametrine+Atrazine)	5th June
	1st Cultivation		1st July
	2nd Chemical control	1.815+1.020 (Ametrine+2-4-D)	31st July
	2nd Cultivation		1st Sept.
	3rd Chemical control	1.815+1.020 (Ametrine+2-4-D)	30th October
Pest control	1st control	1.75 (Carbofuran)	1st June
	2nd control	1.2 (Monocrotophos)	18th Sept.
	3rd control	1.05 (Carbofuran)	27th Nov.
	4th control	1.2 (Monocrotophos)	27th January
Harvest	1st harvest		31st May

Theoretical Bioethanol Calculation Procedure for every HRU.

$TTE = E_s + E_b$

TTE = Total Theoretical Bioethanol (L ha^{-1}).
Es = Bioethanol from Sugar (sucrose) (L ha^{-1}).
E_b = Bioethanol from cellulose + hemicellulose in bagasse and crop residues (L ha^{-1}).

E_s = (Cane dry biomass yield from SWAT) 325
E_b = (Cane dry biomass yield from SWAT) 427

The rate of bioethanol production from bagasse and crop residues was calculated with the Theoretical Ethanol Yield Calculator of the Biomass Program of the Department of Energy of the United States of America. (http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html).

Average chemical composition of sugar cane dry bagasse biomass.

Item	Cellular components (%) of dry matter			Dry matter Sugars (%)				
				6-carbons			5-carbons	
	Cellulose	Hemicellulose	Lignin	Glucan	Galactan	Mannosan	Xylan	Arabinan
Chemical composition	40.23	24.38	23.56	40.23	0.50	0.33	21.87	1.68

Results show volumes of theoretical bioethanol of 269 and 158 L t^{-1} from sugars of six and five carbons, respectively, giving a total volume of 427 L t^{-1} of dry tops and bagasse.

Lower yields (<50 t ha^{-1}) were mainly correlated with shallow, sandy and acid soils and heavy waterlogged soils on flat lands;

Medium yields (50-70 t ha^{-1}) were found over a wide range of soils and flat land

Higher yields (>70 t ha^{-1}) were found mainly in the deeper and more fertile soils

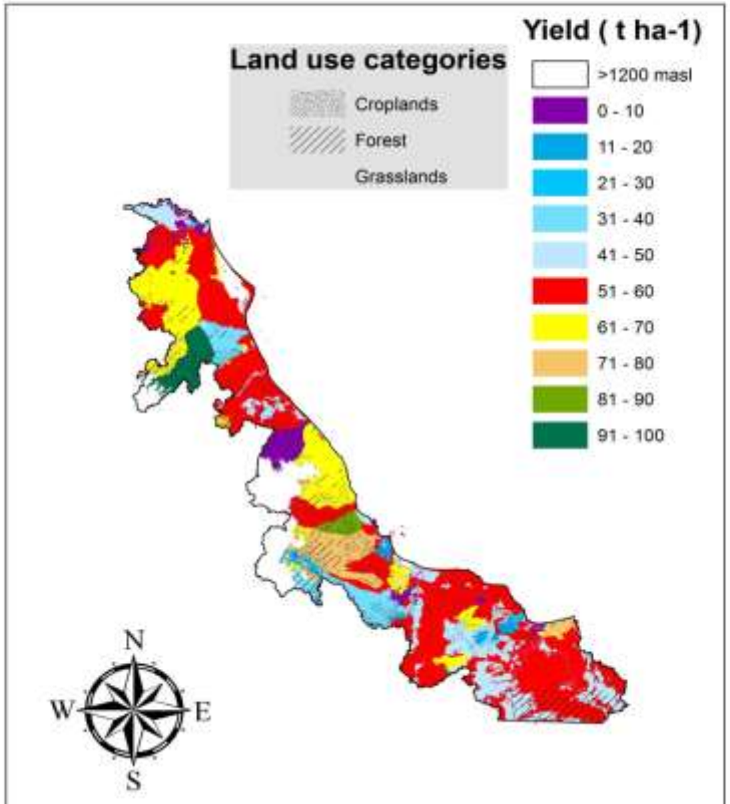


Figure 2. Sugarcane biomass yield simulated by SWAT

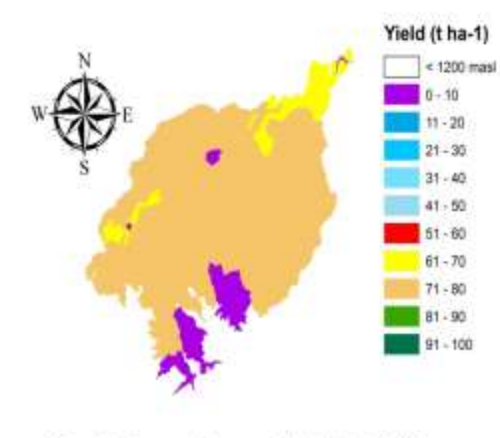


Figure 3. Sugarcane biomass yield simulated by SWAT in subbasin 80 with 12 weather stations

The model located within the watershed 12 weather stations (All different from the 66 located in the entire state of Veracruz)

57 sub-basins and 409 HRU's were created.

The yield ranged between 71 and 80 t ha^{-1}, and is very similar to the yield reported by SIAP (2011) for the watershed.

This finding remarks the relevance of working with a suitable network of weather stations in order to obtain the most accurate simulation.

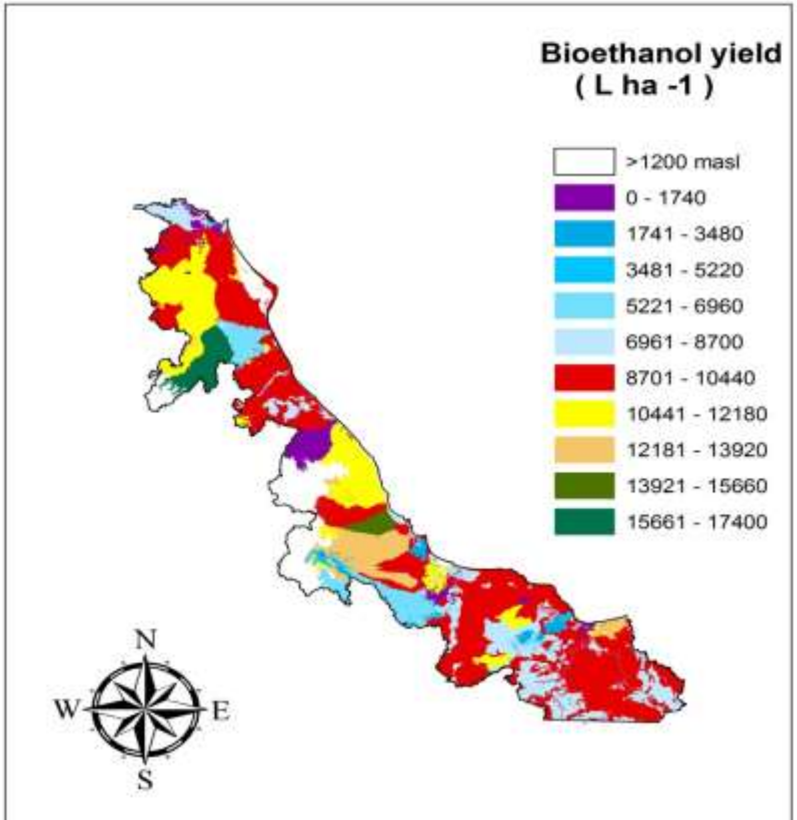


Figure 4. Theoretical Bioethanol yield from sugarcane

<u>For every Bioethanol yield class:</u>

43% corresponds to sucrose bioethanol
36% corresponds to cellulosic bioethanol
21% corresponds to hemi-cellulosic bioethanol

Conclusions:

The biomass and theoretical bioethanol yield of sugar cane from sugars and biomass was simulated and mapped with reasonable accuracy by the SWAT model in the entire state (7.2 million hectares) of Veracruz, México;

Results may assist decision makers in planning bioenergy projects.

The SWAT model is a useful tool for planning bioenergy projects and sustainable rural development in tropical watersheds.

Acknowledgements

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