Mapping King-grass (*Pennisetum purpureum*) biomass yield for cellulosic bioethanol production in Veracruz, México

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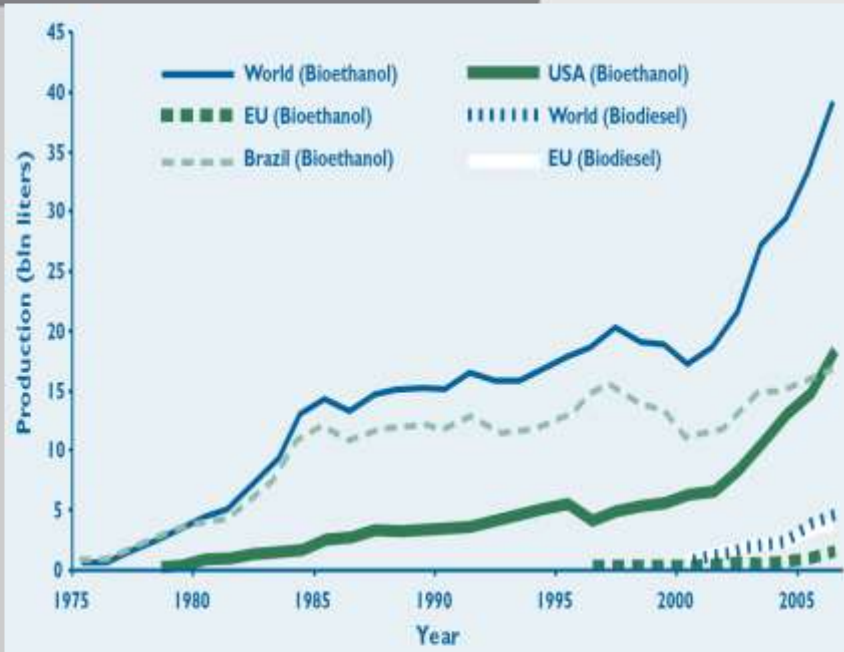
At global scale, since the early 70's the driving forces behind the unprecedented massive promotion and use of liquid biofuels are:

- The fossil energy crisis and the ever increasing need in energy supply and security;
- The Global warming and the need to reduce greenhouse gas emission to mitigate climate change and
- The sustainable rural development to provide a new income stream for farmers.

The main biofuels are bioethanol and biodiesel.

- Bioethanol is mainly produced in USA from corn starch and in Brazil from sugar cane.
- Biodiesel is mainly produced in Europe from vegetable oils.

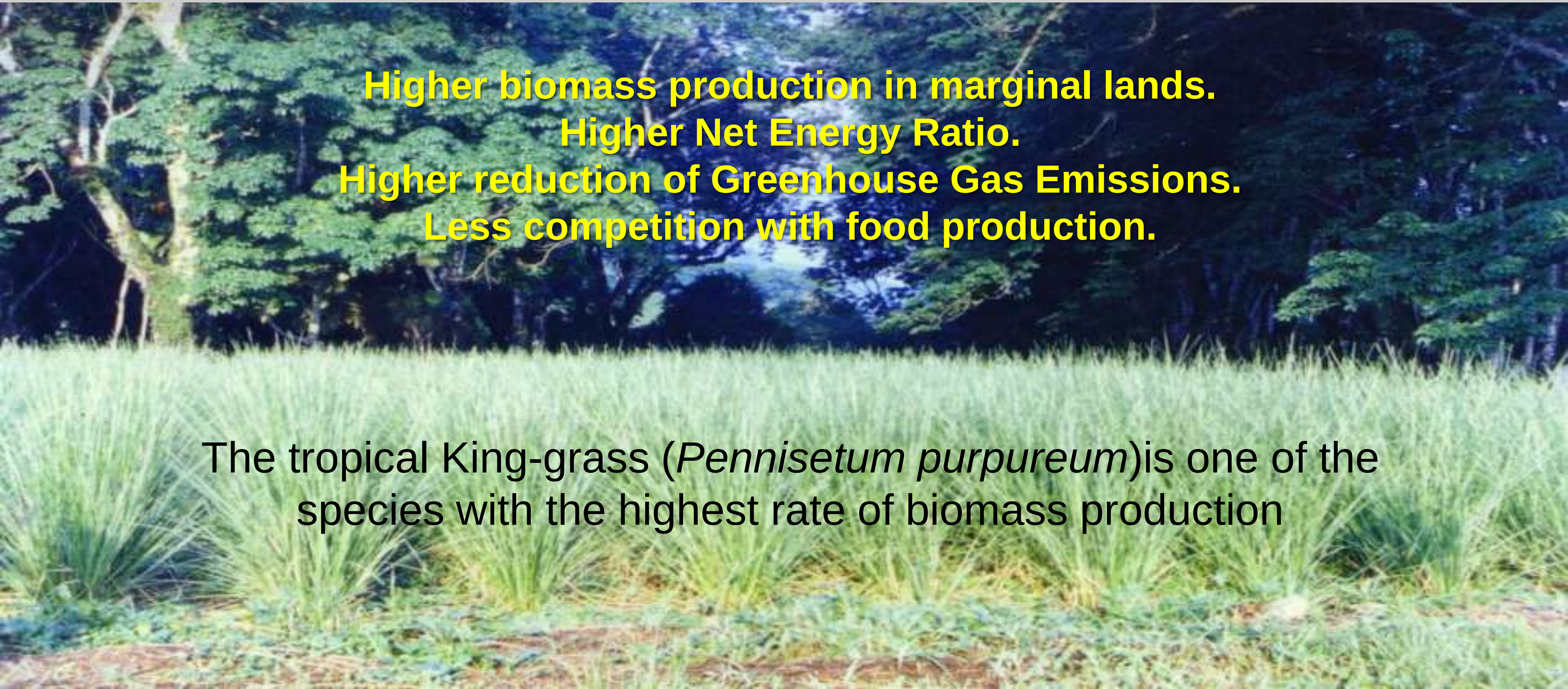


Source: F. O. Licht's *World Ethanol and Biofuels Report*, Vol. 4, No. 16, p. 365 and Vol. 4, No. 17, p. 391 (Tunbridge Wells, U.K.: F. O. Licht, 2006).

However, this type of biofuels are being severely criticized by the scientific community and National and International institutions, by arguing that they present:

Limited contribution to energy security
Negative impact in greenhouse gas emissions
Negative impact in food security

Second generation bioethanol from the sugars contained in the cellulose and hemicellulose of plant biomass (GRASSES AND TREES) seems the most promising, since compared with other plant species they present:



Higher biomass production in marginal lands.
Higher Net Energy Ratio.
Higher reduction of Greenhouse Gas Emissions.
Less competition with food production.

The tropical King-grass (*Pennisetum purpureum*)is one of the species with the highest rate of biomass production

Objectives

- To simulate and map the king-grass biomass yield.
- To estimate theoretical bioethanol yield (from 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 king-grass 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

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 Cambisol eutrico

Horizon	Depth (mm)	Clay (%)	Silt (%)	Sand (%)	pH	O.C. (%)	albedo	K ($mmhr^{-1}$)	AWC	BD ($g\ cm^{-3}$)
A	152	15	37	48	6.1	2.35	0.08	14.3	0.13	1.47
B1	190	17	37	46	6.8	0.9	0.16	12.2	0.13	1.45
B2	732	19	30	51	6.7	0.37	0.20	11.5	0.12	1.45

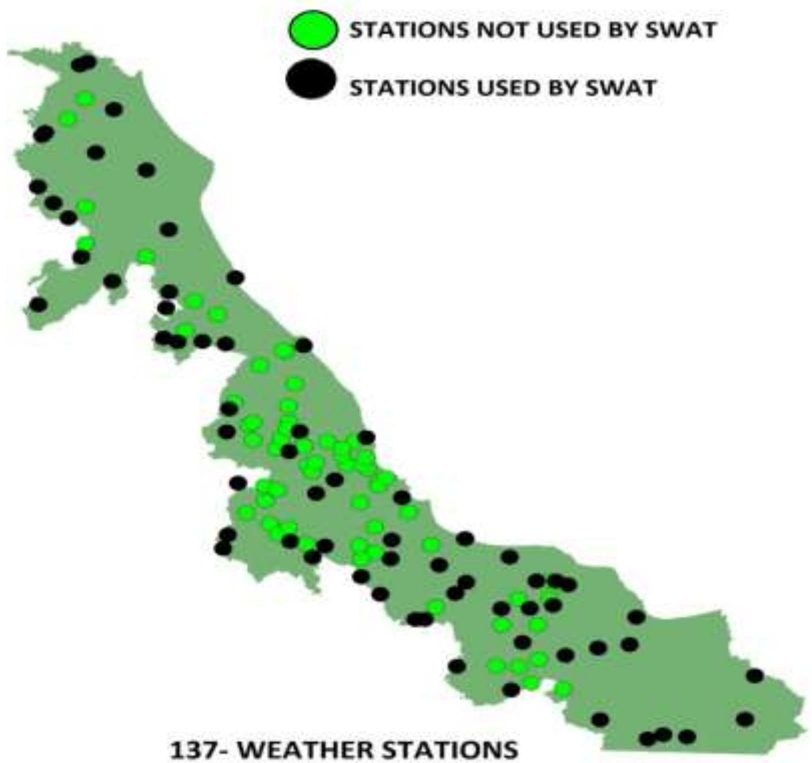
O.C.: Organic carbon, K: Saturated hydraulic conductivity, AWC: Available Water Capacity, BD: Bulk density.

King-grass physiological parameters fed to SWAT.

Species	RUE ($Kgha^{-1}/Mjm^{-2}$)	2nd point RUE	LAI	HI	Canopy Height (m)	Root depth (m)	Optimum temp. ^{0}C	Base temp ^{0}C
King-grass	45	53	8	0.95	3.0	2.5	37	15

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 King-grass Management Schedule

Activity	Operation	Input rate (kg ha^{-1})	Date of application
Land preparation	Slash-blading		2nd may
	Sub-soiling		12th may
	Plowing		20th may
	Harrowing		29th may
	Cross harrowing		30th may
	Furrowing		31st may
Grass establishment	Planting		1st June
Fertilization	1st fertilization	75-33-10 NPK	30th June
	2nd fertilization	150-66-20 NPK	30th July
	3rd fertilization	75-33-10 NPK	31st October
Harvest	1st harvest		30th September
	2nd harvest		31st December

Theoretical Bioethanol Calculation Procedure for every HRU.

E_b = Bioethanol from cellulose + hemicellulose in king-grass dry biomass (L ha^{-1})

E_b = 423 (King-grass dry biomass yield from SWAT)

The rate of bioethanol production from dry biomass 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	38	26	13	38.21	1.17	0.39	21.34	2.91
Bioethanol production (L t^{-1})				260			163	

Results show volumes of theoretical bioethanol of 260 and 163 L t^{-1} from sugars of six and five carbons, respectively, giving a total volume of 423 L t^{-1} of dry biomass.

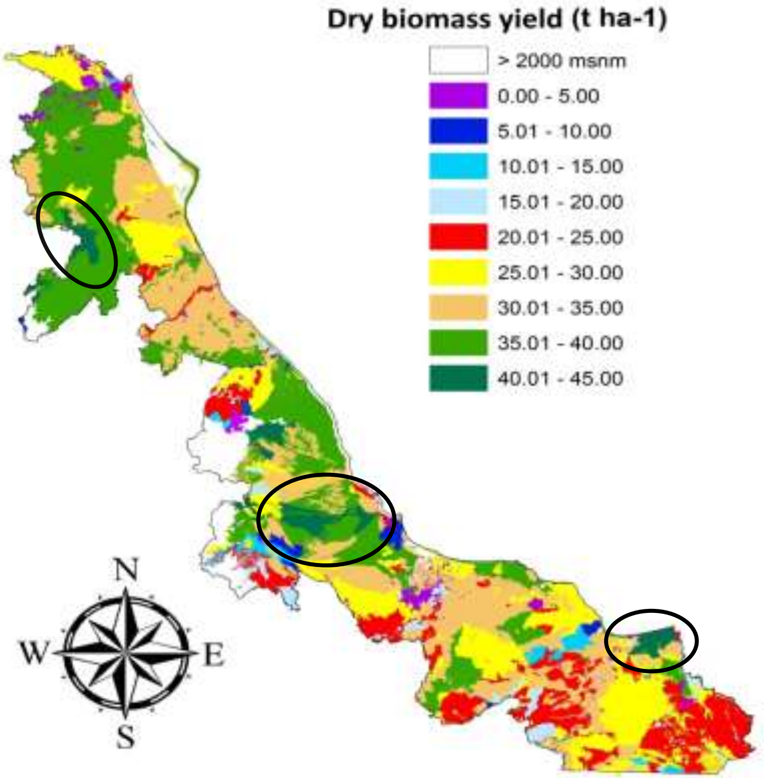


Figure 1. Biomass yield of King-grass (pennisetum purpureum) in the state of Veracruz, México.

Biomass yield showed a wide range with a maximum of 45 t ha^{-1}, which is within the range reported by various authors for tropical conditions similar to those found in Veracruz.

The lower yields (<15 t ha^{-1}) were mainly correlated with shallow and sandy soils on steep lands and waterlogged soils on flat lands;

Medium yields (20-35 t ha^{-1}) were found with the whole range of soils, except the above. Therefore, apparently the climate is playing the most important role in yield.

The higher yields (>35 t ha^{-1}) were found mainly in deeper, flatter and more fertile soils with high availability of water.

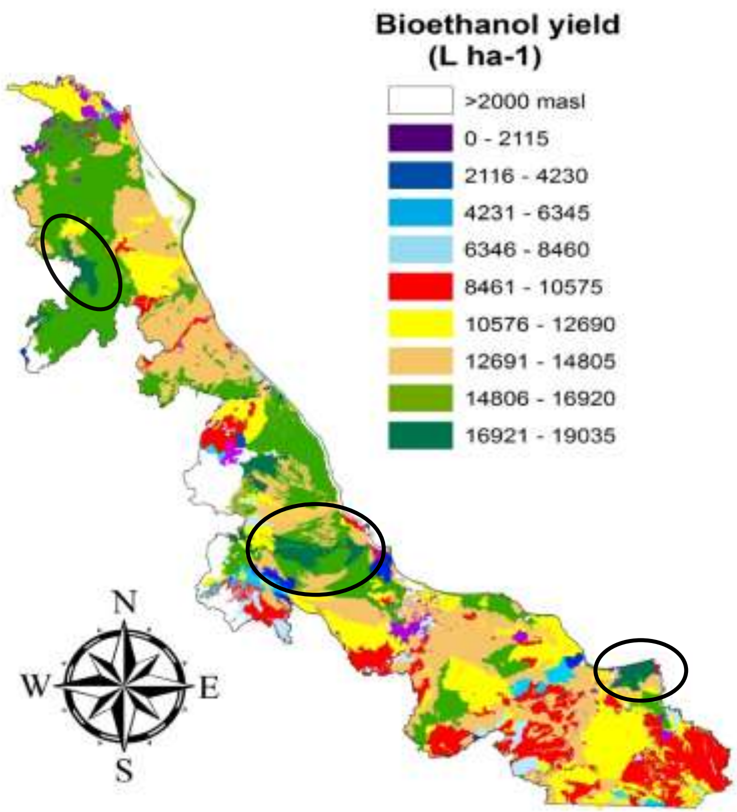


Figure 2. Bioethanol yield of King- grass (Pennisetum purpureum) in the state of Veracruz, México.

the lower range (<6,345 L ha^{-1}) corresponds to that reported for other grass species

The medium and high range (8,500 - 19,000 L ha^{-1}) not references were found in the literature.

This larger volume is mainly due to the effect of the higher biomass yield, rather than the effect of the sugar content in the king-grass biomass, since it is similar to other grasses

Projection of the maximum biorefinery capacity

Area Location	Area (ha)	Ethanol yield (ML Yr-1)	T day-1	Daily Ethanol production (ML) (barrels of oil)
North	44,236	478	5,151	1.31 (8,240)
Central	81,771	883	9,521	2.42 (15,220)
South	44,006	475	5,124	1.3 (8,176)

Conclusions:

The biomass and theoretical bioethanol yield of King-grass 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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