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Where should we grow Switchgrass for biofuel?

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ABSTRACT: Increasing concern over energy prices and availability in the past 20 years has led to an increased interest in obtaining renewable forms of energy. The Energy Security and Independence Act of 2007 in the USA mandated the production of 36 billion gallons of biofuel by 2022. Of this, over 16 billion gallon has to come from cellulosic ethanol. Switchgrass (*Panicum virgatum*) has been studied extensively as a potential energy crop. It however has been established that switchgrass has to be actively managed to be a viable energy crop. Consequently, it is important to map what lands are most suitable for switchgrass growth. GIS based land suitability evaluations have focused on species distribution models with presence only data for switchgrass and climatic variables to derive empirical relationships. However, soil productivity and management are also important factors in the cultivation of switchgrass. This paper describes a multi-criteria evaluation approach incorporating the Corn Suitability Rating (CSR) as a proxy for soil productivity. Further, an economic factor is also introduced using yields simulated by the Soil and Watershed Assessment tool (SWAT). The yields and trends obtained herein are somewhat in agreement with existing literature. Future work would include calibration and validation of the model with existing data.

Increasing energy prices and concern over growing energy demand has fuelled research in the renewable energy sector. EISA 2007 (Energy Independence and Security Act) mandated the production of 36 billion gallons of biofuel by 2022 comprising of 15 billion gallons of corn-based ethanol and 20 billion gallons of advanced biofuel (EISA 2007.http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS- 110hr6enr.pdf) such as cellulosic ethanol and biodiesel. Feedstock identified for cellulosic ethanol includes corn stover, wood and urban residues, and dedicated energy crops.

The Bioenergy Feedstock Development Program (BFDP) at Oak Ridge National Laboratory identified Switchgrass (*Panicum virgatum)* as potentially an important bioenergy crop in 1991. Switchgrass is a high-yielding perennial grass that has high soil conservation capability while also being compatible with conservation practices employed on farms (McLaughlin, 1992). Consequently a lot of the research on energy crops since has focused on various aspects of making the production of switchgrass viable; including research on cultivars/ecotypes, feedstock production and land suitability.

Barney et al., used a species distribution and abundance model, CLIMEX to conclude that it is unlikely that natural switchgrass establishment can be sustained in non-native habitats in the United States (Barney and DiTomaso 2010). Therefore for Switchgrass to be a viable energy crop, it has to be managed. Switchgrass yield when cultivated is dependent on climatic factors such as temperature and precipitation, soil fertility and management practices.

Various spatially explicit techniques have been used to evaluate land-use suitability to growing switchgrass. Davis et al. at the Oakridge National Laboratory used a parametric modeling approach using only two climatic variables, temperature and precipitation along with data on yield gathered from field trials to derive an empirical model. The model was then used to produce a map from gridded temperature and precipitation maps from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Davis, Jager et al. 2008). Evan et al. used two presence-only models – MAXTENT and a Species Vector model to evaluate land suitability and developed a model using altitude and climatic variables such as temperature, precipitation and wind speed. The study concluded that presence-only distribution models were a powerful tool to evaluate landscapes in the context of growing biofuel feedstock (Evans, Fletcher et al. 2010).

SWAT (Soil and Watershed Assessment Tool)- a basin scale model to evaluate landscape impacts of agricultural management techniques was used by Baskaran et al. to include the influence of soil suitability to predict yields (Baskaran, Jager et al. 2010). The yield trends were comparable to those carried out by empirical studies. All the studies have noted a very distinct east-west gradient in predicted switch grass yields.

Model Framework:

The purpose of this study was to construct a suitability map for the production of switchgrass on marginal and agricultural lands in a region of the Corn Belt (Iowa) at the county level. Adair County in Southern Iowa was chosen because agriculture here forms more than seventy percent of land-use. Of this, more than 50% of the land is used to grow corn and most of the other land is used to grow soybean. It is likely that if production of ethanol were to become economically viable, growing switchgrass instead of corn/soybean may become economically attractive.

A multi-criteria evaluation (MCE) approach was used to calculate land-use suitability for growing switchgrass as an alternative to a row crop. As with the CLIMEX, MAXTENT and the empirical model developed by the Oakridge National Laboratory, climatic factors – temperature and precipitation were included. Davis et al. concluded that their empirical regression model was able to explain only about 65% of the variation in yield. As an improvement, a factor to account for soil productivity, the Corn Suitability Rating has been included in this approach.

The Corn Suitability Rating is an index to account for row crop productivity of soils. (http://www.extension.iastate.edu/Publications/PM1168.pdf) It ranges from a value of 100 for soils that have no limitation for intensive row crop production and very low values for soils that have severe limitations for crop production.

Further, in order to account for the economic profitability of growing switchgrass, an economic model was included as a factor in the MCE. The model was based on yield data generated from SWAT for a lowland ecotype, Alamo switchgrass, and yield for corn on the same soils based on the corn suitability rating.

Data Collection and Processing:

Environmental Constraints and Criteria

The environment constraints and criteria with data sources are listed in Table 1.

The land-use constraint was added because future cultivation can only occur on agricultural, pasture or fallow land. The data from the Cropland data layer is at a 30m resolution. For the purposes of the study, the layer was re-classed to a binary mask and resampled to the size of a single corn farm. The average size in Iowa was about 231 acres or nearly 100000 sq. m. (Foreman 2001).

The corn suitability rating was derived from the Iowa Soil Properties and Interpretation Database (ISPAID- http://www.extension.iastate.edu/soils/ispaid) . It is a geographic soil database that compiles all physical and chemical soil properties in Iowa based on soil surveys including its potential for use. A CSR raster with the same resolution as the land-use map was generated from the SSURGO soil polygon for Adair.

Nation-wide temperature and precipitation grids obtained from the PRISM (http://www.prism.oregonstate.edu/products/matrix.phtml) model were at a 30 arc second resolution. They were projected and clipped to Adair County and resampled to the same resolution as the other raster layers.

SWAT

SWAT (Arnold and Fohrer 2005) is a basin scale model that evaluates the water quality impact of land-use on watersheds. It also incorporates a plant growth model that was used in this study to predict yield.

A modified land-use raster with all the agricultural land dedicated to Alamo switchgrass production was input into the model along with the DEM for the county (from National Elevation Dataset). The growth and management parameters for the model were the same as those suggested by Baskaran et al. The switchgrass was assumed to be a mature stand with initial biomass of 500 kg/ha and a leaf area index of 0.5. A base temperature of 12°C and an optimal temperature of 25°C and 1100 physiological heat units (degree C days above the base temperature) were assumed to grow the switchgrass to maturity. SSURGO data is available within the model. A watershed that covered all but one soil type from the county soil resampled raster (from the section above) was delineated within the model. Slope was reclassified into three categories: 0-2%, 2-5% and >5%. Hydrologic Response Units containing the same land use, soil and slope category were created in all sub-basins.

The model was simulated between the years 2000-2007. The yield from the output was obtained for all suitable soils and slopes. Although the model was not calibrated the yields obtained between 2-12 Mg/ha are well within observed yields from field plots (Davis, Jager et al. 2008). Switchgrass yield (tabular) that was obtained was spatially

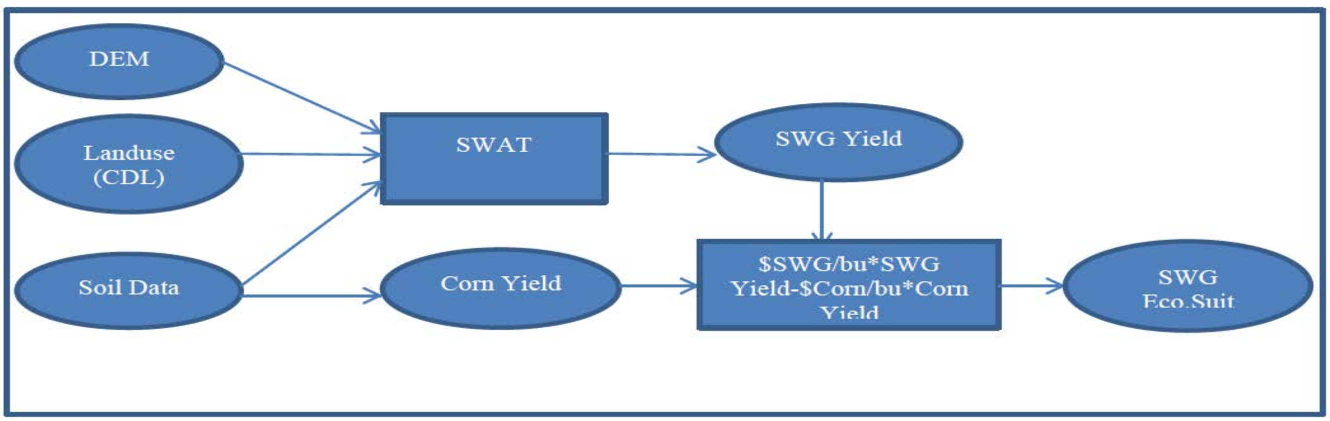

Figure 1: Switchgrass Economic Model

Constraint/Criteria	Effect on Yield	Data
Agricultural/Fallow Land - constraint		Cropland Data Layer 2010 - Iowa (Geospatial Data Gateway)
CSR	Increases with increase in yield	SSURGO (spatial data) Iowa Soil Properties and Interpretation Database Version 7.3(tabular)
Temperature	Empirically given by a Gaussian curve	PRISM
Precipitation	Empirically given by Parabolic curve	PRISM

Table 1: Data Collection

joined to the SSURGO polygon. The polygon was then resampled similar to the other raster layers to derive the switchgrass yield layer.

Economic Suitability

Corn yield was calculated from the CSR raster by interpolating of corn suitability rating based corn yield values from the ISPAID database. The empirical equation is shown in Figure 2. Essentially all the land was evaluated for its corn yield potential irrespective of what was growing on the land.

A biomass price of $60/dry ton was assumed. Corn economic data including cost/bu ($4.94/bu for a mid-yield farm), price of corn ($6.50/bu, Nov 2012) and average subsidy in Iowa paid directly to the farmer ($0.28/bu) was obtained from USDA Economic Research Service data report (Foreman 2001). This was used to calculate the average profit/dry ton corn of $72.44.

Raster calculator was used to get the difference between the Corn profits and Switchgrass profits. The resulting raster was re-classed from 0-100 to get the Switchgrass profitability index raster.

Multi-criteria Evaluation

Davis et al. indicate in their empirical model that temperature and precipitation are correlated and therefore using a multiplicative empirical model, concluded that temperature-precipitation interaction could explain 65% of the variation of yield in their model (Davis, Jager et al. 2008). In this study, based on the yield obtained from the SWAT model, both temperature and precipitation-yield relationships, were well within the linear bounds of the empirical model. So they were directly multiplied to aggregate their effects. The resulting raster was then “Sliced” from 0-100 to get the Climatic Suitability Index.

For the multi-criteria evaluation (MCE), it was assumed that Switchgrass Profitability was 30% of the weight (subjective). From the remaining weight it was assumed (as in the empirical model) that Temperature -Precipitation could explain 65% of variation of the yield and soil productivity (CSR) about 35%.

The weights obtained by the Analytic Hierarchy Process are given in Table 2.

	Temp/Pcp Int	CSF	SWG Profit	Calculated Wt
Temp/Pcp Int	1	1.8	1.5	0.450913
CSF	0.555556	1	1.2	0.282884
SWG Profit	0.666667	0.833333	1	0.266204

Table 2: Weighting for Final Model

The raster that was obtained from the relative weighting of the input raster layers was sliced into three zones for representation.

Results and Discussion:

The resulting land suitability map was very similar to the temperature-precipitation interaction map. There were some distinct patterns that were observed – firstly, there was a slight east to west gradient in the suitability and a south-north gradient. While the first has been observed in literature and corresponds to the natural distribution of switchgrass, the second observation might simply be because a lowland ecotype switchgrass, more suited to warmer southern climates was chosen.

Although the land suitability map itself could not be validated, the yield obtained from the SWAT model is well within observed yields of switchgrass in various field trials. Furthermore, given that the suitability predicted follows what was observed from various other studies for the United States, the model might be reasonably accurate.

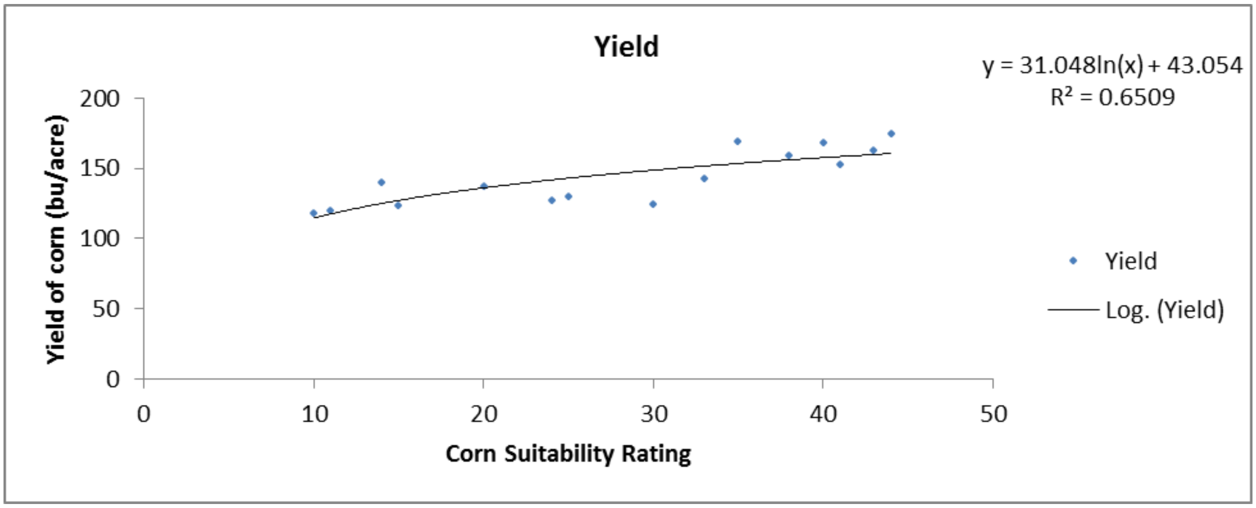

Figure 2: Empirical Relationship between CSR and Yield

An obvious disadvantage of the MCE is the subjective choosing of the weighting for the "economic" model. To gauge the importance of the economic model, a second suitability map without the SWAT yields was calculated with the Climatic variables and CSR. Predictably the area of the highly suitable zone decreases. This is because there is nothing to offset the effect of low CSR values that are observed throughout the country (Figure 3).

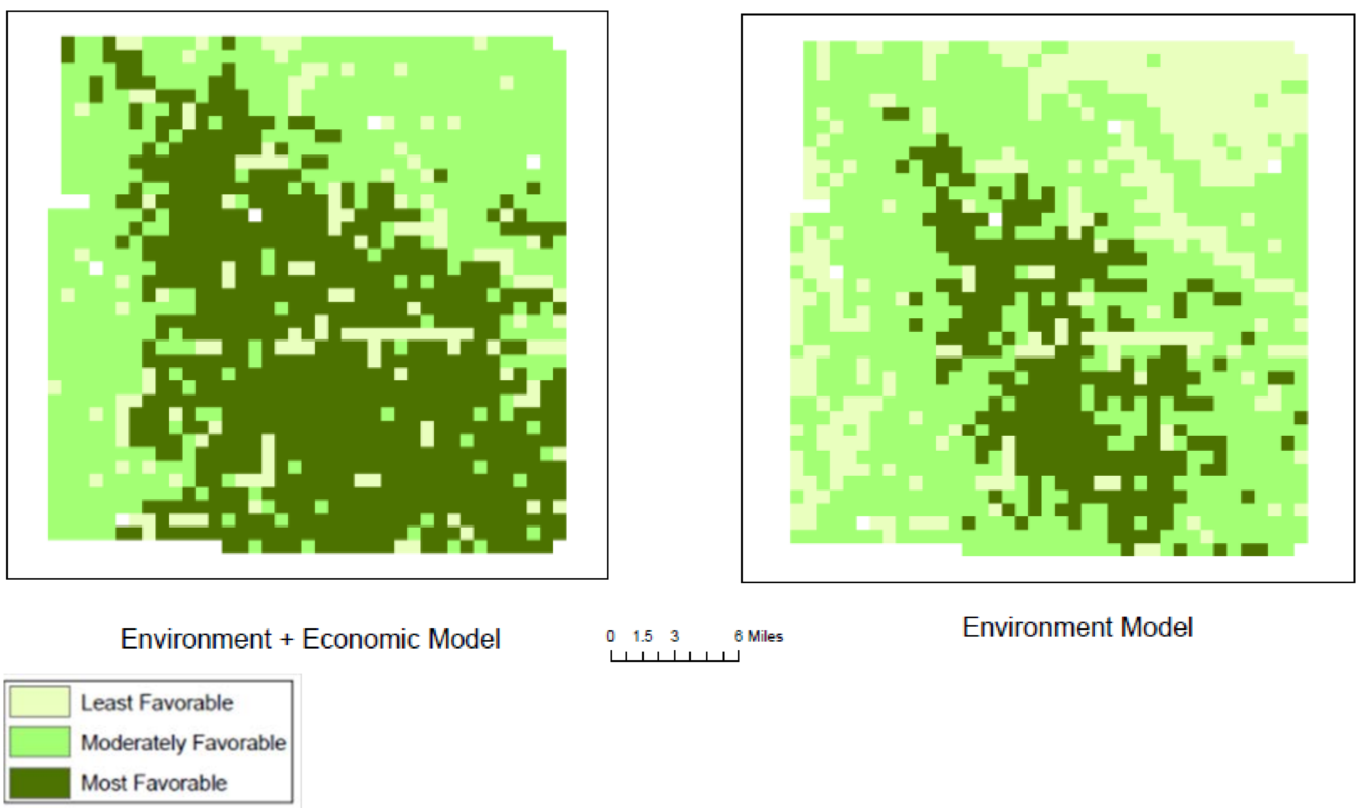

Figure 3: Adair County Switchgrass Suitability

The addition of the economic model has two advantages – it specifically identifies locations for specific alternative land-use i.e. corn/switchgrass. Also, given the right economic incentives, the suitability analysis highlights locations within the county that will perform better economically when compared to other locations. There are potentially other aspects of the model that could lead to error:

1) Assumption of linearity of the yield relationship in the given temperature and precipitation range for lowland ecotypes.

2) Annual average temperature rather than growing season temperature is used that might violate the assump-

tion of linearity.If the yield relationships are not linear, the two climatic factors cannot be aggregated.

3) Errors due to coarsening of the raster grid and conversion of vector grid to raster grid are not dealt with. Chaplot noted that coarsening is particularly significant for model calibration and values have to be adjusted accordingly (Chaplot 2005).

Further, while the CSR is easy to incorporate for analysis, it is not specific to the productivity of any particular crop. Although it has been related to corn, alfalfa and soybean yield, it is not the only factor in determining yield.

The model assumes a mature stand of a switchgrass and the growth parameters are according adjusted. It has to be noted that yields are lesser for young switchgrass.

The errors prevailing in the datasets including the DEM and the Cropland Data Layer as well as modeling errors are also not completely address in this paper.

Given the weaknesses of the model, for future work, SWAT simulation that incorporates climatic, soil as well as elevation properties may present a more accurate method to determine suitability provided there is enough data to calibrate and validate the model. Further sensitivity of model parameters to yield can also be tested. Alternately better yield estimates for soil types, should the data exist would also improve the model.

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