Simulating establishment period of perennial bioenergy grasses in the SWAT model

Qingyu Feng, PhD Candidate
Agricultural & Biological Engineering Department of Purdue University

Coauthors: Dr. Indrajeet Chaubey, Dr. Raj Cibin, Dr. Bernard Engel, Dr. KP Sudheer, Dr. Jeffrey Volenec
Crop growth representation is important for Ecohydrological analysis.

Hydrological cycle

Nitrogen cycle

Phosphorus cycle
Miscanthus, switchgrass and crop residue as biofeedstock

Switchgrass (~10 Mg/ha)  Miscanthus (~25 Mg/ha)
Modeling bioenergy crops in SWAT

- SWAT requires about 25 crop growth parameters
- *Miscanthus* and upland switchgrass are not in the default crop database of SWAT

**Flowchart:**

1. **Identify Parameters**
   - Crop growth representation in the model
   - Sensitivity analysis

2. **Measure/estimate sensitive parameters**
   - Data collected from research plots
   - Biomass, leaf area index, crop height, harvest efficiency

3. **Improve SWAT crop growth algorithm**
   - Check SWAT simulation of perennial grasses and modify if required

4. **Validate crop growth model**
   - Validate energy crop simulations of SWAT with measured data
Crop growth in SWAT

Light Interception → Biomass Production → Yield

RUE* → HI/HEFF
Data Collection: Purdue Research Stations

Purdue Water Quality Field Station
Switchgrass – Shawnee (2007)
Miscanthus x giganteus (2008)
Data Collection WQFS and TPAC

- Emergence dates (daily observations)
- Daily temperature (°C)
- Daily solar radiation (x0.5 determined PAR)
- Total biomass (Monthly destructive sampling)
  - Top growth, stem base, rhizome, root
- Leaf Area Index (Decagon AccuPAR LP-80)
- Canopy height measurement (m)
- Tissue Nitrogen or phosphorus
- Annual yield: Biomass removed at harvest (g/m²)
- Field residue after harvest (g/m²)
- Root distribution to 60 cm (percent)
Crop Growth Algorithm Improvement

- **Plant nutrient uptake in stress periods**
- **Harvest operation representation** – Harvest Index (HI) adjustments with water and nutrient stress
- **Dormancy period representation and dead root allocation** in harvest operation
- **LAI after the crop maturity** – **senescence** representation
Better growth and nutrient uptake representation by revised SWAT

- Nutrients stored in below ground biomass not considered
- About 100 kg N/ha & 30 kg P/ha stored

- Affect nutrient uptake process
- Water quality estimations impacted
Perennial rhizomatous grasses as bioenergy feedstock in SWAT: parameter development and model improvement

ELIZABETH M. TRYBULA¹,²,‡, RAJ CIBIN¹,‡, JENNIFER L. BURKS², INDRAJEET CHAUBEY¹,³, SYLVIE M. BROUDE² and JEFFREY J. VOLENEC²

¹Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, IN, USA, ²Department of Agronomy, Purdue University, West Lafayette, IN, USA, ³Department of Earth, Atmospheric and Planetary Sciences, Purdue University, West Lafayette, IN, USA

Abstract

The Soil and Water Assessment Tool (SWAT) is increasingly used to quantify hydrologic and water quality impacts of bioenergy production, but crop-growth parameters for candidate perennial rhizomatous grasses

- Model improvements are now incorporated in the official SWAT model: Version 612 (http://swat.tamu.edu/software/swat-model/)
Establishment period of perennial bioenergy grasses
Perennial grasses is building their biomass during the establishment period.

Establishment period

Post-Establishment period

Picture source: https://auntiedogmasgardenspot.wordpress.com/2013/07/02/switchgrass-panicum-virgatum-plant-care-guide/
Objectives

- Understand establishment stages for perennial bioenergy crops
- Develop growth curves of biomass and LAI
- Improve SWAT algorithms to represent establishment stage
Yield data collection

Miscanthus fields:
1. Mainly in Europe
2. 18 fields

Switchgrass fields:
1. Mainly in the US
2. 24 fields

Data collection criteria
1. Longer than 2 years
2. Only one cut harvest
3. All N fertilization rates
Threshold yield for determining establishment period was recommended.
Threshold yield for determining establishment period was recommended

<table>
<thead>
<tr>
<th>Threshold yields</th>
<th>Establishment period</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 Mg/ha for lowland switchgrass</td>
<td>2 to 3 years for switchgrass of both cultivars</td>
</tr>
<tr>
<td>10 Mg/ha for upland switchgrass</td>
<td></td>
</tr>
<tr>
<td>15 Mg/ha for Miscanthus in Europe</td>
<td>3 to 6 years for Miscanthus in Europe</td>
</tr>
<tr>
<td>20 Mg/ha for Miscanthus in the US</td>
<td>2 to 4 years for Miscanthus in the US</td>
</tr>
</tbody>
</table>
Leaf Area Index (LAI) also increased during the establishment period

\[ f(x) = \frac{\phi_1}{1 + \exp((\phi_2 - x)/\phi_3)} \]

(Miguez et al. 2008)

\( \phi_1 \): the maximum LAI for established Miscanthus.
\( \phi_2 \): the point at which the crop achieved half of the maximum LAI.
\( \phi_3 \): the time between achieving \( \frac{1}{2} \) and approximately \( \frac{3}{4} \) of the maximum LAI by the crop.
SWAT model improvements tested with field scale simulation – One HRU models

<table>
<thead>
<tr>
<th>Location</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Quality Field Station</td>
<td>Indiana</td>
</tr>
<tr>
<td>Throckmorton Purdue Agriculture Center</td>
<td>Indiana</td>
</tr>
<tr>
<td>Brookings</td>
<td>South Dakota</td>
</tr>
<tr>
<td>Arlington</td>
<td>Wisconsin</td>
</tr>
<tr>
<td>Lafayette</td>
<td>Indiana</td>
</tr>
<tr>
<td>Schoochah</td>
<td>Kentucky</td>
</tr>
</tbody>
</table>
SWAT model modification validation: Yield simulation
Conclusion

Establishment period

Threshold yield recommended for switchgrass and *Miscanthus*

Impacts on hydrology and water quality

Lower Evapotranspiration are expected to happen during the establishment period, which tend to increase water yield and soil erosion as well as nitrogen and phosphorus loss.

SWAT model modification

Leaf Area Index calculation equation updated for representation of establishment post establishment period.

Modified SWAT model provide good simulation results of yield against the observed data.
Other model improvements at Purdue

- Woody bioenergy crops representation in SWAT
  - The improved model could simulate reasonably well

- Soil moisture representation in SWAT
  - Better simulation of bioclimate stress effects on annual yield and interannual variability

- CO2 input to the model as time series for climate change representation

- Vegetative Filter Strip (VFS) representation SWAT model to simulate energy crop production in VFS areas (Session K2)
SWAT model modification

```python
select case(idc(idp))
  case(6)
    rto_per = 1/(1+ Exp((bio_leaf(idp)-
    if (co2(hru_sub(j)) > 330.) then
      beadi = ((100. * co2(hru_sub(j))
        / (co2(hru_sub(j)) +
          Exp(wac21(idp)-
          co2(hru_sub(j))
          * wac22(idp)))) + rto_per
    end
  end
select case (idc(idp))
  case (1,2,3,4,5)
    laimax = blai(idp)
  case (6)
    laimax = blai(idp)*rto_per
  case (7)
    laimax = rto_per * blai(idp)
```

- Calculate the ratio of BLAI development according to the equation provided by [Liu and others (2008)](http://engineering.purdue.edu/ecohydrology).
- Bio_E was also assumed to be reduced proportionally according to the ratio used for BLAI. Thus the Bio_E was multiplied with.
- Modified the BLAI calculation choices, to include the case of perennial grasses and reduce BLAI according to “rto_per”.

http://engineering.purdue.edu/ecohydrology