SWAT model improvements to simulate bioenergy crops production

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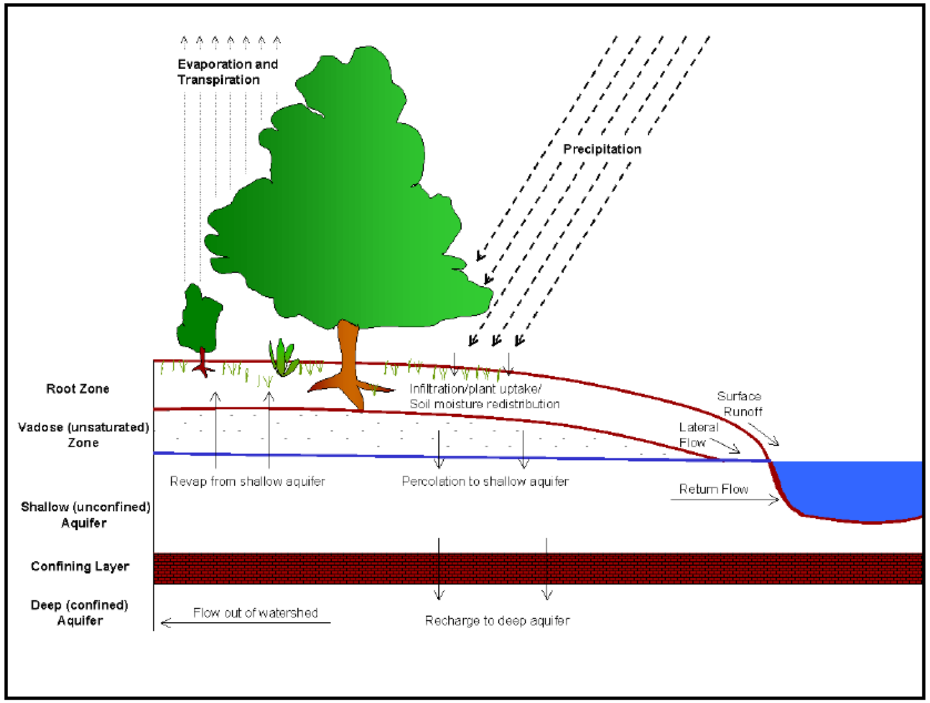
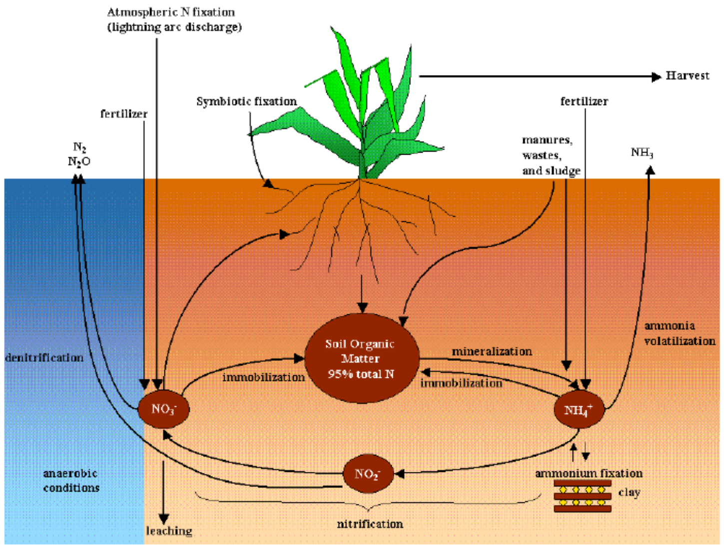
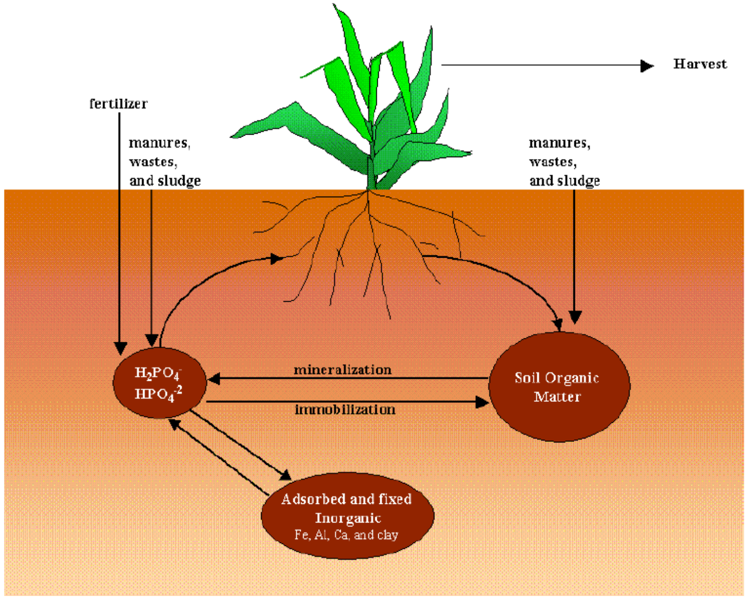
Crop growth representation is important for Ecohydrological analysis



Hydrological cycle



Nitrogen cycle



Phosphorus cycle

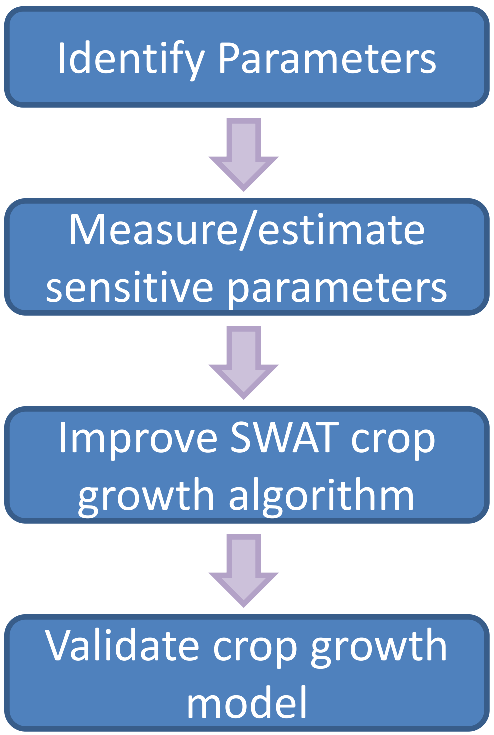
Miscanthus, switchgrass and crop residue as biofeedstock

Switchgrass (~10 Mg/ha) *Miscanthus (~25 Mg/ha)*

Miscanthus

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



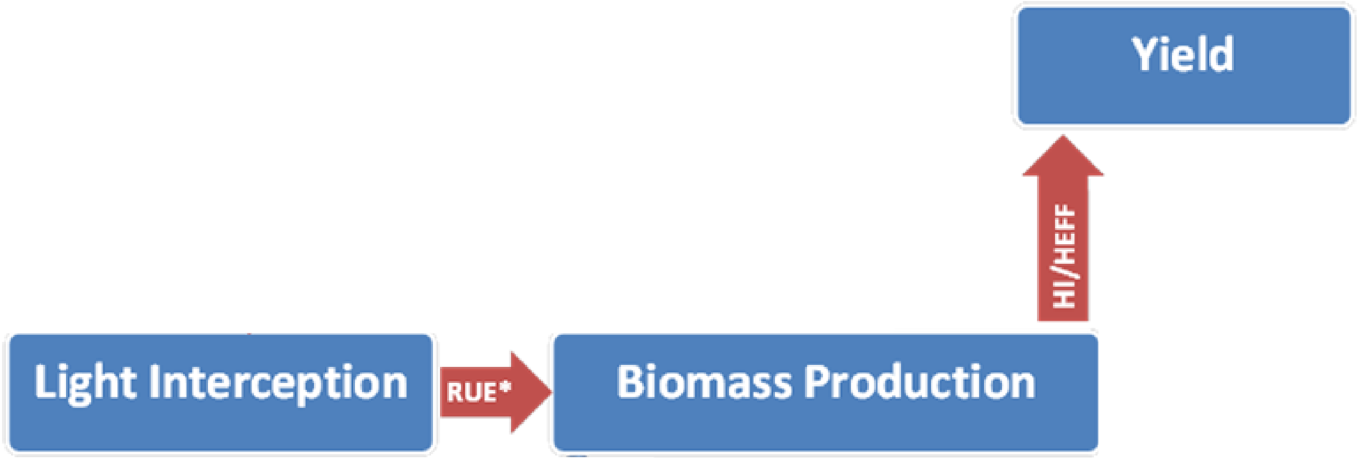
Crop growth representation in the model
Sensitivity analysis

Data collected from research plots
Biomass, leaf area index, crop height, harvest efficiency

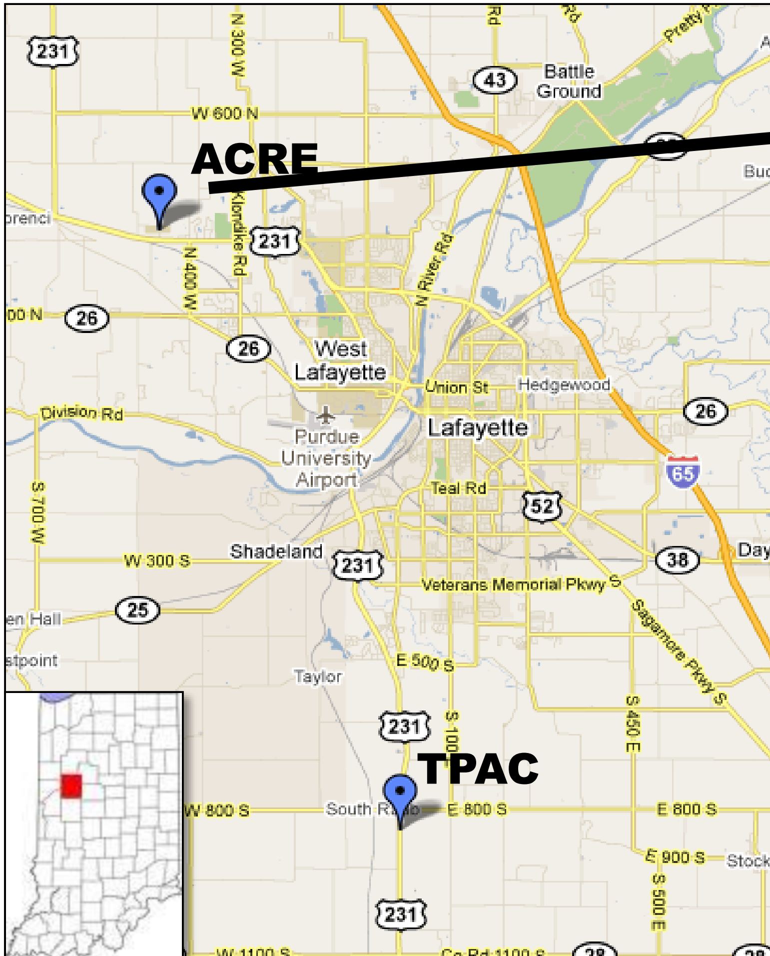
Check SWAT simulation of perennial grasses and modify if required

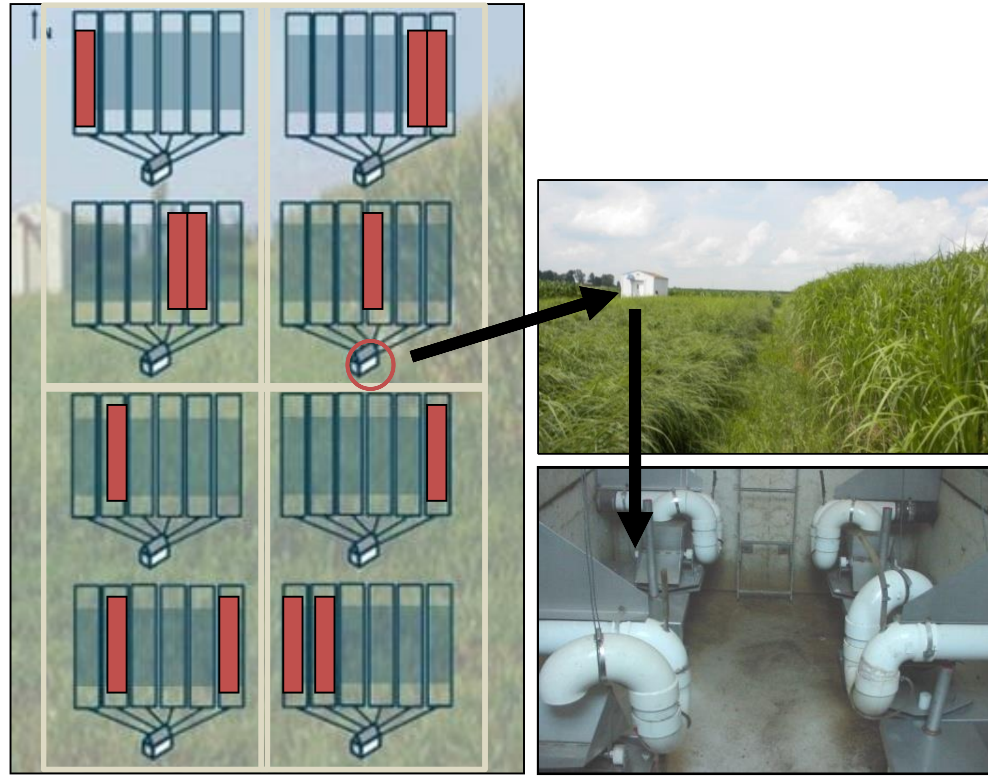
Validate energy crop simulations of SWAT with measured data

Crop growth in SWAT



Data Collection: Purdue Research Stations





Purdue Water Quality Field Station

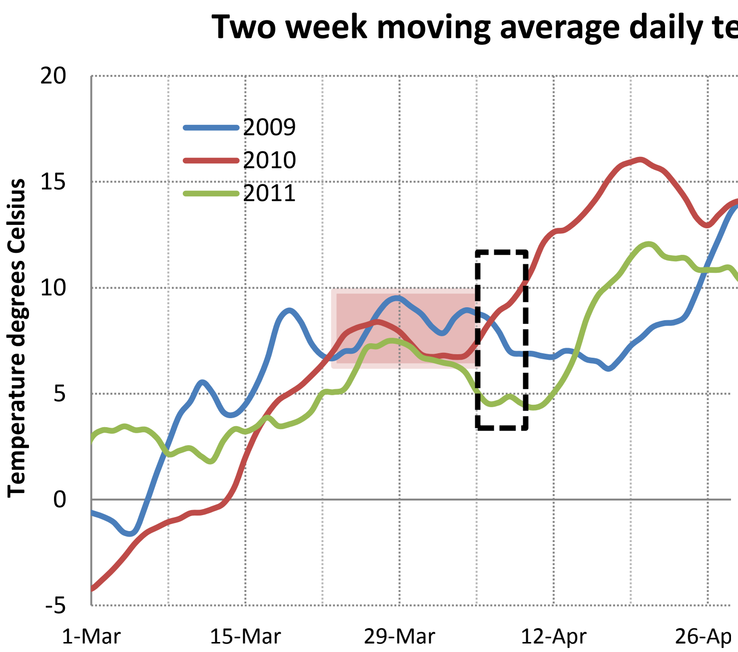
Switchgrass – Shawnee (2007)

Miscanthus x giganteus (2008)

Data Collection WQFS and TPAC

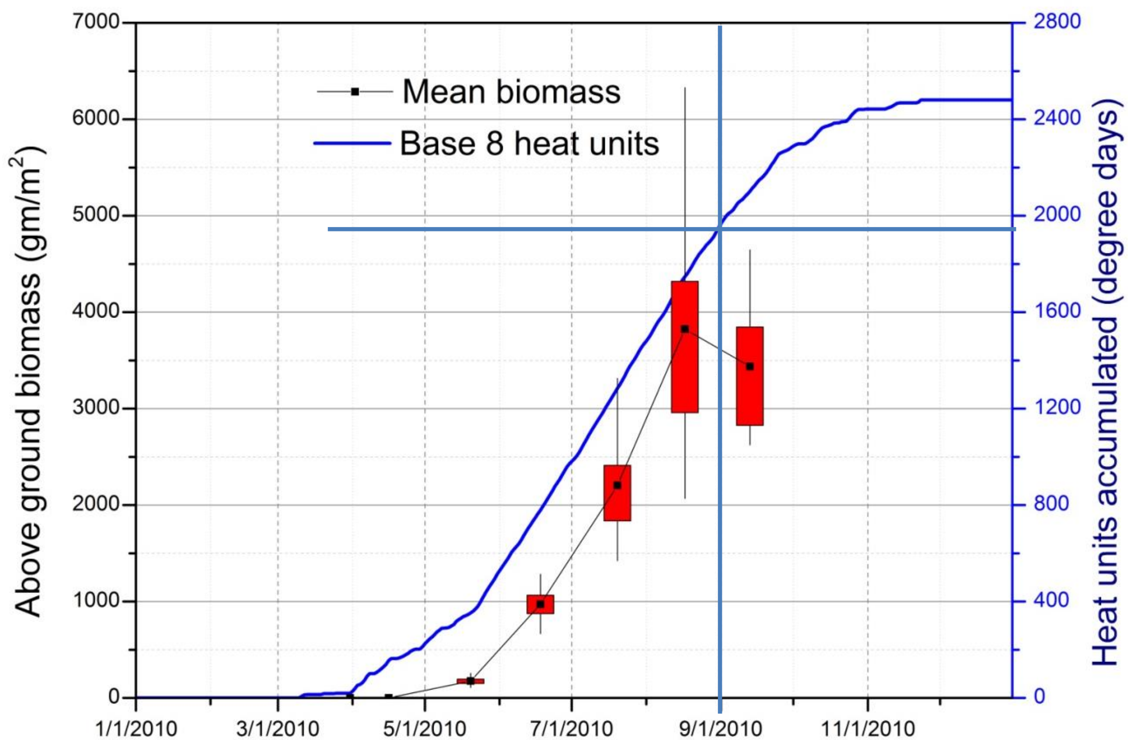
- Emergence dates (daily observations)
- Daily temperature (^{o}C)
- Daily solar radiation (x0.5 determined PAR)
- Total biomass (Monthly destructive sampling)
  - Top growth, stem base, rhizome, root
- Leaf Area Index (Decagon AccuPAR LP-80)
- Canopy height measurement (m)
- Tissue Nitrogen or phosphorus
- Annual yield: Biomass removed at harvest (g/m^2)
- Field residue after harvest (g/m^2)
- Root distribution to 60 cm (percent)

Parameter estimation: Base temperature and heat units to maturity



Heat Unit = Avg daily temp – base temp

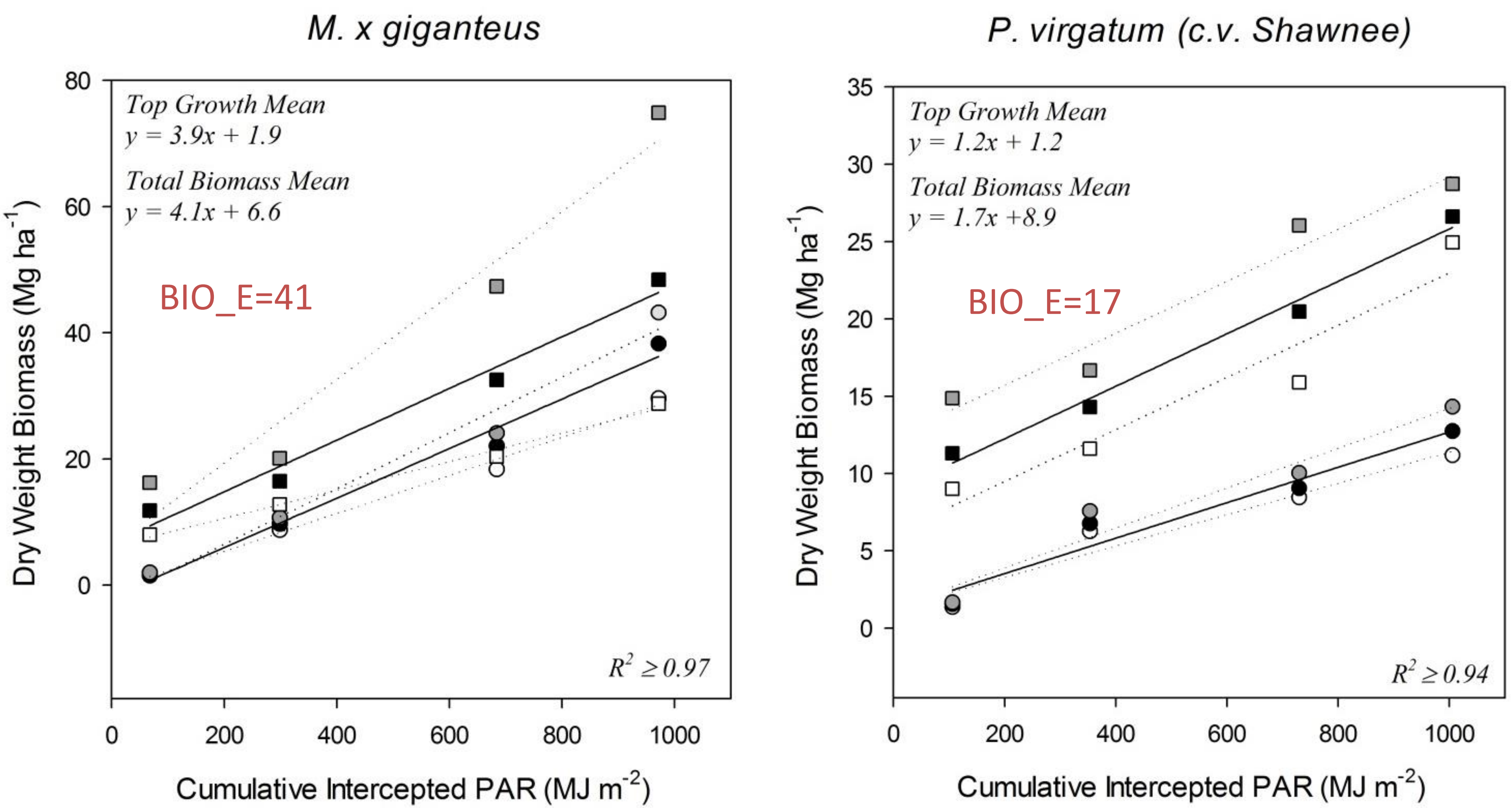
Heat Units to maturity =1830



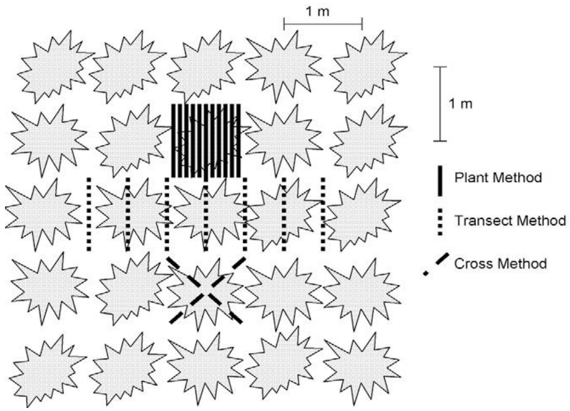
Base Temp = 8 °Celsius

Range= 7 to 10 °Celsius

Radiation use efficiency (Bio_E)

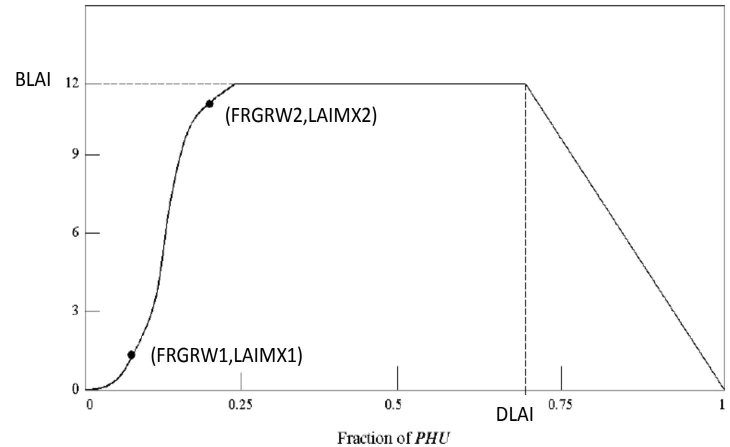


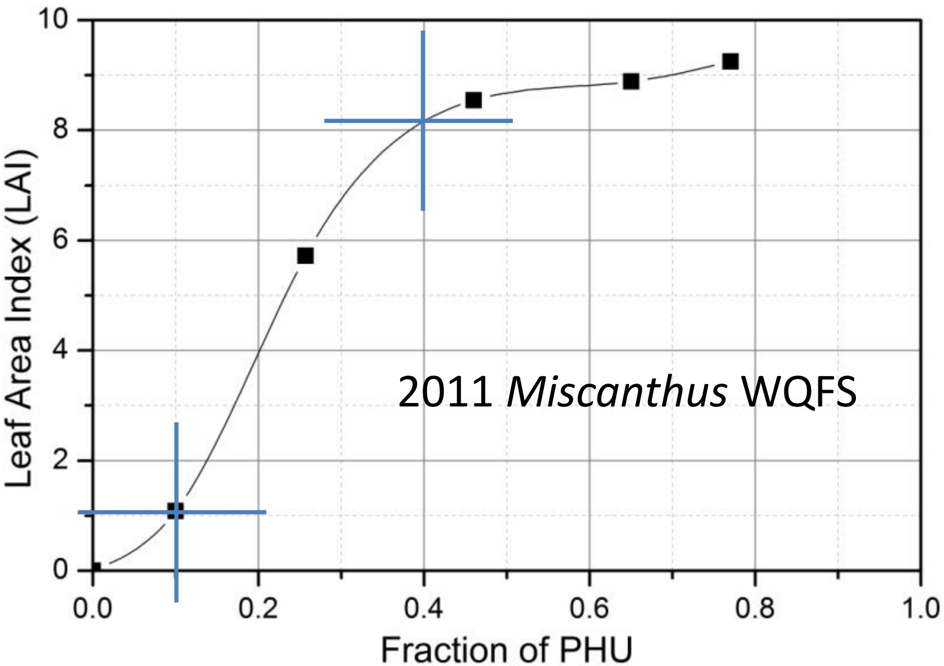
Optimal Leaf Area Development



Decagon Devices, AccuPAR LP-80, Adapted Plant /Transect Method (Johnson, Kiniry, Burson, 2010)

SWAT Manual





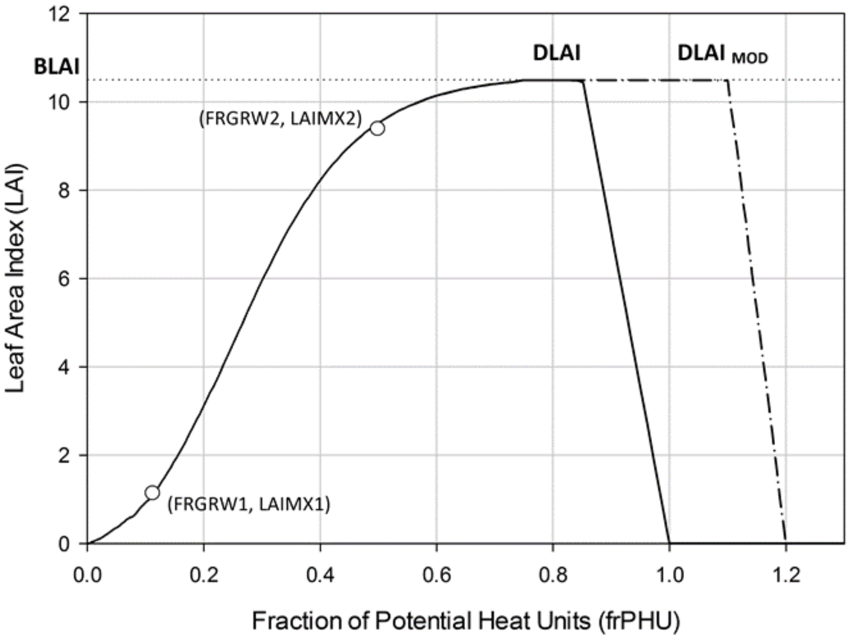
Parameter	*Miscanthus x giganteus*		
	Lower Bound	Mean	Upper Bound
BLAI	-	***10***	12
LAIMX1	0.05	***0.1***	0.15
LAIMX2	0.75	***0.8***	0.85
FRGRW1	0.05	***0.1***	0.15
FRGRW2	0.35	***0.4***	0.45

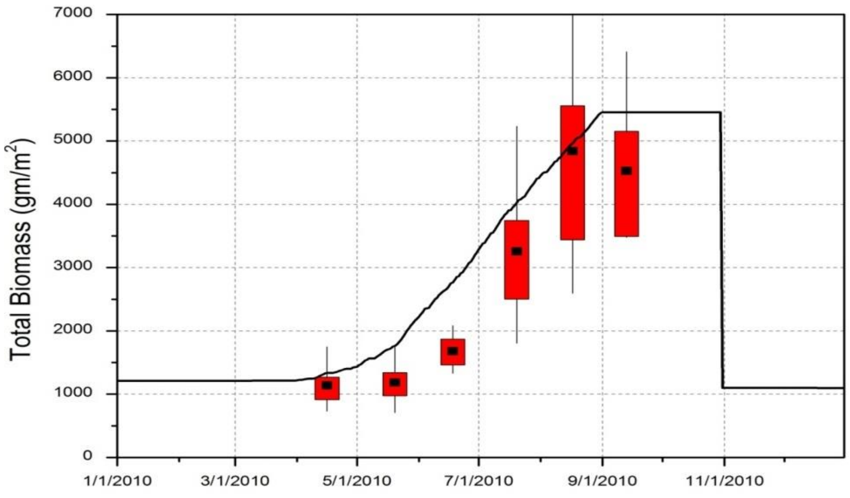
Modification of LAI curve

- No biomass accumulation after September1

plant was still green and physiologically active

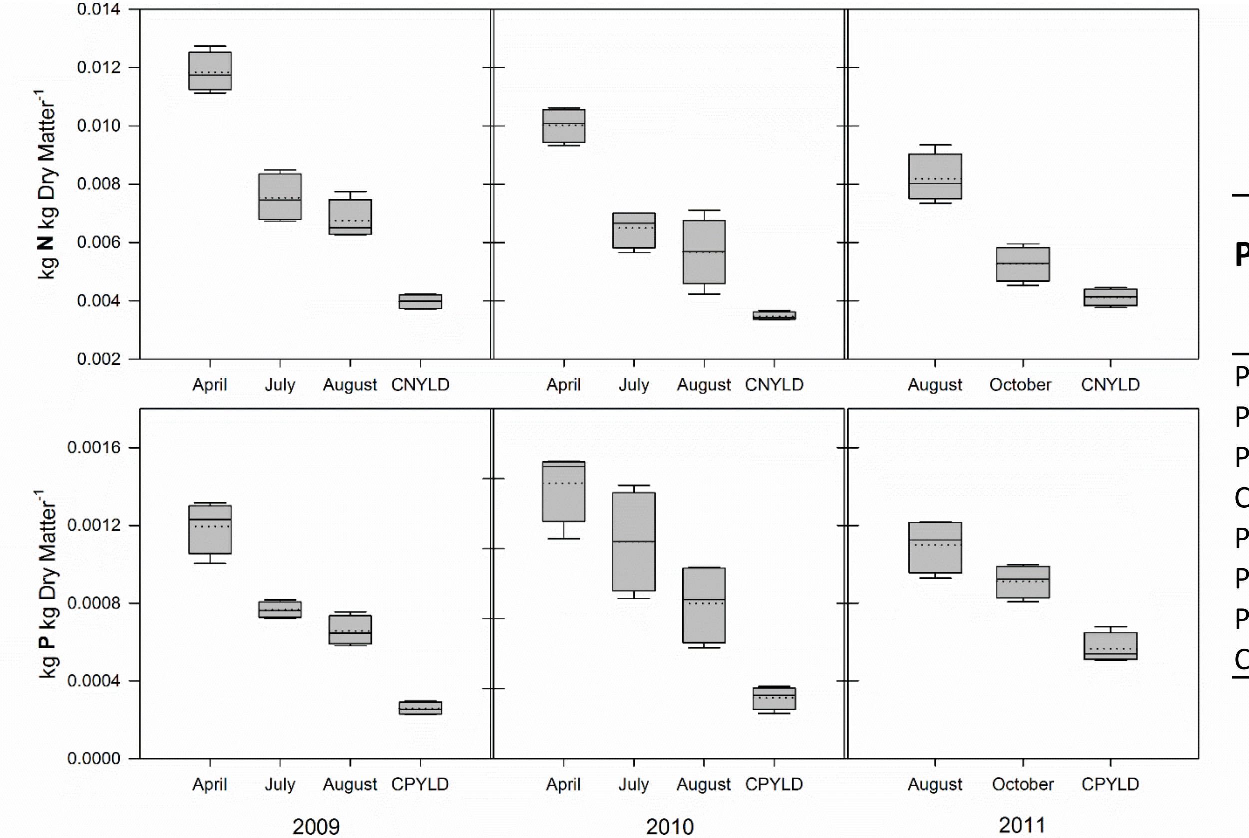
- Senescence start at October1
  - PHU=1.1 : DLAI =1.1
- Senescence End : PHU 1.2





Nutrient fractions – Tissue N and P

Miscanthus x giganteus



Parameter	*Miscanthus x giganteus*		
	Lower Bound	Mean	Upper Bound
PLTNFR(1)	0.0097	***0.0100***	0.0104
PLTNFR(2)	0.0062	***0.0065***	0.0070
PLTNFR(3)	0.0053	***0.0057***	0.0060
CNYLD	0.0034	***0.0035***	0.0035
PLTPFR(1)	0.0016	***0.0016***	0.0017
PLTPFR(2)	0.0010	***0.0012***	0.0014
PLTPFR(3)	0.0007	***0.0009***	0.0011
CPYLD	0.0003	***0.0003***	0.0004

Harvest representation

- Harvest Index (HI) and Harvest Efficiency (HARVEFF)
- *Miscanthus* yield ≅ 70% of above ground biomass
- Representation: HI = 1, and HARVEFF = 0.7

This ensures total aboveground biomass is removed and 30% to residue pool. Only below ground biomass is retained for next year.

Bioenergy crop parameters

	Miscanthus		Shawnee Switchgrass		Alamo Switchgrass
Parameter	**Suggested**	**Range**	**Suggested**	**Range**	**Database value**
T_OPT	25	-	25	-	25
T_BASE	8	7-10	10	8-12	12
PHU	1830	2100-1600	1400	1600-1200	
BIO_E	41 (39*)		17 (12*)	10-13	47
HVSTI	1	-	1	-	0.9
HEFF	0.7	0.65-0.75	0.75	0.7-0.75	
BLAI	11	10-13	8	-	6
DLAI	1.1	-	1		0.7
EXT_COEFF	0.55	0.45-0.65	0.5	0.4-0.55	0.33
LAIMX1	0.1	-	0.1	-	0.2
LAIMX2	0.85	-	0.85	-	0.95
FRGRW1	0.1	-	0.1	-	0.1
FRGRW2	0.45	-	0.4	-	0.2
PLTNFR(1)	0.0100	0.0097-0.0104	0.0073	0.0066-0.0081	0.035
PLTNFR(2)	0.0065	0.0062-0.0070	0.0068	0.0067-0.0072	0.015
PLTNFR(3)	0.0057	0.0053-0.0060	0.0053	0.0051-0.0055	0.0038
CNYLD	0.0035	0.0034-0.0035	0.0054	0.0053-0.0058	0.0160
PLTPFR(1)	0.0016	0.0016-0.0017	0.0011	0.0010-0.0012	0.0014
PLTPFR(2)	0.0012	0.0010-0.0014	0.0014	0.0013-0.0016	0.001
PLTPFR(3)	0.0009	0.0007-0.0011	0.0012	0.0011-0.0012	0.0007
CPYLD	0.0003	0.0003-0.0004	0.0010	0.0010-0.0011	0.0022
CHTMX	3.5	-	2	-	2.5
RDMX	3	2-4	3	2-4	2.2
WSYF	1	-	1	-	0.9
ALAI_MIN	0	-	0	-	0
USLE_C	Existing Alamo Value		Existing Alamo Value		0.003
VPDFR	Existing Alamo Value		Existing Alamo Value		4
GSI	Existing Alamo Value		Existing Alamo Value		0.005

Estimated/ Literature

From Measured WQFS Data

From SWAT Database

All switchgrass are not same

	Miscanthus		Shawnee Switchgrass		Alamo Switchgrass
Parameter	Suggested	Range	Suggested	Range	Database value
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PLTPFR(2)	0.0012	0.0010-0.0014	0.0014	0.0013-0.0016	0.001
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VPDFR	Existing Alamo Value		Existing Alamo Value		4
GSI	Existing Alamo Value		Existing Alamo Value		0.005

Estimated/ Literature

From Measured WQFS Data

From SWAT Database

Nutrient translocation is significant in perennials

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Parameter	**Suggested**	**Range**	**Suggested**	**Range**	**Database value**
T_OPT	25	-	25	-	25
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HEFF	0.7	0.65-0.75	0.75	0.7-0.75	
BLAI	11	10-13	8	-	6
DLAI	1.1	-	1		0.7
EXT_COEFF	0.55	0.45-0.65	0.5	0.4-0.55	0.33
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PLTPFR(1)	0.0016	0.0016-0.0017	0.0011	0.0010-0.0012	0.0014
PLTPFR(2)	0.0012	0.0010-0.0014	0.0014	0.0013-0.0016	0.001
PLTPFR(3)	0.0009	0.0007-0.0011	0.0012	0.0011-0.0012	0.0007
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Estimated/ Literature

From Measured WQFS Data

From SWAT Database

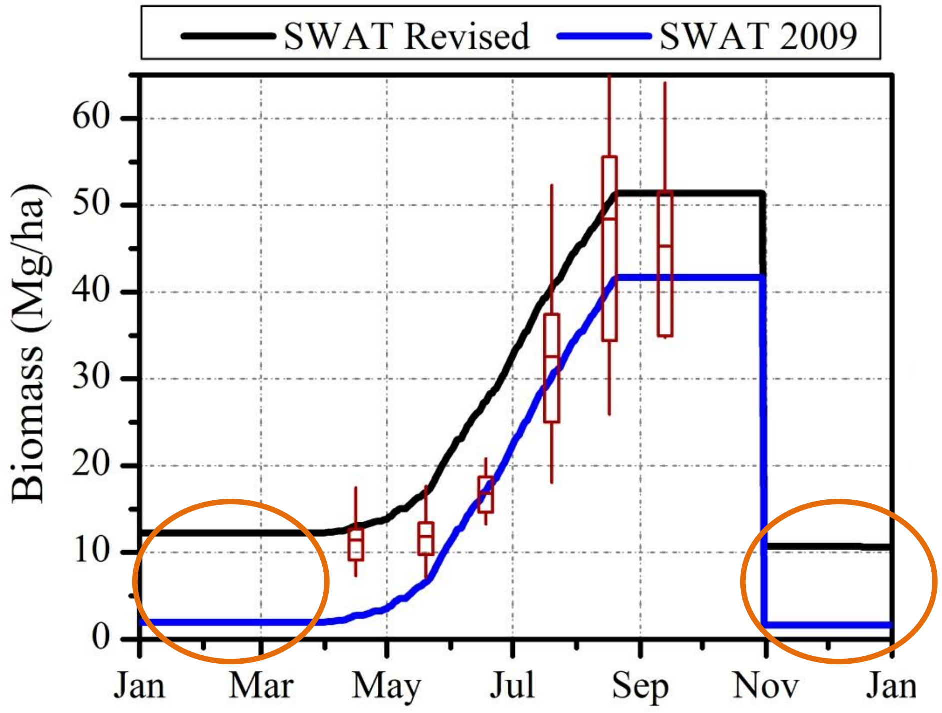
Crop Growth Algorithm Improvement

- 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

One HRU SWAT model to verify

- Soil Data – WQFS
  - SSURGO data
  - WQFS – “Drummer soils”
- Slope : 0.009 m/m
- Weather data – ACRE- iClimate.org
  - Temperature
  - Precipitation
- 2004 – 2010 , 7 years simulation, 3 years model warm-up

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

GLOBAL CHANGE BIOLOGY
BIOENERGY

GCB Bioenergy (2014), doi: 10.1111/gcbb.12210

Perennial rhizomatous grasses as bioenergy feedstock in SWAT: parameter development and model improvement

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

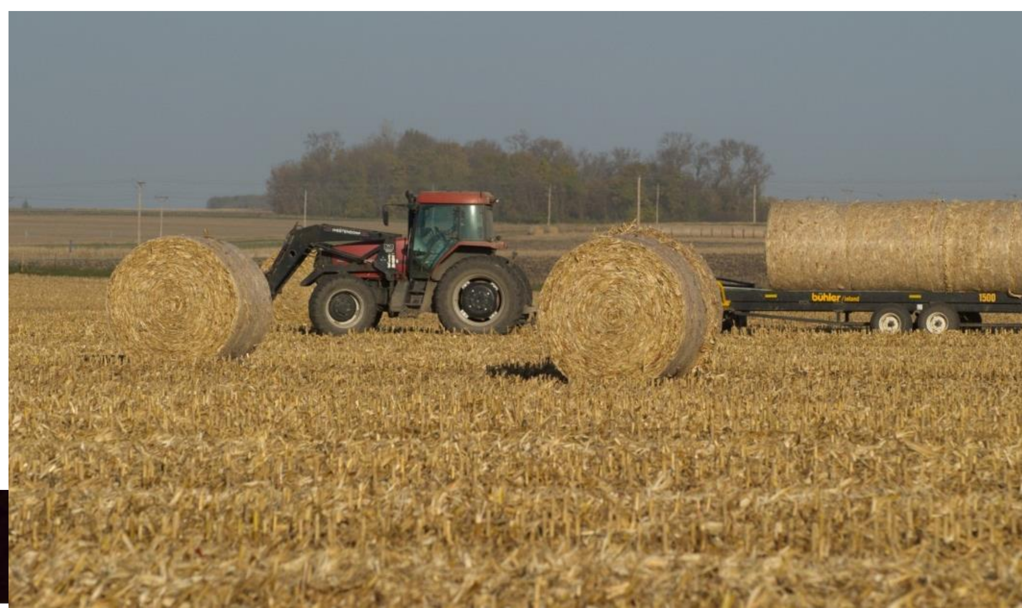
Abstract

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/)

Crop residue removal

- Residue harvested after grain harvest
- Model harvest algorithms updated to represent nutrient removal as a fraction of available nutrient after grain harvest
- Grain and residue harvest printed out as separate output variable



Crop residue removal representation (.mgt file)

- Residue harvested on same date after grain harvest: The root fraction update is based on heat unit accumulated

000010001_5.mgt - Notepad

File Edit Format View Help

```
                  0     | IRRSC: irrigation code
                  0     | IRRNO: irrigation source location
              0.000     | FLOWMIN: min in-stream flow for irr diversions (m^3/s)
              0.000     | DIVMAX: max irrigation diversion from reach (+mm/-10^4m^3)
              0.000     | FLOWFR: : fraction of flow allowed to be pulled for irr
Tile Drain Management Parameters
           1000.000     | DDRAIN: depth to subsurface tile drain (mm)
             24.000     | TDRAIN: time to drain soil to field capacity (hr)
             48.000     | GDRAIN: drain tile lag time (hr)
Management Operations:
           2      | NROT: number of years of rotationOperation Schedule:
Operation Schedule:
  5 10             3   55          56.00000   0.20
  5 24             6    4
  5 24             1   56        1250.00000   0.00      0.00000 0.00    0.00   0.
 10  7             7        1
 10  7             8
                   0
  4 15             6   59
  4 22             3    3         252.00000   0.20
  4 22             3   55          81.00000   0.20
  4 22             4    3           2.20000
  5  6             6   88
  5  6             1   19        1500.00000   0.00      0.00000 0.00    0.00   0.00
 10 14             7        1
 10 14             7        0                 0.50
 10 14             8
                   0
```

50% Stover removal-corn soybean rotation

HYDROLOGICAL PROCESSES
Hydrol. Process. (2011)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.8280

Simulated watershed scale impacts of corn stover removal for biofuel on hydrology and water quality

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[2] *Departments of Agricultural and Biological Engineering, and Earth and Atmospheric Sciences, Division of Environmental and Ecological Engineering, Purdue University, West Lafayette, IN, USA–47907*

Abstract:

Ethanol from corn stover is expected to play an important role in achieving the Energy Independence and Security Act 2007 target of 136.25 billion liters (36 billion gallons) of biofuel by 2022. The 2010 USDA biofuel strategic report estimates that 16.3 billion liters (4.3 billion gallons) of biofuel from crop residues such as corn stover and straw is possible. Corn stover is expected to provide the majority of the estimated biofuel from crop residues, especially from the Midwestern US Corn Belt. A major concern related to removing corn stover is potential negative hydrologic and water quality impacts. The overall goal of this study

- Quantified potential impacts of crop residue (corn stover) removal at three rates

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
- CO_2 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

Crop growth representation

- Fundamental differences between annual and perennial cropping systems
- Environment and genotype results in different physiological responses
- Representative crop parameters will improve hydrologic output at watershed scale

Heat units to maturity needs to be updated with base temperature

Heat Unit = Avg daily temp – base temp