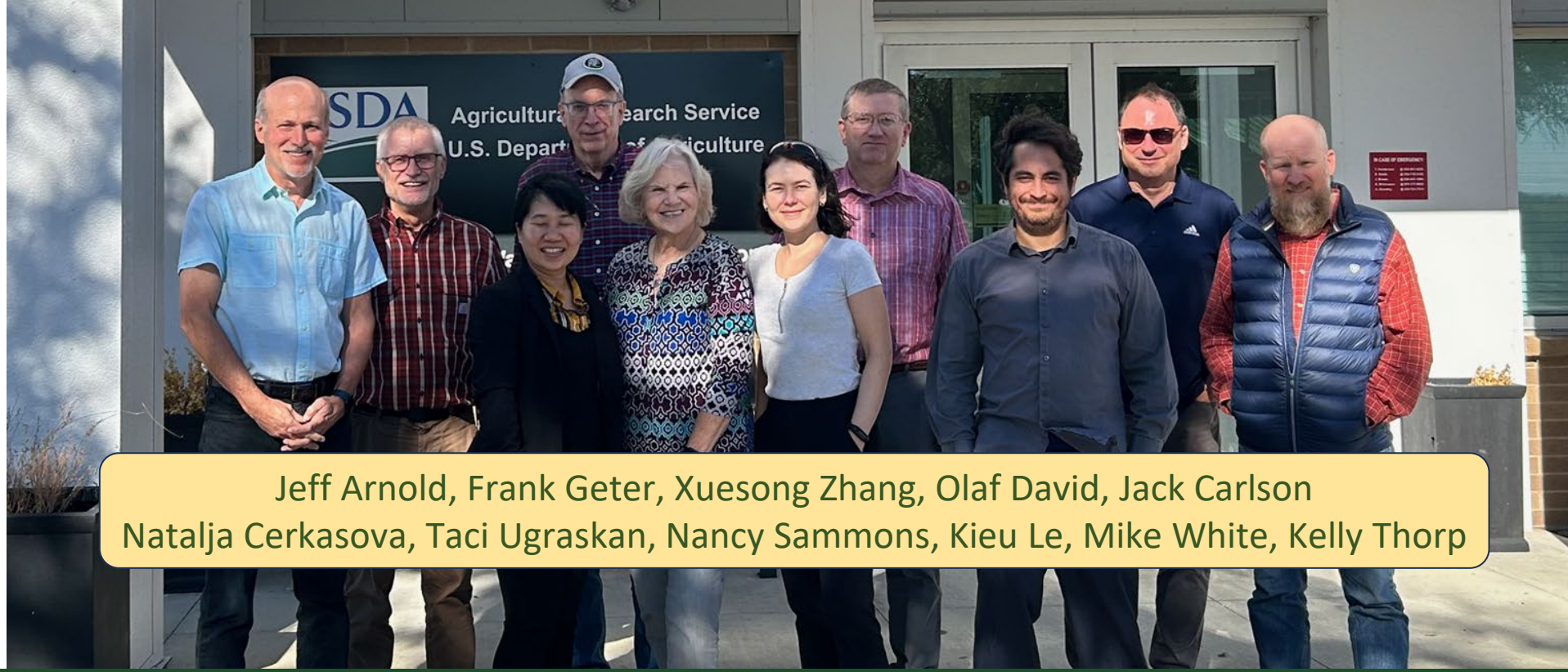


Updates to SWAT+ to Support Carbon Balance Modeling

2025 SWAT Conference

Fort Collins, Colorado November 18, 2025

COLORADO STATE UNIVERSITY

TEXAS A&M AGRILIFE

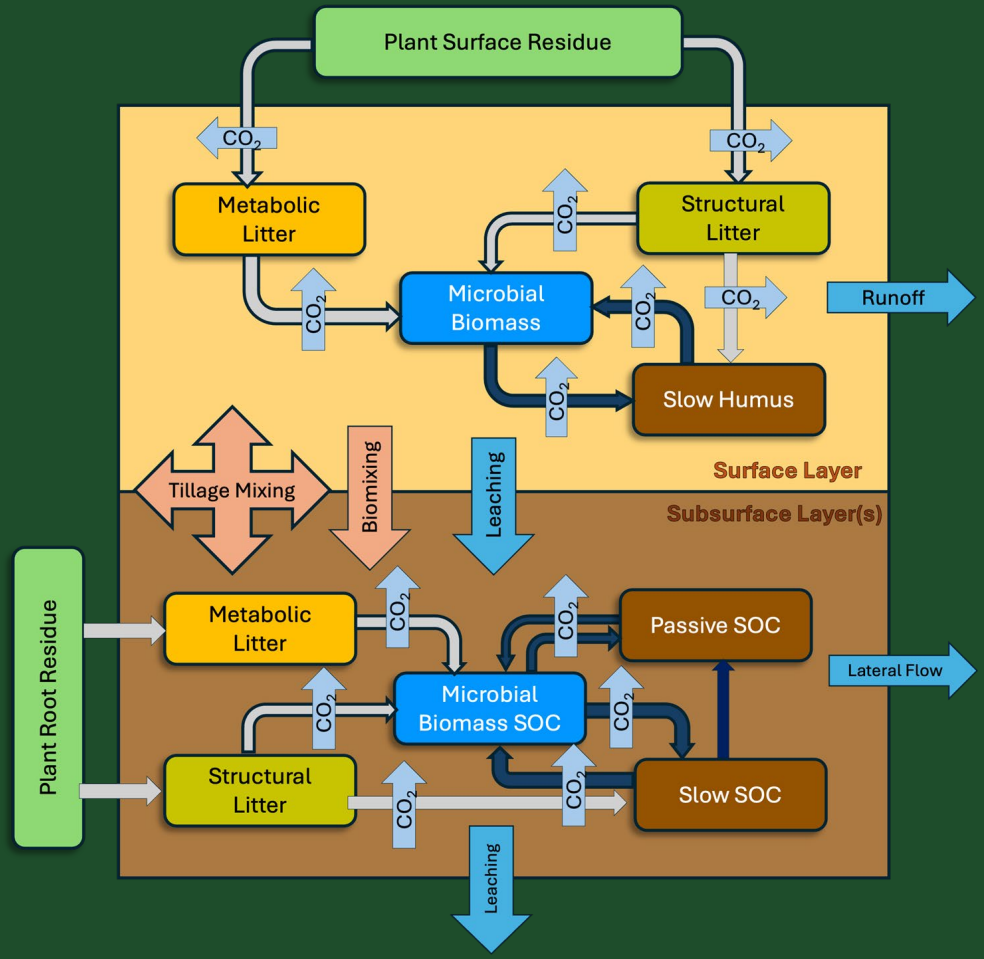
USDA

Carbon balance dynamics for a watershed were updated in the 2012 SWAT codebase configured as the SWAT-C model (Zhang et al 2013, 2018, Liang et al 2022)

SWAT-C carbon balance processes have roots in CENTURY, EPIC/APEX, DSSAT, and DNDC

Starting spring 2023, work began to bring SWAT-C processes into the SWAT+ codebase (carbon option 2 in codes.bsn) to support carbon balance assessments on individual cropped farm fields

This brief presentation summarizes model development progress to date, to the point that web services running the updated model support the quantification of soil carbon and other sustainability metrics at scale for Field-to-Market and other users.



Carbon pools and fluxes modeled by SWAT+

One-HRU Configuration for Field Scale Carbon Balance Modeling

```
file.cio: ${scenario} (${date})
simulation        time.sim          print.prt         null              object.cnt        null
basin             codes.bsn         parameters.bsn
climate           weather-sta.cli   weather-wgn.cli   null              ${wpcp:null,%-18s} ${wtmp:null,%-18s} ${wslr:null,%-18s} ${whmd:null,%-18s} ${wwnd:null,%-18s} null
connect           hru.con           null              null              null              null              null              null              null  null       null  null  null
channel           null              null              null              null              null              null              null              null
reservoir         null              null              null              null              null              null              null              null
routing_unit      null              null              null              null
hru               hru-data.hru      null
exco              null              null              null              null              null
recall            null
dr                null              null              null              null              null              null
aquifer           null              null
herd              null              null              null
water_rights      null              null              null
link              null              null
hydrology         hydrology.hyd     topography.hyd    null
structural        tiledrain.str     null              filterstrip.str   grassedww.str     null
hru_parm_db       plants.plt        fertilizer.frt    tillage.til       pesticide.pes     null              null              null              null              null  snow.sno
ops               harv.ops          graze.ops         irr.ops           chem_app.ops      fire.ops          null
lum               landuse.lum       management.sch    cntable.lum       cons_practice.lum ovn_table.lum
chg               null              null              null              null              null              null              null              null              null
init              plant.ini         soil_plant.ini    null              null              null              null              null              null              null  null       null  null
soils             soils.sol         nutrients.sol     null
decision_table    lum.dtl           null              null              null
regions           ls_unit.ele       null              null              null              null              null              null              null              null  null       null  null  null  null  null  null  null
pcp_path          null
tmp_path          null
slr_path          null
hmd_path          null
wnd_path          null
```

file.cio settings

```
hru-data.hru: (Sun Oct 05 17:32:36 MDT 2025)
      id  name          topo          hydro          soil          lu_mgt    soil_plant_init      surf_stor         snow         field
       1  hru0001     topohru0001      hyd0001         Otley       this_lum         soilplant1          null      snow001          null
```

hru-data.hru settings

```
landuse.lum: (Sun Oct 05 17:32:36 MDT 2025)
name          cal_group      plnt_com       mgt          cn2          cons_prac      urban      urb_ro          ov_mann      tile      sep       vfs       grww       bmp
this_lum          null     this_comm     mgt_01   rc_strow_g     up_down_slope       null        null   convtill_nores      null      null      null       null      null
```

landuse.lum settings

SWAT+ carbon option 2 enables setting custom soil hydrology layer depths in a new soil_lyr_depth.sol input file, here set to 15 layers, as compared to CENTURY and DayCent recommendations; each soil hydrology layer inherits soil properties derived from soil.sol

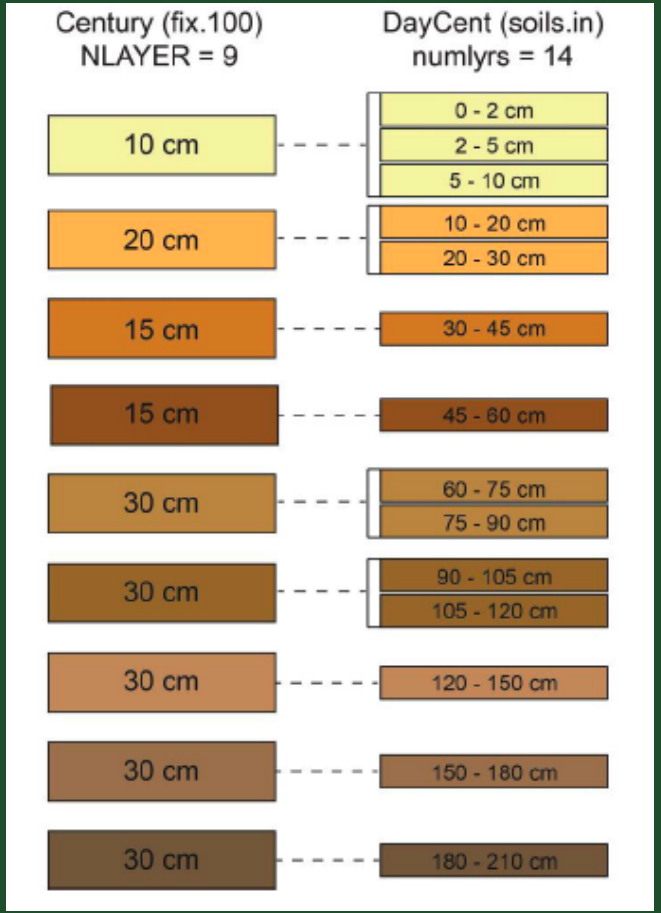
PET setting in codes.bsn defaults to the Penman-Monteith method, and the cn2 setting to the NRCS curve number method for surface runoff and infiltration

Percolation occurs at Ksat controlled rates when soil water in a layer exceeds field capacity

Lateral flow occurs via a kinematic wave function when soil water in a layer exceeds field capacity

```
Custom soil layers depths
depth
mm
10
25
50
100
200
300
450
600
750
900
1050
1200
1500
1800
2100
```

soil_lyr_depths.sol



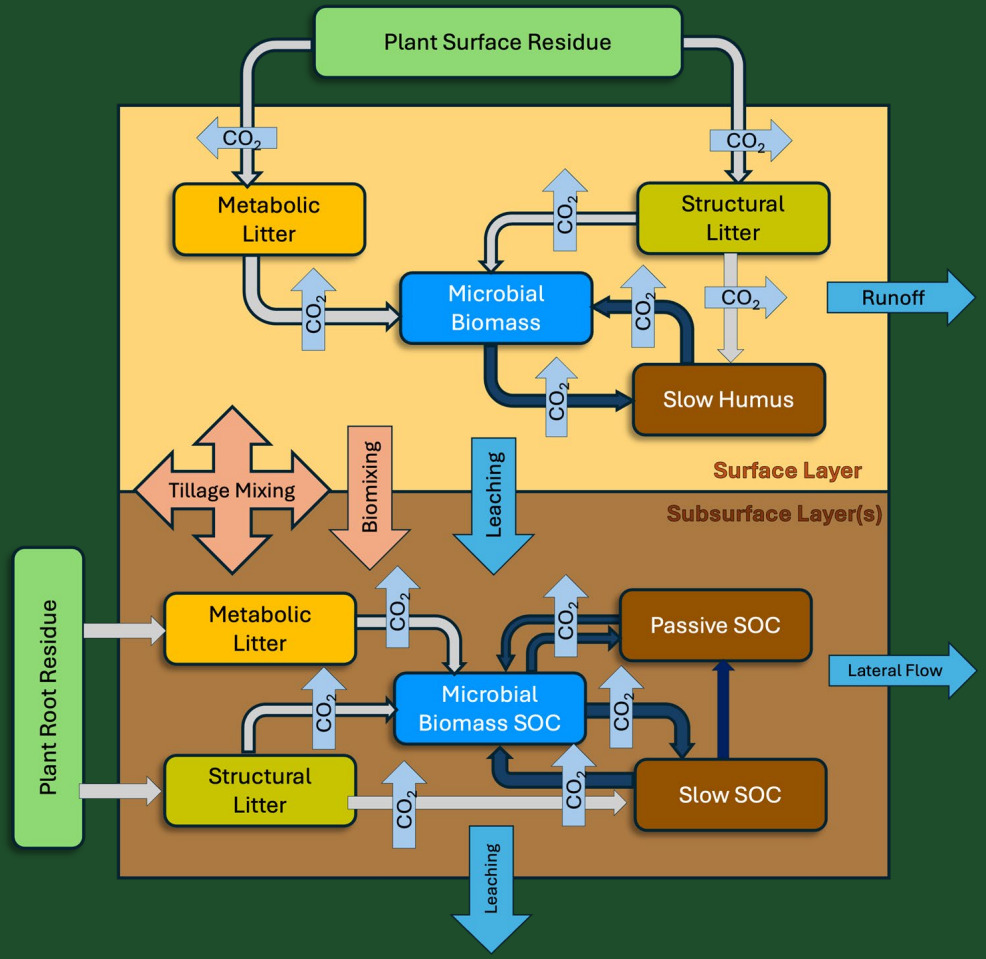
Hartman et al 2020

The cbn_zhang2.f90, nut_organc2.f90, and cbn_rsd_decomp.f90 subroutines contain most of the new carbon option 2 code in SWAT+

The cbn_rsd_decomp.f90 subroutine daily allocates crop residue biomass above and below ground to metabolic and structural litter pools controlled by temperature, soil water, and soil mixing factors, as well as lignin content

Tillage mixes soil, controlled by duration, depth, and disturbance parameters

Depth controlled biomixing occurs when tillage effects have dissipated and the ground is not frozen



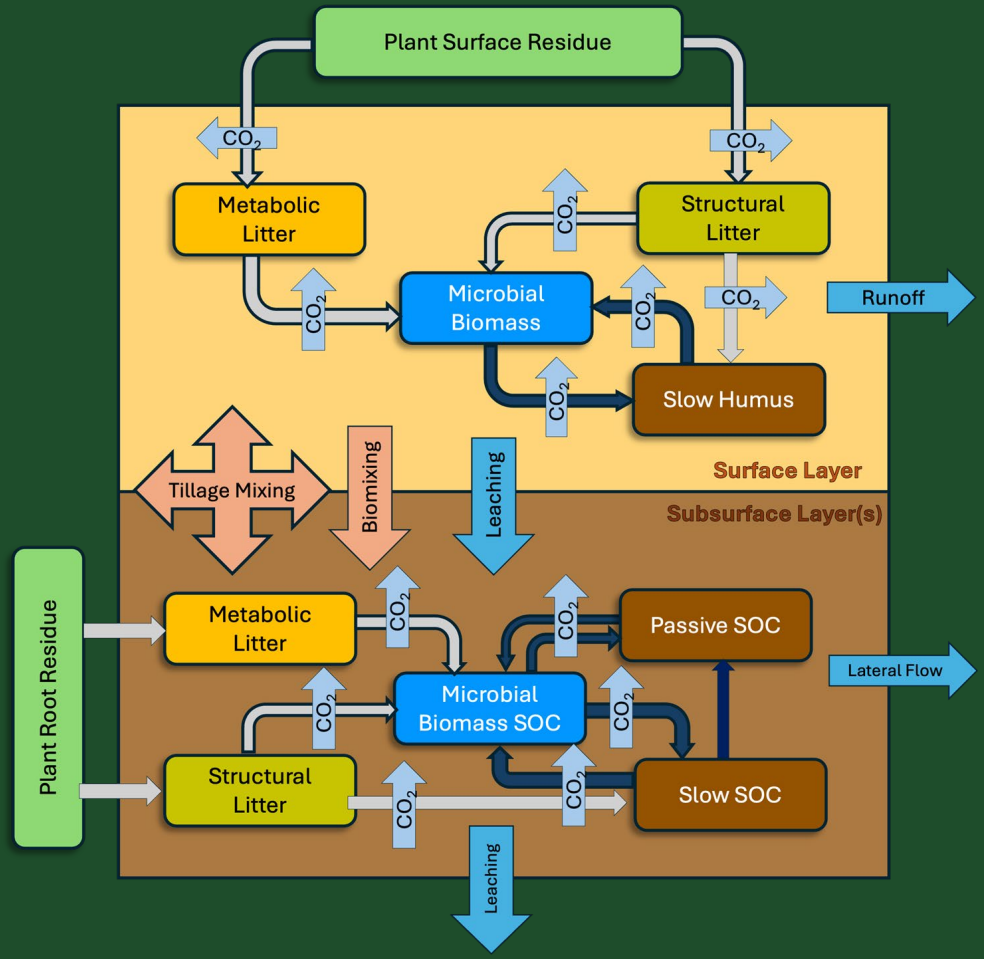
Carbon pools and fluxes modeled by SWAT+

For each layer the cbn_zhang2.f90 subroutine simulates microbial action on the metabolic and structural litter pools transforming and fluxing C, N, and P to microbial pool (biomass) while respiring CO2

Microbial C, N, and P then transform and flux to the slow and passive pools while respiring CO2

Slow and passive pool C, N, and P also transform with slow pool to the passive pool and back to the microbial pool, and the passive pool back to the microbial pool, while respiring CO2

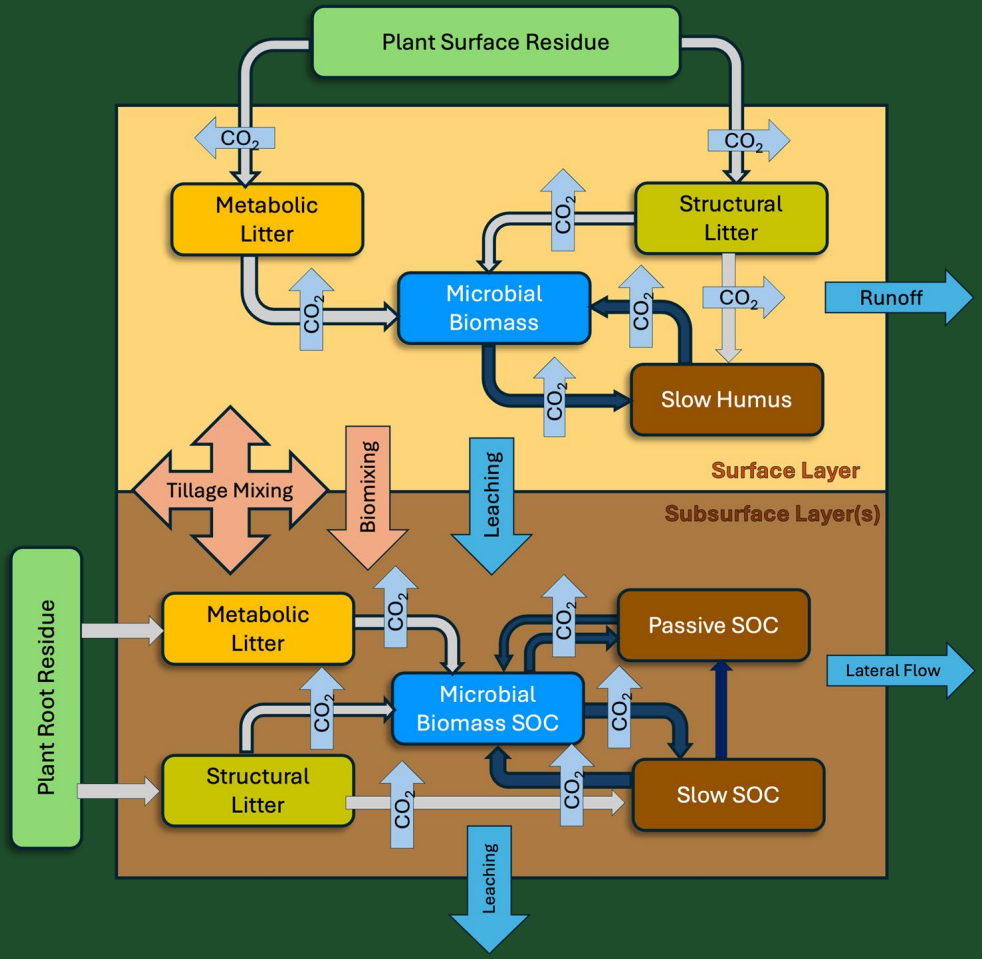
A combined factor of tillage/biomixing, soil water, temperature, and oxygen effects adjusts maximum transformation rates to potential rates; then N supply further adjusts potential rates to actual rates



Carbon pools and fluxes modeled by SWAT+

For each layer after precipitation or irrigation events, and soil water conditions permit, the nut_orgnc2.f90 subroutine extracts C, N, and P from the microbial pool into solution to surface runoff, lateral flow, and/or percolation deeper in the subsurface profile

Solution partitioning coefficients control the allocation of C, N, and P to runoff, lateral flow, and percolation



Carbon pools and fluxes modeled by SWAT+

Maximum carbon pool daily transformation/flux rates

- hp_rate – passive pool transformation
- hs_rate – slow pool transformation
- microb_rate – microbial pool transformation
- meta_rate – metabolic litter pool transformation
- str_rate – structural litter pool transformation
- hs_rate – slow to passive pool flux rate

CO2 emission rates

- a1co2 – fraction transformed metabolic and structural litter carbon to CO2
- asco2 – fraction transformed slow pool carbon to CO2
- apco2 – fraction transformed passive pool carbon to CO2
- abco2 – fraction transformed microbial pool carbon to CO2 (calculated for subsurface layers depending on sand content)

```
File: carb_coefs.cbn   Carbon coefficients used if cswat == 2

# carbdb coefficients
#                 1st_lyr      other_lyrs
hp_rate           1.2e-05      1.2e-05
hs_rate           2.92e-04     1.81e-04
microb_rate       0.0164       0.02
meta_rate         0.0405       0.0507
str_rate          0.0107       0.0134
microb_top_rate   0.0164       0.02
hs_hp             0.05         0.05

# org_allo coefficients
#                 1st_lyr      other_lyrs
a1co2             0.600        0.55
asco2             0.55         0.55
apco2             0.55         0.55
abco2             0.55         0.0

# carbon water partitioning coefficients
prmt_21           1000.
prmt_44           0.5

# Length of days that a tillage event will be effective
till_eff_days   30

# Manure carbon coefficients
rtof          0.5
man_to_c      0.42

# meta, str, and lignin partioning fractions
meta_frac         0.85
str_frac          0.15
lig_frac          0.12

# Soil Test Values (sname and depth_mm are required, enter 0.0 for missing values).
# If sand, silt, clay are not 0.0 they must total to 100.0
# data are assumed to be weighted average values down to depth_mm
nmbr_soil_tests  2
#         soil_name      depth_mm  bulk_density carbon %sand    %silt    %clay
soil_test soil_01-h1     150         2.0          4.0     30.0     30.0     40.0
soil_test soil_03-h3     150         1.6          3.0     40.0     30.0     30.0
```

carb.coefs.cbn

Solution carbon partitioning coefficients

prmt_21 – KOC (tendency to adsorb to sediment)

prmt_44 – runoff to percolate ratio

Manure carbon allocation coefficients

rtof – ratio of fresh to stable manure

man_2_c – fraction manure solids converted to C

Crop/plant residue partitioning fractions

meta_frac – fraction allocated to metabolic litter

str_frac - fraction allocated to structural litter

lig_frac – fraction allocated to lignin

Soil test results

soil_name – soil sample identifier

depth_mm – sample depth in mm

bulk_density – sampled bulk density in SSURGO units

carbon - sampled organic matter * 0.58

sampled %sand, %silt, %clay (=100)

```
File: carb_coefs.cbn   Carbon coefficients used if cswat == 2

# carbdb coefficients
#                1st_lyr      other_lyrs
hp_rate          1.2e-05      1.2e-05
hs_rate          2.92e-04     1.81e-04
microb_rate      0.0164       0.02
meta_rate        0.0405       0.0507
str_rate         0.0107       0.0134
microb_top_rate  0.0164       0.02
hs_hp            0.05         0.05

# org_allo coefficients
#                1st_lyr      other_lyrs
a1co2            0.600        0.55
asco2            0.55         0.55
apco2            0.55         0.55
abco2            0.55         0.0

# carbon water partitioning coefficients
prmt_21          1000.
prmt_44          0.5

# Length of days that a tillage event will be effective
till_eff_days    30

# Manure carbon coefficients
rtof         0.5
man_to_c     0.42

# meta, str, and lignin partioning fractions
meta_frac        0.85
str_frac         0.15
lig_frac         0.12

# Soil Test Values (sname and depth_mm are required, enter 0.0 for missing values).
# If sand, silt, clay are not 0.0 they must total to 100.0
# data are assumed to be weighted average values down to depth_mm
nmbr_soil_tests  2
#         soil_name      depth_mm  bulk_density carbon %sand    %silt    %clay
soil_test soil_01-h1     150         2.0          4.0     30.0     30.0     40.0
soil_test soil_03-h3     150         1.6          3.0     40.0     30.0     30.0
```

carb.coefs.cbn

New SWAT+ Carbon Balance Output

Soil C, N, and P Stock

- hru_cbn_lyr – total C by layer by day/month/year
- hru_seq_lyr - sequestered C by layer by mon/day/year
- hru_cpool_stat - – C pool amounts by layer/day
- hru_n_p_pool_stat – N and P pool amounts by layer/day

Residue Decomposition, Soil Carbon Transformation, Flux, CO2

- hru_cfflux_stat – C, N flux and CO2 emission among pools by layer/day
- hru_org_trans_vars – Potential C pool transformation by layer/day
- hru_org_trans_vars – Actual C pool transformation amount by layer/day
- hru_org_allo_vars – Fraction C allocated among pools and to CO2 emission by layer/day

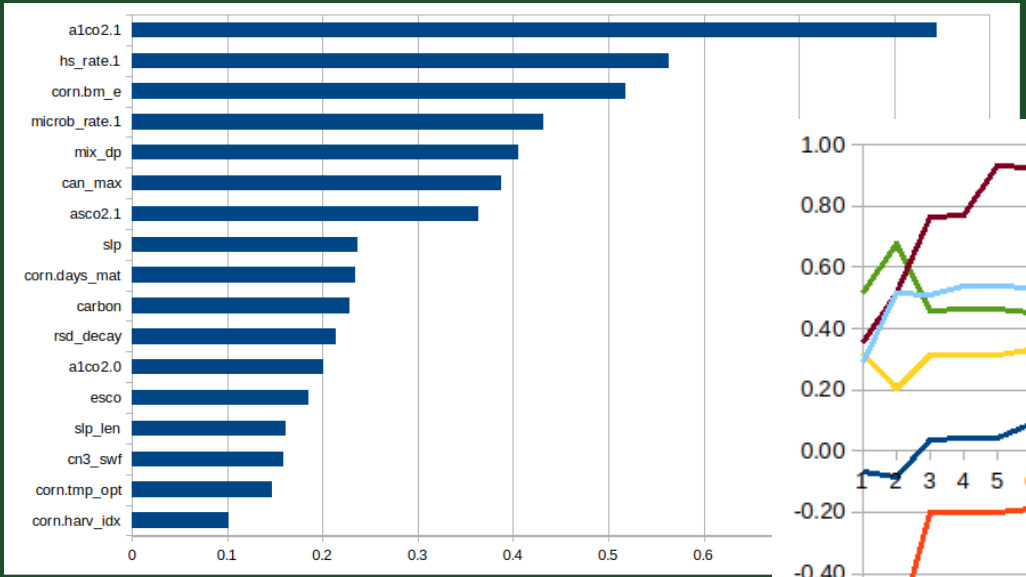
Factors Affecting C, N, and P Pools and Fluxes

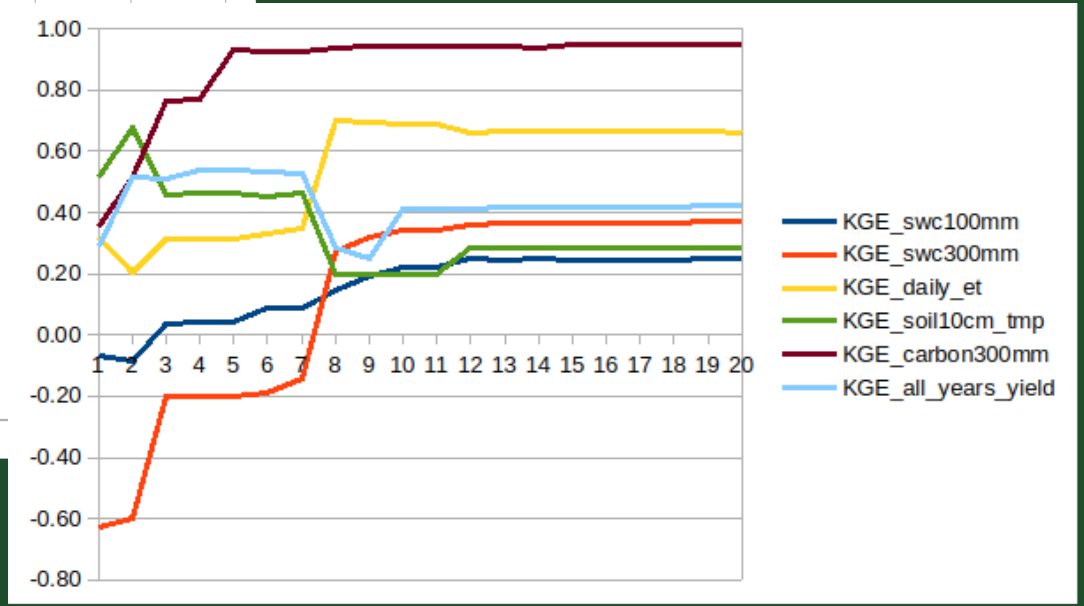
- hru_carb_vars – tillage, temperature, soil water, oxygen, and combined effects by layer/day
- hru_org_ratio_vars – N/C ratios of microbial, slow, and passive pools by layer/day

```
print.prt: ${scenario} (${date})
nyskip          day_start     yrc_start       day_end       yrc_end    interval
0           ${dst,%12s } ${yst,%12s } ${den,%12s } ${yen,%12s }           1
aa_int_cnt
0
csvout         dbout          cdfout
n              y              n
crop_yld       mgtout         hydcon         fdcout
b              y              n              n
objects                  daily          monthly          yearly       avann
hru_wb           ${wb_d,%10s }  ${wb_m,%10s }  ${wb_y,%10s }           y
hru_nb                           y              n              n           n
hru_ls                           y              n              n           n
hru_pw           ${pw_d,%10s }  ${pw_m,%10s }  ${pw_y,%10s }           n
hru_cb           ${cb_d,%10s }  ${cb_m,%10s }  ${cb_y,%10s }           y
```

print.prt

SWAT+ Carbon Balance Calibration/Validation





Field study datasets (GraceNet, Other)

SW Minnesota; E Nebraska; NW/NE/NE/C/SW/SC/SE Iowa;
NW Indiana

SWAT + Model Web Services

http://csip.engr.colostate.edu:8088/csip-soils/d/swatplus/2.0

Resolve soils.sol input file

http://csip.engr.colostate.edu:8088/csip-climate/d/gridmet/2.0

Fetches data from GridMet for SWAT+ weather input files

http://csip.engr.colostate.edu:8088/csip-swatplus/m/swatplus/4.0

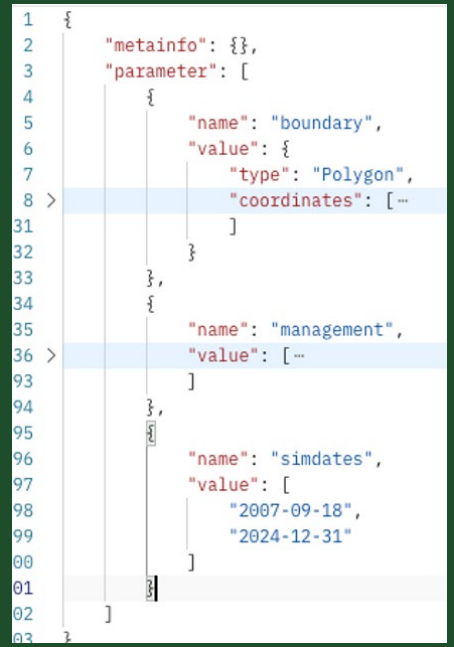
Runs SWAT+ simulation for soil component

http://csip.engr.colostate.edu:8088/csip-swatplus/m/swatplus/4.1

Runs one or more SWAT+ simulations for farm field

http://csip.engr.colostate.edu:8088/csip-swatplus/m/swatplus-cal/4.1

Runs SWAT+ calibration simulations



Sessions << < 1 - 25 (of 57844) > >> **Archives** at 2025-10-12 22:05:04

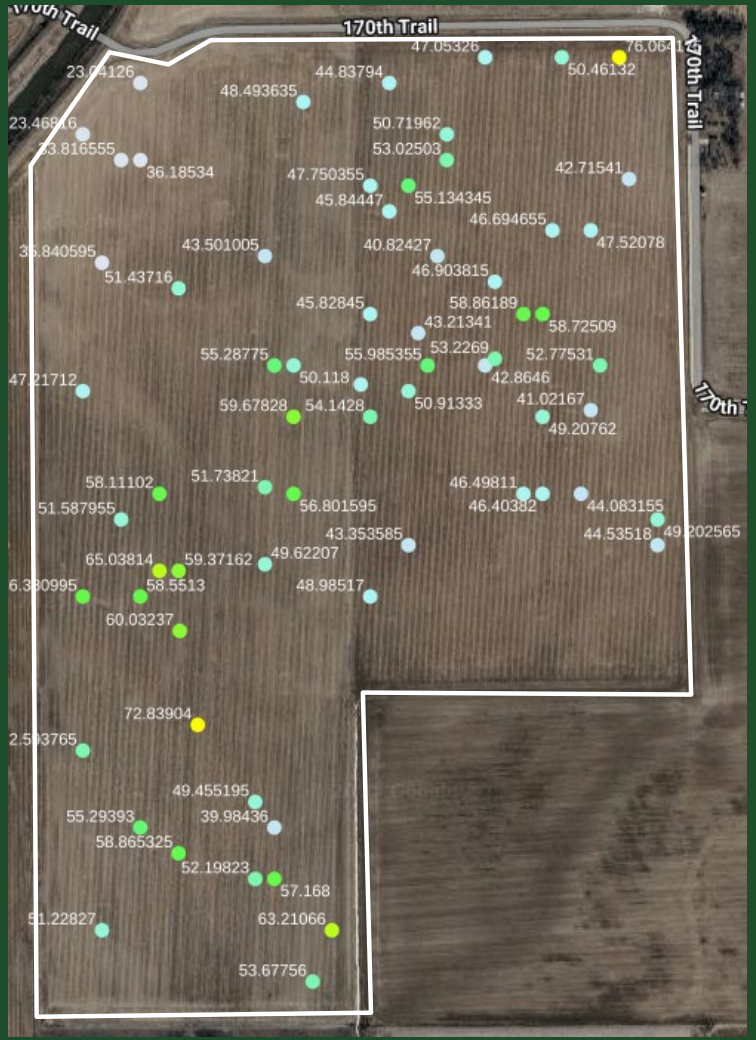
suid	status	req IP	archived at	expiration	service	files	
5ba912d3-a5eb-11f0-afdc-6ff5afe36800	Finished	129.82.21.91	2025-10-10 09:11:15	2025-10-11 09:11:15	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b0e3302-a5eb-11f0-955a-c1330da0cb96	Finished	129.82.21.91	2025-10-10 09:11:14	2025-10-11 09:11:14	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b0e325f-a5eb-11f0-afdc-67d4ee8abadd	Finished	129.82.21.91	2025-10-10 09:11:14	2025-10-11 09:11:14	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b0e5a14-a5eb-11f0-955a-8341a9c23a22	Finished	129.82.21.91	2025-10-10 09:11:14	2025-10-11 09:11:14	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b0e3260-a5eb-11f0-afdc-43cb266ecada	Finished	129.82.21.91	2025-10-10 09:11:14	2025-10-11 09:11:14	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b0e5a15-a5eb-11f0-955a-471e2321c82e	Finished	129.82.21.91	2025-10-10 09:11:14	2025-10-11 09:11:14	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b0e5972-a5eb-11f0-afdc-41f1bbe152ef	Finished	129.82.21.91	2025-10-10 09:11:14	2025-10-11 09:11:14	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b0e5a13-a5eb-11f0-955a-3f02625130b9	Finished	129.82.21.91	2025-10-10 09:11:14	2025-10-11 09:11:14	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b0e5971-a5eb-11f0-afdc-837ca9be8284	Finished	129.82.21.91	2025-10-10 09:11:14	2025-10-11 09:11:14	http://csip.engr.colostate.edu:8084/csip-swatplus/m/swatplus/4.0	download	del
5b04bd21-a5eb-11f0-955a-19a2da0cd2f9	Finished	34.238.177.11	2025-10-10 09:11:13	2025-10-11 09:11:13	http://csip.engr.colostate.edu:9084/csip-swatplus/m/swatplus/4.1	download	del

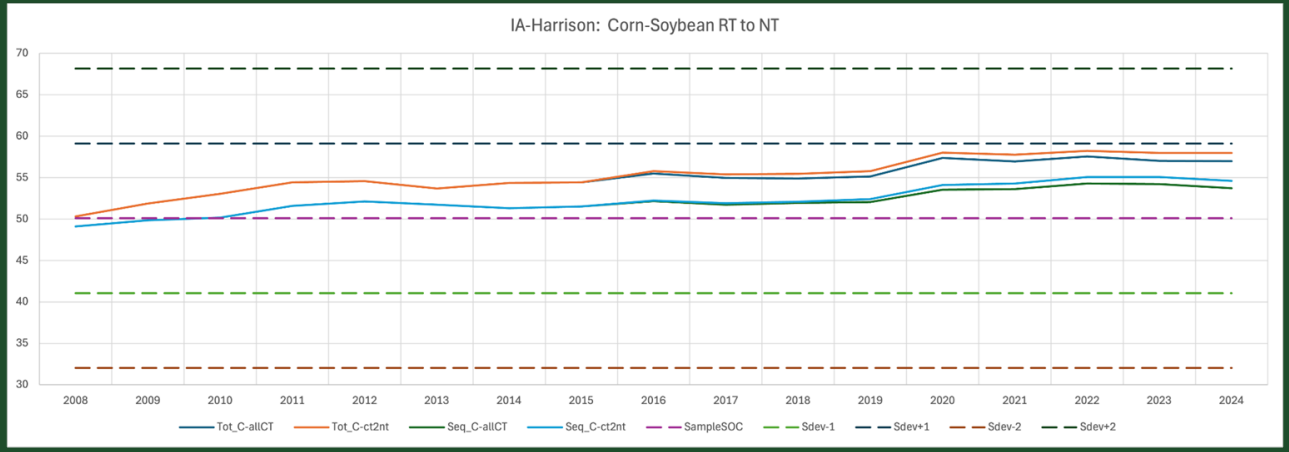
SWAT + Model To-Do List for Supporting Sustainability Metrics

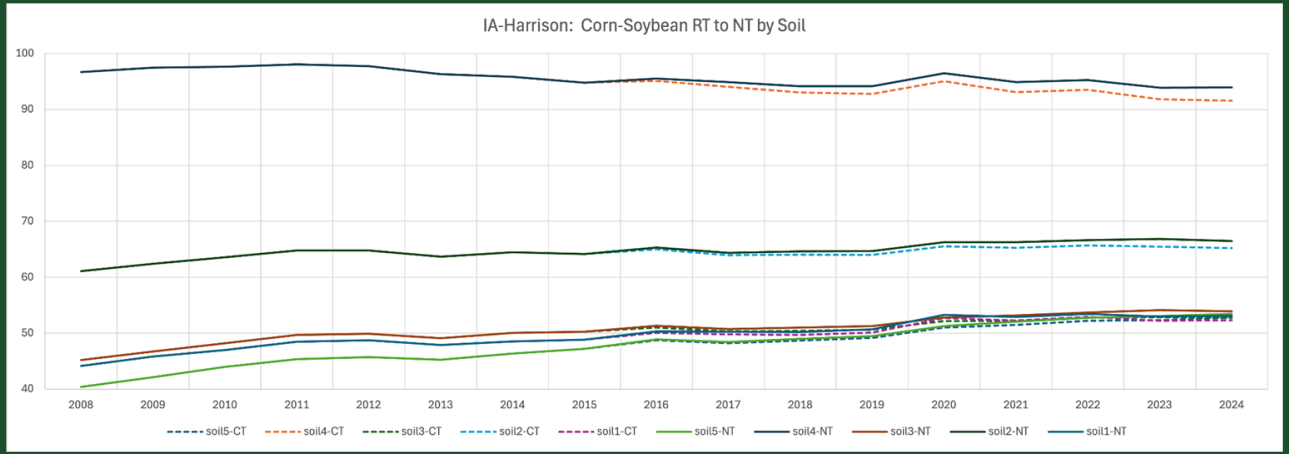
- Updated manure carbon dynamics
- Ongoing regional calibration/validation
- Flooded crop (rice) carbon dynamics (Jeong et al 2025)
- N2O emissions (Liang et al 2023)
- Add more tillage, soil water, and temperature factor methods options (Liang et al 2022)
- New crop parameter sets for plants.plt (e.g. safflower)
- Align WEPP water erosion and WEPS wind erosion model simulation periods to 2008-2025 cropping sequences

IA-Harrison Example

- 67 SOC (30cm) samples, 23-76 Mg/ha, mean 50 Mg/ha
- 5 Soil Components
- Corn/Soybean cropping sequence




IA-Harrison: Corn-Soybean RT to NT
70
65
60
55
50
45
40
35
30
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
Tot_C-allCT
Tot_C-ct2nt
Seq_C-allCT
Seq_C-ct2nt
SampleSOC
Sdev-1
Sdev+1
Sdev-2
Sdev+2


IA-Harrison: Corn-Soybean RT to NT by Soil
100
90
80
70
60
50
40
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
soil5-CT
soil4-CT
soil3-CT
soil2-CT
soil1-CT
soil5-NT
soil4-NT
soil3-NT
soil2-NT
soil1-NT