C-FARM: A Simple Model to Evaluate the Soil Carbon Balance in Cropping Systems

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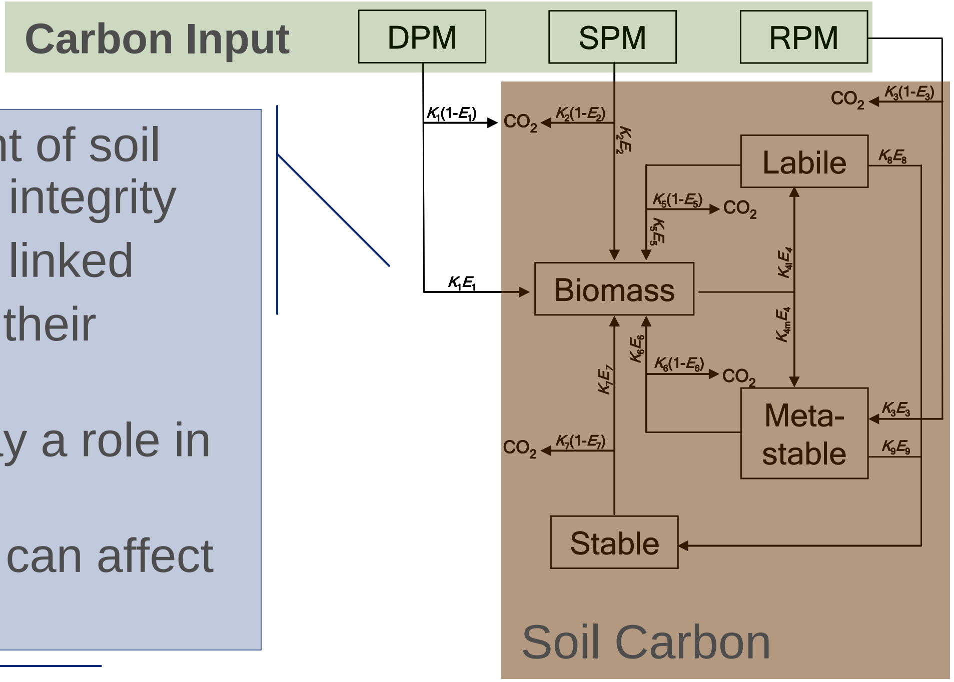
Introduction Carbon Cycling Modeling Relevance



- Soil Carbon is a key component of soil productivity and environmental integrity
- C, N, and P cycling are closely linked
- Carbon content of soils affects their erodability
- Carbon storage in soils can play a role in regulating atmospheric [CO_2]
- Biomass harvest for bioenergy can affect soil carbon balance

- **There is a strong demand for methods to compute and certify the soil carbon balance under different agricultural managements due to both environmental concerns and to support the carbon and environmental credits markets**

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Objective

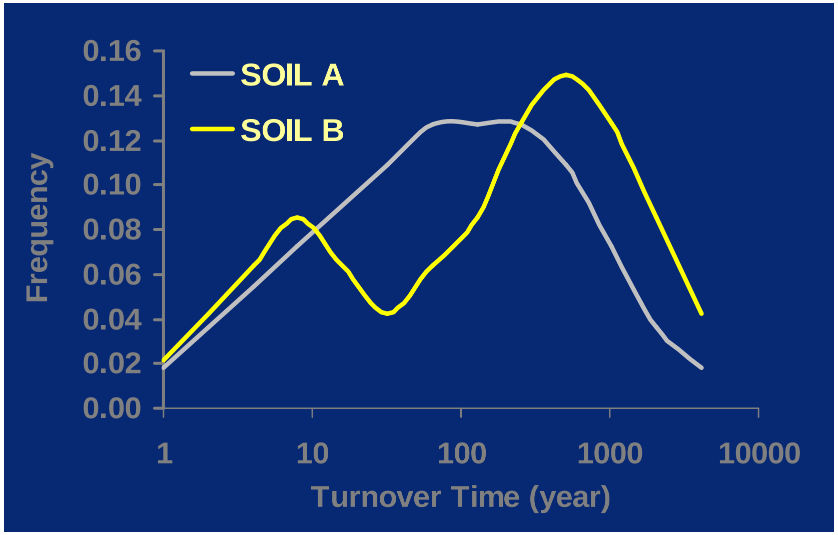
Develop a tool to compute soil C balance

- The following are desirable features of a soil carbon model:
  - Simple structure
  - Consider the entire soil profile
  - No or minimum calibration needs
  - Transferable across locations
  - Consider environmental and management effects on soil carbon turnover
  - Accommodate different management scenarios

Concept evolution More than a century of research

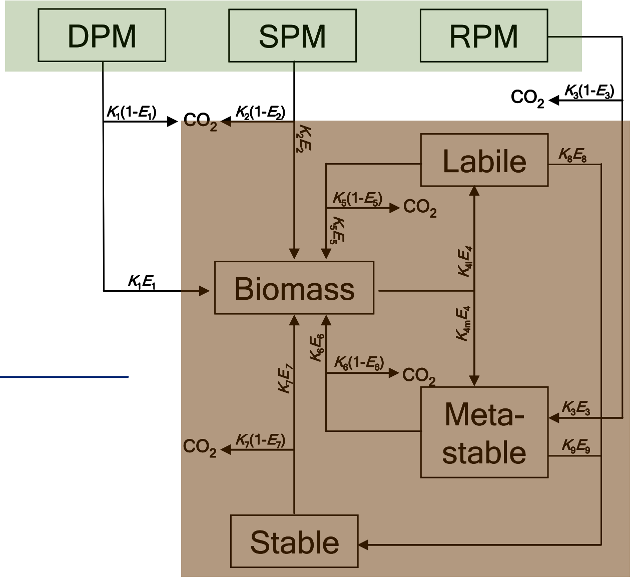
- Hénin and Dupuis (1945): carbon balance
- Jansson (1958): tracer experiments
- Swift (1979): the cascade of decomposition
- Jenkinson and Rayner (1977): multiple carbon pools, Roth-C model
- Paul & coworkers (1979 - present)
- Phoenix model (McGill et al. 1981)
- Century, NCSoil, Verberne et al. (1980 - 1990)
- Hassink & Withmore (1997): Carbon saturation

Challenge Quantitative treatment of complex processes



- Soil organic matter is composed of fractions with varying (continuum) turnover rates
- At best, SOM is treated as composed of discrete fractions with distinct properties

- Alternative approaches to treat this complexity:
  - Multiple carbon pools with fixed properties
  - **Only one carbon pool, with variable properties**
  - Multiple carbon pools with variable properties



C-FARM Analytical solutions

Change in Carbon Storage = Inputs - Outputs

Hénin and Dupuis (1945) $\mathbf{dC_s/dt = hC_i - kC_s}$

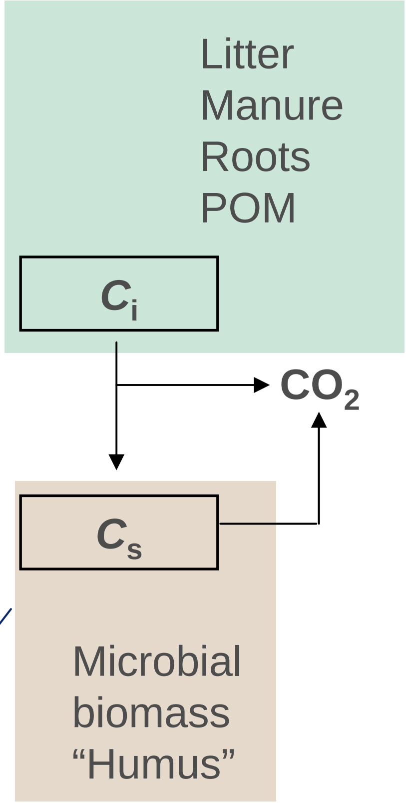
C_s is the soil organic Carbon (Mg ha^{-1})

t is time (year)

h is the humification constant

C_i is the carbon input

k is the apparent soil turnover rate



Litter
Manure
Roots
POM

C_i

CO_2

C_s

Microbial
biomass
“Humus”

C-FARM Analytical solution for variable humification rate

Change in Carbon Storage = Inputs - Outputs

$$\mathbf{d}\boldsymbol{C}_{\mathbf{s}}\mathbf{/d}\boldsymbol{t} = \mathbf{h}_{\mathbf{x}}\mathbf{(1 - C_s/C_x)}\boldsymbol{C}_{\mathbf{i}} - \boldsymbol{kC}_{\mathbf{s}}$$

$$\boldsymbol{C_s(t) = h_xC_i/c + (C_o - h_xC_i/c)\mathbf{exp}(-ct)}$$

$c = h_xC_i/C_x + k$

h_x is the maximum humification

C_x is the maximum soil carbon carrying capacity (Mg ha^{-1})

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C-FARM Analytical solution for variable turnover rate

Change in Carbon Storage = Inputs - Outputs

$$\mathrm{d}C_s/\mathrm{d}t = hC_i - k_n(1 + C_s/C_k)C_s$$

$$C_s(t) = C_k[a_2A\exp(-k_n(a_2 - a_1)t - a_1] \,/\, [1 - A\exp(-k_n(a_2 - a_1)t)]$$

$a_1 = -\ [(1 + (1 + 4b)^{1/2}] / 2$

$a_2 =\ \ [(1 + 4b)^{1/2} - 1] / 2$

$b = hC_i / (k_nC_k)$

A is an integration constant

C_k is a reference soil carbon content (Mg ha^{-1})

C-FARM The core carbon balance equation for each layer

$$dC_s/dt = hC_i - kC_s$$

$$h = h_c[1 - (C_s/C_x)^n]$$

$$k = f_e f_t k_x (C_s/C_x)^m C_s$$

h_c depends on soil texture resembling Roth-C

C_x depends on soil texture (Hassink and Withmore, 1997)

f_e soil temperature and water content factor (energy balance)

f_t is a function of tillage tool and number of operations (NRCS)

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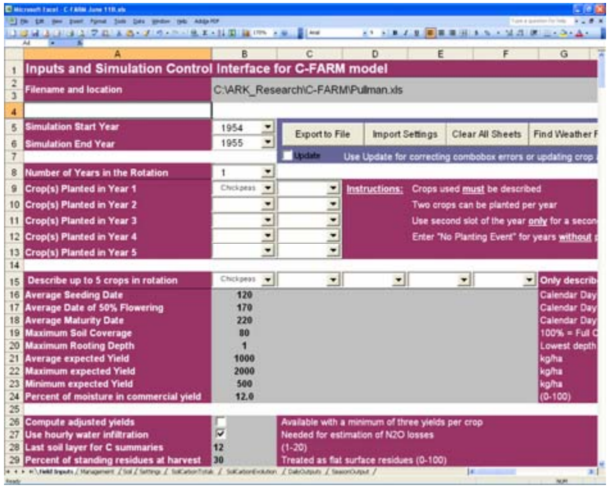
C-FARM Input and Output structure and capabilities

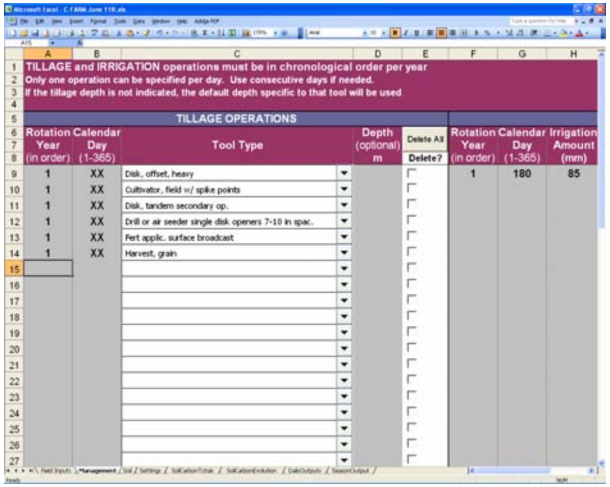
Inputs

- daily weather
- soil texture and organic carbon by layer
- cropping systems sequence (seeding and maturity dates)
- grain yield (max, min, average) for each crop
- tillage sequence (tools, date, depth of operation)
- Irrigation scheme



Inputs and Simulation Control Interface for C-FARM model

	A	B	C	D	E	F	G
2–3	Filename and location	C:\ARK_Research\C-FARM\Pullman.xls					
4							
5	Simulation Start Year	1954	Export to File	Import Settings	Clear All Sheets	Find Weather F	
6	Simulation End Year	1955					
7			☐ Update	Use Update for correcting combobox errors or updating crop			
8	Number of Years in the Rotation	1					
9	Crop(s) Planted in Year 1	Chickpeas		Instructions:	Crops used must be described		
10	Crop(s) Planted in Year 2				Two crops can be planted per year		
11	Crop(s) Planted in Year 3				Use second slot of the year only for a secon		
12	Crop(s) Planted in Year 4				Enter "No Planting Event" for years without		
13	Crop(s) Planted in Year 5						
14							
15	Describe up to 5 crops in rotation	Chickpeas					Only describ
16	Average Seeding Date	120					Calendar Day
17	Average Date of 50% Flowering	170					Calendar Day
18	Average Maturity Date	220					Calendar Day
19	Maximum Soil Coverage	80					100% = Full C
20	Maximum Rooting Depth	1					Lowest depth
21	Average expected Yield	1000					kg/ha
22	Maximum expected Yield	2000					kg/ha
23	Minimum expected Yield	500					kg/ha
24	Percent of moisture in commercial yield	12.0					(0-100)
25							
26	Compute adjusted yields	☐	Available with a minimum of three yields per crop				
27	Use hourly water infiltration	☑	Needed for estimation of N2O losses				
28	Last soil layer for C summaries	12	(1-20)				
29	Percent of standing residues at harvest	30	Treated as flat surface residues (0-100)				



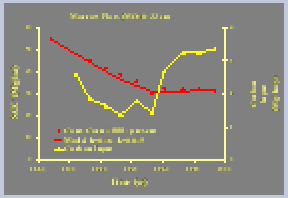
TILLAGE and IRRIGATION operations must be in chronological order per year
Only one operation can be specified per day. Use consecutive days if needed.
If the tillage depth is not indicated, the default depth specific to that tool will be used

TILLAGE OPERATIONS

	Rotation Year (in order)	Calendar Day (1-365)	Tool Type	Depth (optional) m	Delete All Delete?	Rotation Year (in order)	Calendar Day (1-365)	Irrigation Amount (mm)
9	1	XX	Disk, offset, heavy		☐	1	180	85
10	1	XX	Cultivator, field w/ spike points		☐			
11	1	XX	Disk, tandem secondary op.		☐			
12	1	XX	Drill or air seeder single disk openers 7-10 in spac.		☐			
13	1	XX	Fert applic. surface broadcast		☐			
14	1	XX	Harvest, grain		☐			
15					☐			
16					☐			
17					☐			
18					☐			
19					☐			
20					☐			
21					☐			
22					☐			
23					☐			
24					☐			
25					☐			
26					☐			
27					☐			

Outputs

- soil organic carbon evolution by layer / year
- estimated carbon input
- estimated humified carbon
- estimated “respired” carbon
- water balance



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C-FARM Testing: Pendleton OR summer fallow wheat

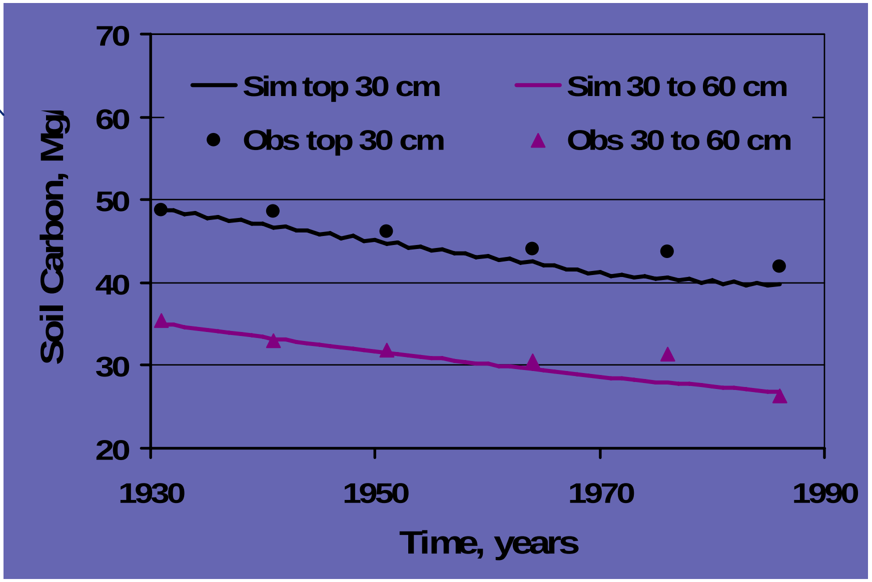
Site: gently to strongly sloping landscape
Climate: semi-arid, winter precipitation, dry summer
Soils: mixed mesic Typic Haploxeroll (Walla Walla silt loam)
Original vegetation: shrub / sagebrush – grassland

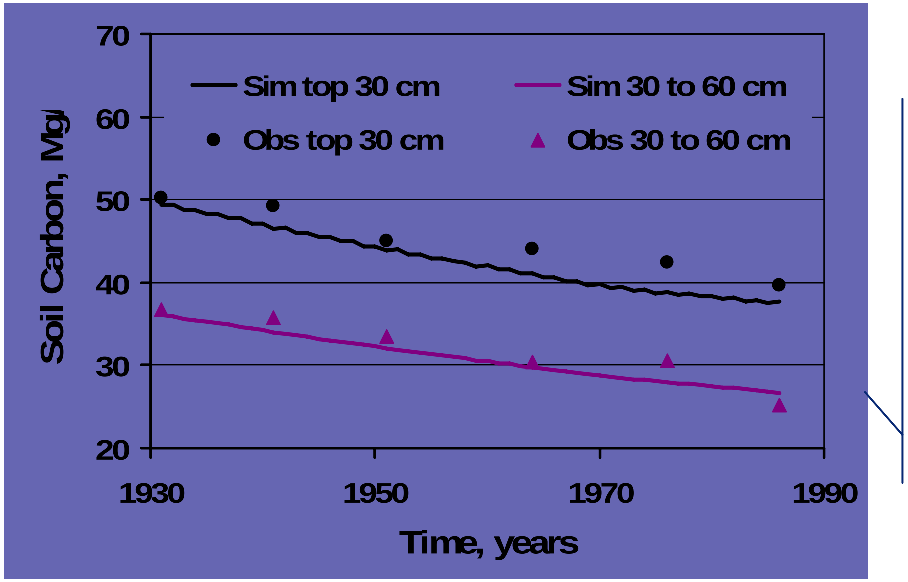
Cropping System: winter wheat / summer fallow
Seeding: October / Harvest: July
Tillage: moldboard plow in April/May, three operations to control weeds during summer, fertilizer applied 15-cm deep in October, rodweeded before seeding, and seeded 25-cm row with spacing

C-FARM Testing: Pendleton OR summer fallow wheat

Treatment: 90 kg N ha^{-1}, no residue burn

	Obs	Sim
Average yield, Mg ha^{-1}	**3.73**	**3.97**
Average aboveground carbon input, Mg ha^{-1}	**1.24**	**1.27**





Treatment: no N input, no residue burn

	Obs	Sim
Average yield, Mg ha^{-1}	**2.62**	**3.09**
Average aboveground carbon input, Mg ha^{-1}	**0.95**	**0.96**

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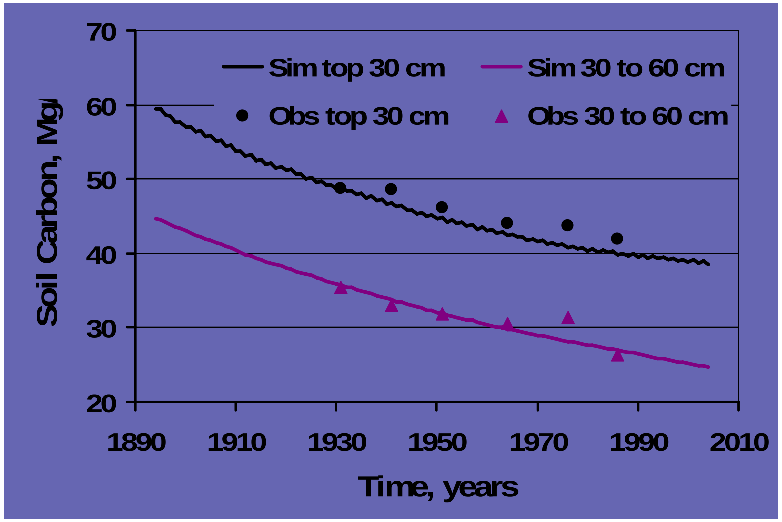
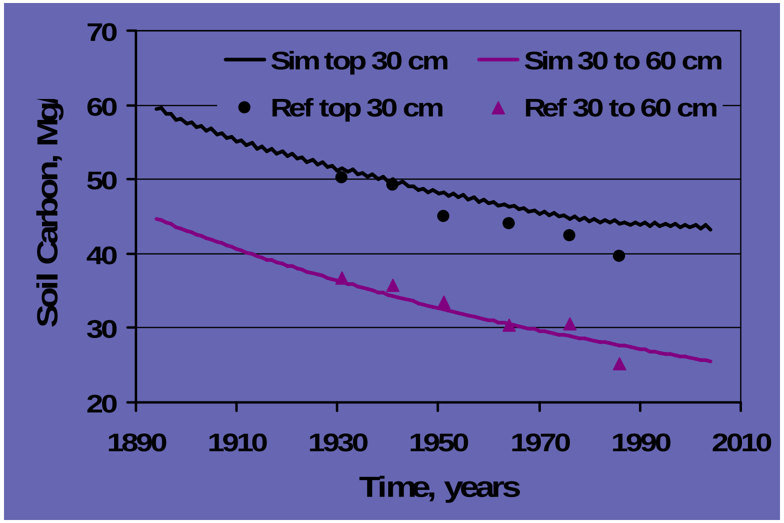
C-FARM Testing: Pendleton OR summer fallow wheat

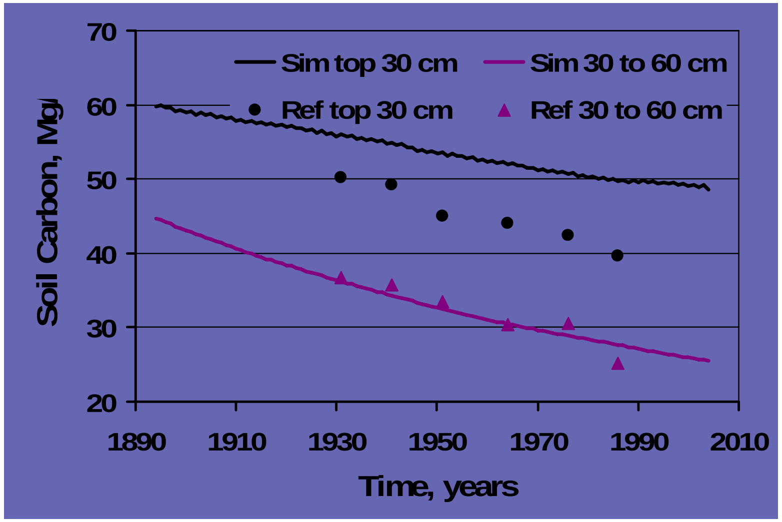
Treatment: 90 kg N ha^{-1}, no residue burn

Projected soil carbon evolution from the beginning of agriculture in the area





Likely soil carbon evolution with residue input of 1.8 Mg C ha^{-1} year^{-1} under *conventional tillage* and summer fallow



Likely soil carbon evolution with residue input of 1.8 Mg C ha^{-1} year^{-1} under *no-tillage* and summer fallow

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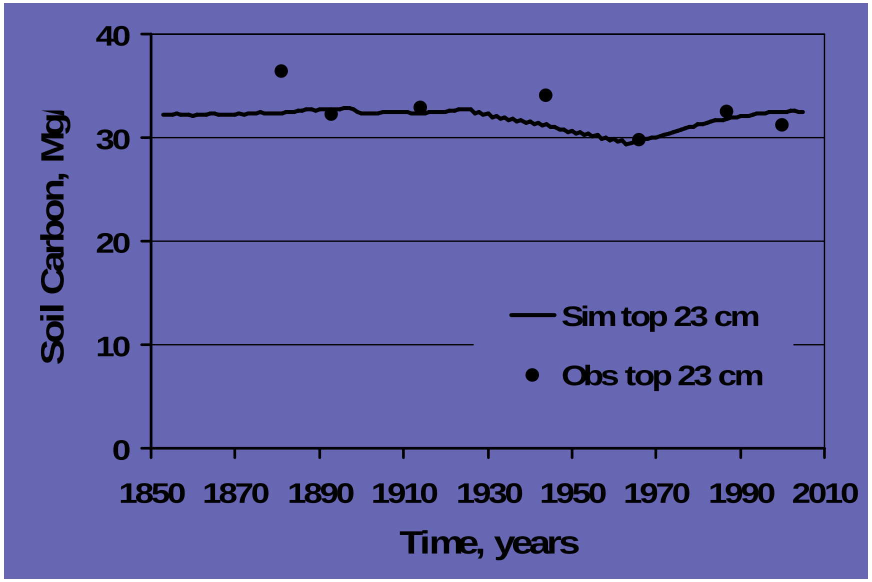
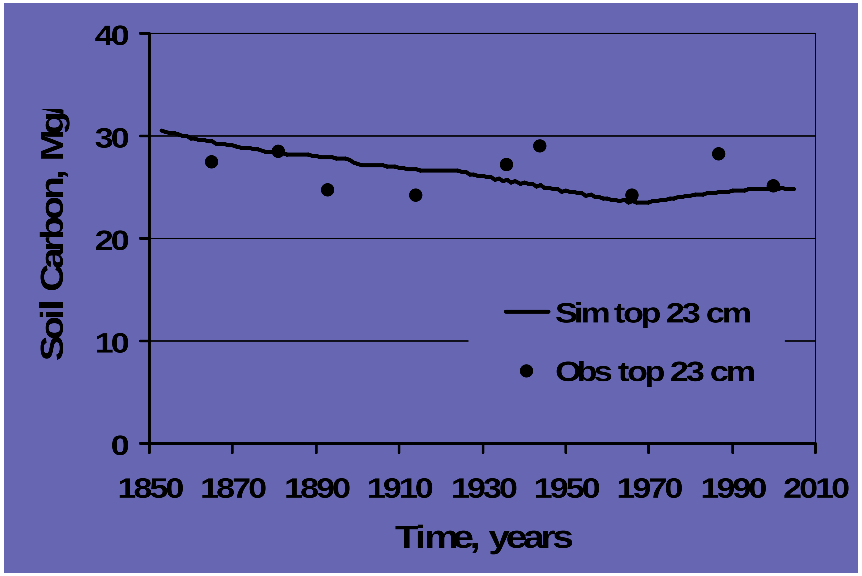
C-FARM Testing: Rothamsted UK continuous wheat

Treatment: 144 kg N ha-1, no residue burn

1853 – 1926 continuous wheat
1927 – 1962 wheat – fallow
1963 – 2005 continuous wheat

Average aboveground carbon input: approximately 2.2 Mg ha-1 year-1





Treatment: 0 kg N ha-1, no residue burn

1853 – 1926 continuous wheat
1927 – 1962 wheat – fallow
1963 – 2005 continuous wheat

Average aboveground carbon input: approximately 1.2 Mg ha-1 year-1

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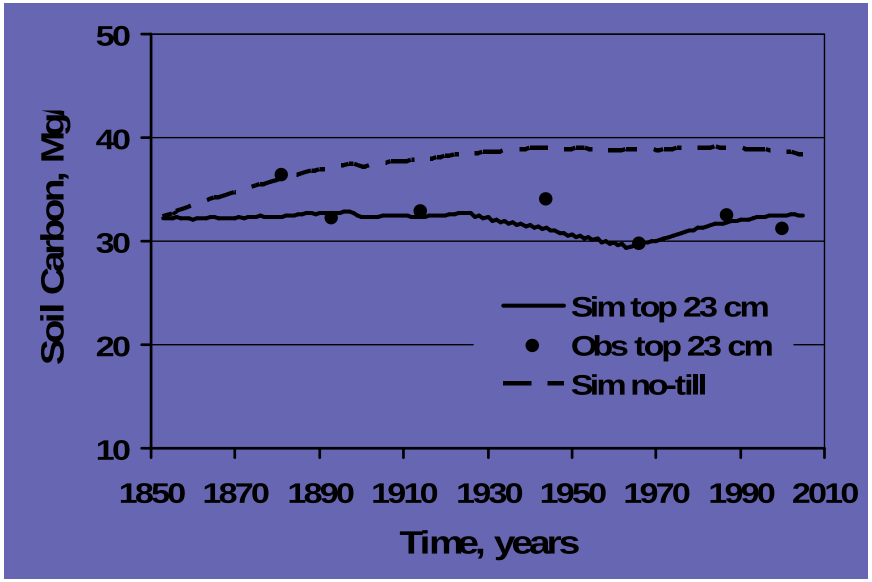
C-FARM Rothamsted: carbon input and tillage system

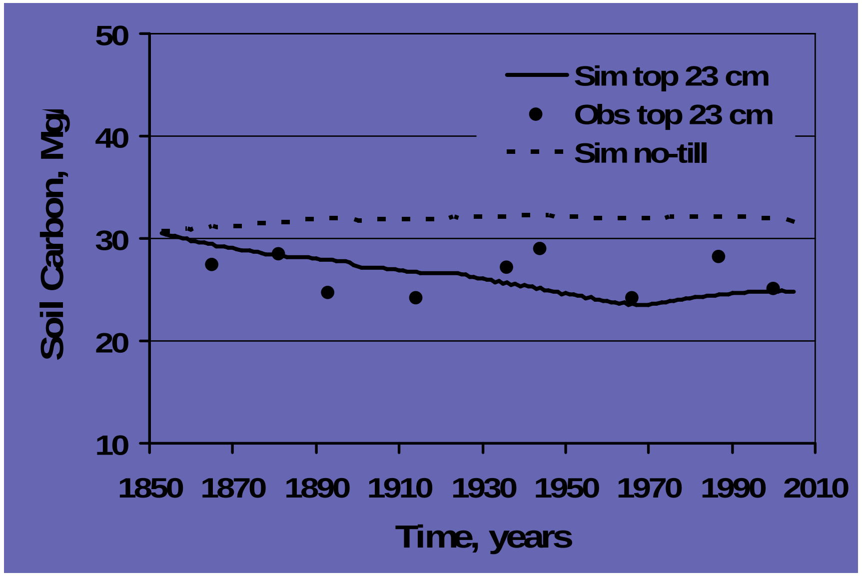
Treatment: 144 kg N ha^{-1}, no residue burn

Compare *till* vs. *no-till* (simulated) systems

Difference between systems: 6 Mg C ha^{-1}

Average aboveground carbon input:
approximately 2.2 Mg ha^{-1} $year^{-1}$





Treatment: 0 kg N ha^{-1}, no residue burn

Compare *till* vs. *no-till* (simulated) systems

Difference between systems: 7 Mg C ha^{-1}

Average aboveground carbon input:
approximately 1.2 Mg ha^{-1} $year^{-1}$

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C-FARM Concluding Remarks

- C-FARM carbon dynamic representation is scientifically sound
- The model has been successfully tested in two environments with different precipitation patterns and management systems
- The representation of tillage effects is tool-specific
- The interface and limited input requirements makes it useful for consultants and farmers, allowing a quick assessment of the soil carbon balance under different management systems

- Future developments:
  - simple N balance and estimations of denitrification and nitrous oxide emission
  - estimation of erosion

- Stand alone version + web-based simulation capabilities

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Acknowledgements

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    - the Paul Allen Family Foundation through the Climate Friendly Farming^{TM} Project of Washington State University,
    - Texas Agricultural Experiment Station

- Shawn Quisenberry provided programming support

- Request more information and a trial version:
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    - stockle@wsu.edu

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