Overview of C-Farm® simulation model

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C-Farm is a cropping systems model that simulates, in a daily time step, the soil carbon balance, water balance, crop growth and yield, and other processes. The main objective is to provide accurate simulations of soil carbon and nitrous oxide emissions when accumulated over 3 to 5 years. The inputs to the model are simple, readily accessible, or easy to define. The inputs to the model are: (1) a daily weather file that includes the location description (latitude, longitude, and elevation), (2) a soil description for the site, layer by layer, (3) a cropping sequence, (4) basic agronomic info about each crop (average planting, flowering, and maturity date), (5) a list of the tillage tools used (from a drop down menu of available tools) with the approximate date for each operation, (6) irrigation set up (automatic or fixed-date irrigation). Once the weather and soil files are available, it takes a few minutes to set up a simulation. The outputs are available in a daily or annual basis for several soil and crop variables, including crop yield, residues yield, root biomass per layer, soil carbon balance by layer, crop transpiration, soil evaporation, runoff, percolation, and other variable of interest. We are in the process of linking the carbon cycling with already developed nitrogen cycling algorithms to provide estimates of nitrous oxide emissions. The model input/output interface is user-friendly and accessible through Excel spreadsheets. A stand-alone version will substitute the current beta version in VBA.

The basic input information is relatively easy to acquire but it has to be accurate for the model to provide realistic estimates of carbon storage rates for a given site. In particular, the current soil carbon content needs to be provided as initial soil carbon is a key element affecting carbon storage rates.

Unique features of C-Farm

Three general features are unique in C-Farm:

(1) **Soil carbon cycling**: the carbon cycling subroutine has been originally developed for this model. Soil carbon is composed of a single carbon pool whose turnover rate depends on the size of the pool. The higher the carbon pool, the higher the turnover rate. Unlike C-Farm, in multi-compartment models the soil carbon pool is subdivided in several pools (typically three) each having a different turnover rate. Thus, the overall turnover rate depends on the relative amount of each pool in the total soil carbon. A weakness of the multi-pool model is the difficulty in setting up the actual turnover rate of each pool, and the implicit assumption that as a carbon pool increases or decreases in size, the turnover rate remains stable, which is likely not true. The approach taken in C-Farm to regulate the soil carbon turnover rate is much simpler, and empirical evidence suggests it is sufficient to represent carbon turnover for different soils and climates. Similarly, the humification rate (the fraction of the decomposed carbon in plant residues or manure that remains in the soil as humus after an "effective" microbial attack) is controlled by the soil carbon

level in each layer. We consider that physical protection exerts a major control on humification rate (Withmore and Hassink, 1997; Six et al, 20XX). Therefore, clay content and soil carbon content control the humification rate of each layer. These are, of course, empirical approaches to represent complex processes.

(2) **Tillage effect on carbon turnover**: Tillage accelerates the turnover rate of soil carbon; however, no robust and scientific accepted procedure has been developed to represent this effect. In C-Farm, we developed a methodology to accelerate the turnover rate which is based on soil texture, the tool performing the operation (based on information developed by USDA National Resource Conservation Service for different tools), and the number of operations.

(3) **Soil water balance**: there are multiple robust models for soil water balance. Nonetheless, and to conform to the structure of C-Farm and its computational efficiency, new sub-routines were developed for soil water redistribution (for water above field capacity) and soil water evaporation. These approaches accurately reproduce water flow in the profile and the typical two-stage soil water evaporation rate for soils with different texture, without resorting to a numerical solution to the water flow in soils.

(4) **Crop growth and radiation interception**: crop growth is driven by radiation or transpiration. The transpiration-driven growth in C-Farm follows the approach outlined in Kemanian et al. (2005), which introduced a variant to the Tanner (1981) and Tanner and Sinclair (1983) approach. This modification improved the simulation of biomass production and therefore the estimation of carbon inputs. To the best of our knowledge this is the first time it is parameterized for several crops and used in a crop simulation model.

Below are screen shots of the C-Farm model Excel Interface, which is a beta version written in Visual Basic for Applications. A standalone version in Visual Basic substituted this beta version.

Input Control Interface

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Inputs and Simulation Control Interface for C-Farm Model   Revision: 081111.01

Weatherfile Name and Location	C:\ARK Research\C-Farm\Pullman.xls

Simulation Start Year	1963	
Simulation End Year	1966	

Export to File   Import Settings   Clear All Sheets   Find Weather File   Run C-FARM

Number of Years in the Rotation 1

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Crop 1	Winter Wh	No Planting								
Crop 2										

Instructions: Crops used **must** be described   Enter "No Planting Event" for years **without** planting events

Perennial Crops will be harvested and killed 3 weeks before next crop planting unless listed earlier with a "Kill Crop" tillage operation

Describe Up to 5 Crops in Rotation	Winter Wh					Only describe a crop once
Average Seeding Date	290					Calendar Day (1-365)
Average Date of 50% Flowering	165					Calendar Day (1-365)
Average Maturity Date	200					Calendar Day (1-365)
Maximum Soil Coverage	100					100% = Full Coverage (0-100)
Maximum Rooting Depth	1.99					Lowest depth roots can reach (meters)
Average Expected Yield	3000					kg/ha
Maximum Expected Yield	4000					kg/ha
Minimum Expected Yield	2000					kg/ha
Percent of Moisture in Commercial Yield	12.0					(0-100)
Percent Standing Residue at Harvest	50.0					(0-100)
Percent of Residue Removed	0.0					(0-100)
Harvest Timing as a Percentage of Maturity						(0-100) Perennials **only**

Use hourly water infiltration	✓	Needed for estimation of N2O losses

Daily Crop Outputs	✓	Last Imported From:
Daily Soil Outputs	✓	Last Exported To: C:\ARK Research\C-Farm\EEMAC Copy of C-FARM Nov 11 v1 daily.xls
Daily Weather Outputs	✓	
Annual Soil Outputs	✓	Last Import Date Friday, November 28, 2008 Time 9:49:29 AM
Annual Soil (Profile) Outputs	✓	Last Export Date Friday, November 28, 2008 Time 9:47:58 AM
Season Outputs	✓	Last Simulation Date Wednesday, December 17, 2008 Time 11:30:19 AM

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Management Control Interface

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TILLAGE OPERATIONS					IRRIGATION OPERATIONS				

Rotation Year	Calendar Day	Tool Type	Depth (optional) m	Delete?	Rotation Year	Calendar Day	Irrigation Amount (mm)	Delete?	
1	230	Plow, disk	0.23	☐		1	100	☐	
1	250	Disk, tandem secondary op.		☐		2	100	☐	
1	260	Cultivator, field w/ spike points		☐		3	100	☐	
1	270	Harrow, spike tooth		☐		4	100	☐	
1	290	Fert. applic. anhyd knife 30 in		☐		5	100	☐	
1	300	Drill, heavy, direct seed, dbl disk opnr		☐		6	100	☐	
	100	Cultivator, field 6-12 in sweeps		☐		7	100	☐	
	180	Cultivator, field 6-12 in sweeps		☐		8	100	☐	
				☐		9	100	☐	

Sort Tillage Operations   Delete All
Sort Irrigation Operations   Delete All

Fixed Irrigation schedule? ☐
Irrigation operations to the left will not be used
Automatic Irrigation? ☐
Parameters listed below will not be used
Allowable plant available water depletion (0-1)
Last soil layer number to monitor for depletion
Day of the year to begin automatic irrigation
Day of the year to end automatic irrigation

Cultipacker , Roller
Cultivator, field 6-12 in sweeps
Cultivator, field w/ spike points
Cultivator, hipper, disk hiller on beds
Cultivator, off bar w/disk hillers on beds
Disk, offset, heavy
Disk, offset, heavy >12 in depth
Disk, tandem heavy primary op.
Disk, tandem secondary op.
Drill or air seeder double disk openers 7-10 in spac.

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Sample of Output – Annual summary per soil layer

A1   Soil Carbon Balance

Soil Carbon Balance

| | | | | | | | (based on computed yield) | | | if + then C gain |
| | | | | | | | | | | if - then C loss |

Year & Layer #	Layer Thickness m	Clay %	Composite Decomposition Factor (unitless)	Annual Apparent Soil Carbon Decomposition Rate 1/year	Initial Soil Carbon Mg/ha	Apparent Soil Carbon Decomposition Mg C / year	Carbon Input per Layer Mg C / year	Humified Carbon per Layer Mg C / year	Humification Coefficient	Annual Soil Carbon Balance Mg C / ha
1963										
1	0.05	22	0.060	0.003	6.05	0.017	0.000	0.000	0.00	-0.017
2	0.05	22	0.102	0.005	6.05	0.031	0.000	0.000	0.00	-0.031
3	0.13	22	0.199	0.008	15.65	0.118	0.000	0.000	0.00	-0.118
4	0.10	22	0.198	0.004	5.18	0.021	0.000	0.000	0.00	-0.021
5	0.10	22	0.191	0.003	4.02	0.014	0.000	0.000	0.00	-0.014
6	0.10	22	0.183	0.003	2.63	0.007	0.000	0.000	0.00	-0.007
7	0.10	22	0.178	0.002	1.85	0.004	0.000	0.000	0.00	-0.004
8	0.20	22	0.171	0.002	2.27	0.004	0.000	0.000	0.00	-0.004
9	0.50	22	0.163	0.001	3.29	0.004	0.000	0.000	0.00	-0.004
10	0.50	22	0.155	0.001	2.19	0.002	0.000	0.000	0.00	-0.002
11	0.50	22	0.150	0.001	1.43	0.001	0.000	0.000	0.00	-0.001
12	0.50	22	0.147	0.001	1.22	0.001	0.000	0.000	0.00	-0.001
1964										
1	0.05	22	0.113	0.005	6.20	0.032	1.955	0.295	0.00	0.263
2	0.05	22	0.133	0.006	6.19	0.039	1.094	0.157	0.00	0.118
3	0.13	22	0.108	0.004	15.90	0.066	1.555	0.226	0.00	0.160
4	0.10	22	0.047	0.001	5.18	0.005	0.052	0.005	0.00	0.000
5	0.10	22	0.046	0.001	4.02	0.003	0.030	0.003	0.00	0.000
6	0.10	22	0.044	0.001	2.63	0.002	0.015	0.001	0.00	0.000
7	0.10	22	0.044	0.001	1.85	0.001	0.010	0.001	0.00	0.000
8	0.20	22	0.044	0.000	2.27	0.001	0.013	0.001	0.00	0.000
9	0.50	22	0.048	0.000	3.29	0.001	0.027	0.003	0.00	0.001
10	0.50	22	0.127	0.001	2.20	0.002	0.100	0.011	0.00	0.009
11	0.50	22	0.122	0.001	1.44	0.001	0.098	0.010	0.00	0.010
12	0.50	22	0.120	0.001	1.22	0.001	0.000	0.000	0.00	-0.001
1965										
1	0.05	22	0.085	0.004	6.31	0.026	1.761	0.266	0.00	0.241
2	0.05	22	0.073	0.003	6.29	0.020	0.714	0.106	0.00	0.086
3	0.13	22	0.060	0.002	16.07	0.032	0.567	0.085	0.00	0.052
4	0.10	22	0.048	0.001	5.20	0.005	0.176	0.018	0.00	0.013
5	0.10	22	0.047	0.001	4.02	0.003	0.105	0.011	0.00	0.008
6	0.10	22	0.046	0.001	2.64	0.002	0.067	0.007	0.00	0.005
7	0.10	22	0.046	0.001	1.86	0.001	0.044	0.005	0.00	0.004
8	0.20	22	0.046	0.000	2.28	0.001	0.057	0.006	0.00	0.005
9	0.50	22	0.045	0.000	3.30	0.001	0.089	0.009	0.00	0.008
10	0.50	22	0.062	0.000	2.20	0.001	0.052	0.006	0.00	0.005
11	0.50	22	0.156	0.001	1.45	0.001	0.112	0.013	0.00	0.012
12	0.50	22	0.154	0.001	1.22	0.001	0.000	0.000	0.00	-0.001
1966										
1	0.05	22	0.060	0.003	6.39	0.022	1.156	0.178	0.00	0.156
2	0.05	22	0.088	0.005	6.40	0.031	1.340	0.201	0.00	0.170
3	0.13	22	0.030	0.001	16.36	0.019	1.274	0.182	0.00	0.163
4	0.10	22	0.029	0.001	5.21	0.003	0.169	0.018	0.00	0.015
5	0.10	22	0.027	0.000	4.03	0.002	0.096	0.010	0.00	0.008
	0.10	22	0.025	0.000	2.64	0.001	0.056	0.006	0.00	0.005

Field Inputs / Management / Soil / Settings / SoilCarbonTotals / SoilCarbonEvolution / DailyOutputs \ SoilOutputs / ProfileOutputs / SeasonOutput /

Sample of Output – Soil carbon evolution

C9   52.83072054159919

Soil Carbon Evolution

Carbon Mass (Mg C / ha)

Year	Profile	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 9	Layer 10	Layer 11	Layer 12	Layer 13
1963	51.83024	6.047554	6.049823	15.65468	5.182389	4.015772	2.634934	1.852861	2.272752	3.28615	2.188698	1.427318	1.217316	
1964	52.39097	6.200916	6.192616	15.8999	5.182437	4.015397	2.634743	1.852885	2.273118	3.28759	2.197714	1.436955	1.216689	
1965	52.83072	6.314384	6.293282	16.06695	5.195854	4.022982	2.639997	1.856478	2.278034	3.295846	2.202469	1.448559	1.215883	
1966	53.36532	6.392946	6.404886	16.3661	5.210704	4.031181	2.644946	1.85883	2.280607	3.29964	2.205338	1.455067	1.215073	
1967	53.97358	6.514936	6.506236	16.68613	5.227359	4.040218	2.650879	1.863494	2.287051	3.307269	2.210771	1.465032	1.214212	
1968	54.68879	6.643068	6.649415	17.06167	5.250546	4.051425	2.658029	1.86814	2.292676	3.313259	2.215327	1.472901	1.213426	
1969	55.08828	6.735												
1970	55.66851	6.8455												
1971	56.47501	6.9879												
1972	57.01294	7.1154												
1973	57.40207	7.1463												
1974	57.8244	7.2143												
1975	58.91554	7.4405												
1976	59.42013	7.5698												
1977	59.77241	7.57												
1978	60.15467	7.680												
1979	60.75894	7.7855												
1980	61.26225	7.908												
1981	61.95805	8.0304												
1982	62.70669	8.1990												
1983	63.53993	8.3444												
1984	64.0175	8.4240												
1985	64.65364	8.526												
1986	65.15174	8.6100												
1987	65.41152	8.636												
1988	65.84926	8.7440												
1989	66.56161	8.8689												
1990	67.0962	8.9966												
1991	67.54063	9.0536												
1992	68.31173	9.2019												
1993	68.46789	9.2102												
1994	68.74694	9.2526												
1995	69.4623	9.4283												
1996	69.97148	9.525												
1997	70.73753	9.685												
1998	71.3053	9.7726												
1999	71.96974	9.8856												
2000	72.46112	10.01057	10.02213	25.70128	5.799177	4.384013	2.877825	2.019556	2.497932	3.666238	2.531644	1.761392	1.189369	
2001	72.88316	10.05275	10.06804	25.97219	5.81872	4.395206	2.884977	2.023094	2.500929	3.670985	2.537544	1.770146	1.188595	
2002	73.22764	10.12403	10.12327	26.12479	5.832478	4.403652	2.89073	2.027869	2.508368	3.681675	2.544638	1.77823	1.187915	
2003	73.92143	10.26866	10.28284	26.43223	5.852256	4.415098	2.897855	2.033204	2.515921	3.692779	2.554855	1.788724	1.187006	

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