Sustainable, environmentally friendly, and cost-effective production of energy efficient biofuels in California

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General Background

Two main areas of intensive research needs:

1) the economically and environmentally sound production of biomass
2) the economically and environmentally sound conversion of biomass to energy.

We need to address the first through an interdisciplinary approach based on

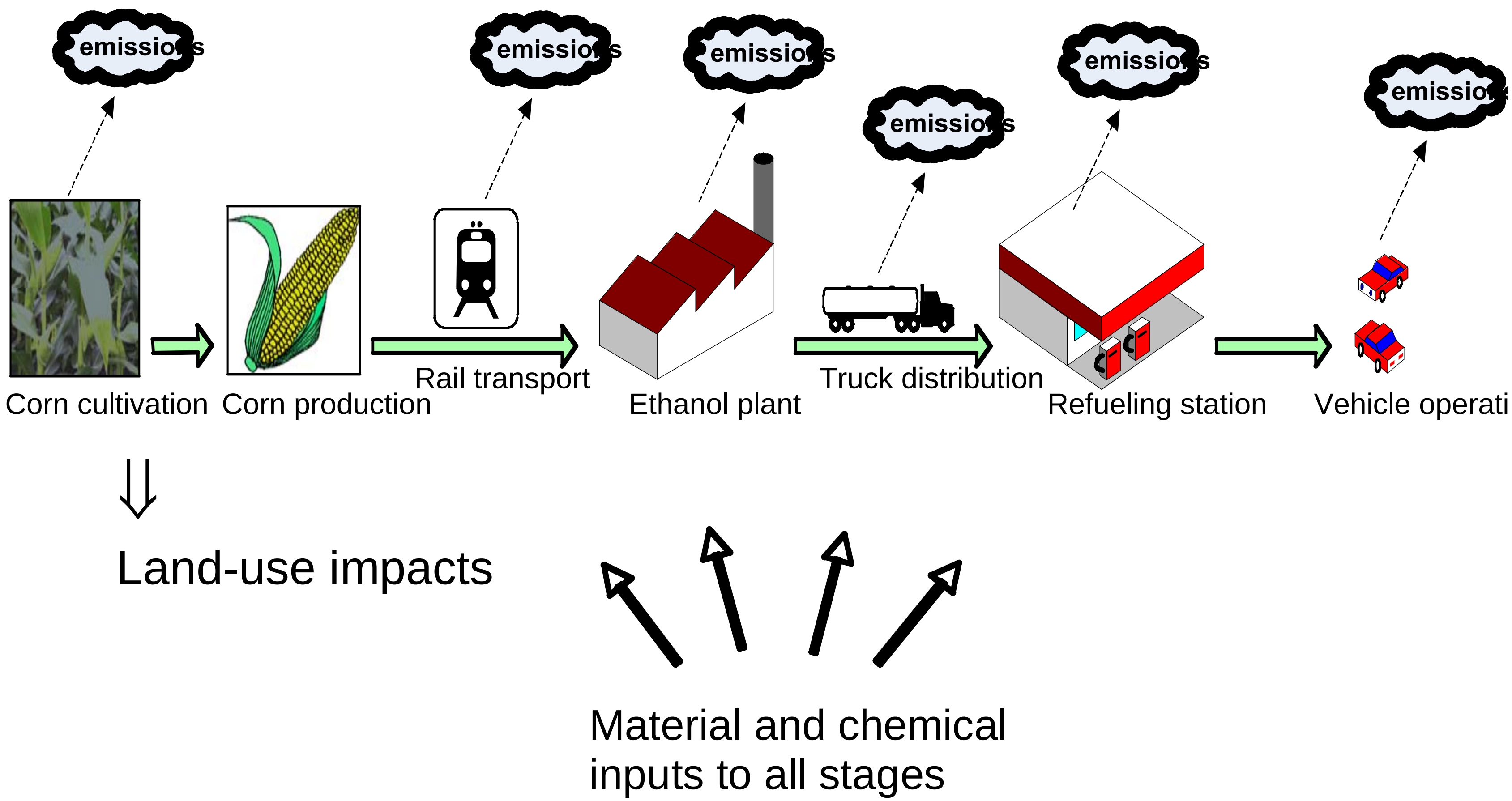
- basic plant sciences
- biogeochemical modeling
- economic principles
- life cycle analyses.

To ensure a comprehensive assessment of the long-term potential for biomass production under California conditions that will be

- energy efficient,
- environmentally acceptable
- sustainable
- cost-effective

from the farmer's field to the gas pump.

Corn-to-ethanol fuel pathway



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Objectives

1) determine short- and long-term biomass production potentials at 5 field experiments representing the different bioenergy sources and types of land in California

2) use published data on biomass production and data generated from the 5 experiments to calibrate and validate a biogeochemical model (DAYCENT)

3) integrate the biogeochemical model with economic analyses predict the biophysical and economic sustainability of different biomass production scenarios

4) employ the model to investigate the spatio-temporal variation of biomass production and greenhouse gas emissions at the regional scale and construct a "meta model"

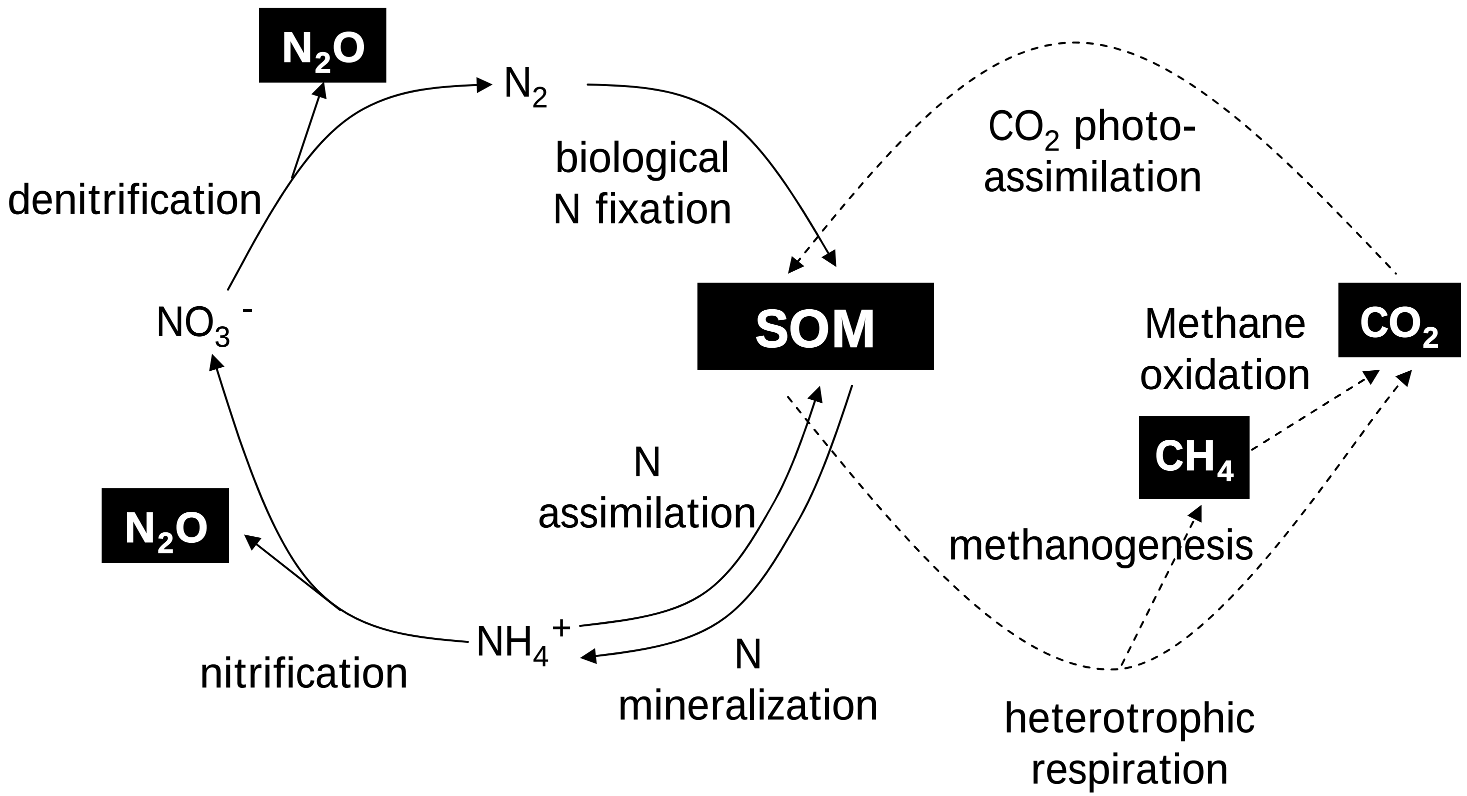
5) integrate the “meta-model” into life cycle analyses to assess the overall energy efficiency of biofuels compared to other fuels.

Full on-farm GHG budget needs to be considered:

- Crop yield
- Carbon sequestration
- Nitrous oxide emission
- CH_4 adsorption
- Inputs required for farm operations

All of the above dependent on chosen <u>crop production practices and system</u> in a <u>specific environment</u> (i.e. climate, soil type, etc) and has <u>a price</u>

Nitrogen and carbon cycles



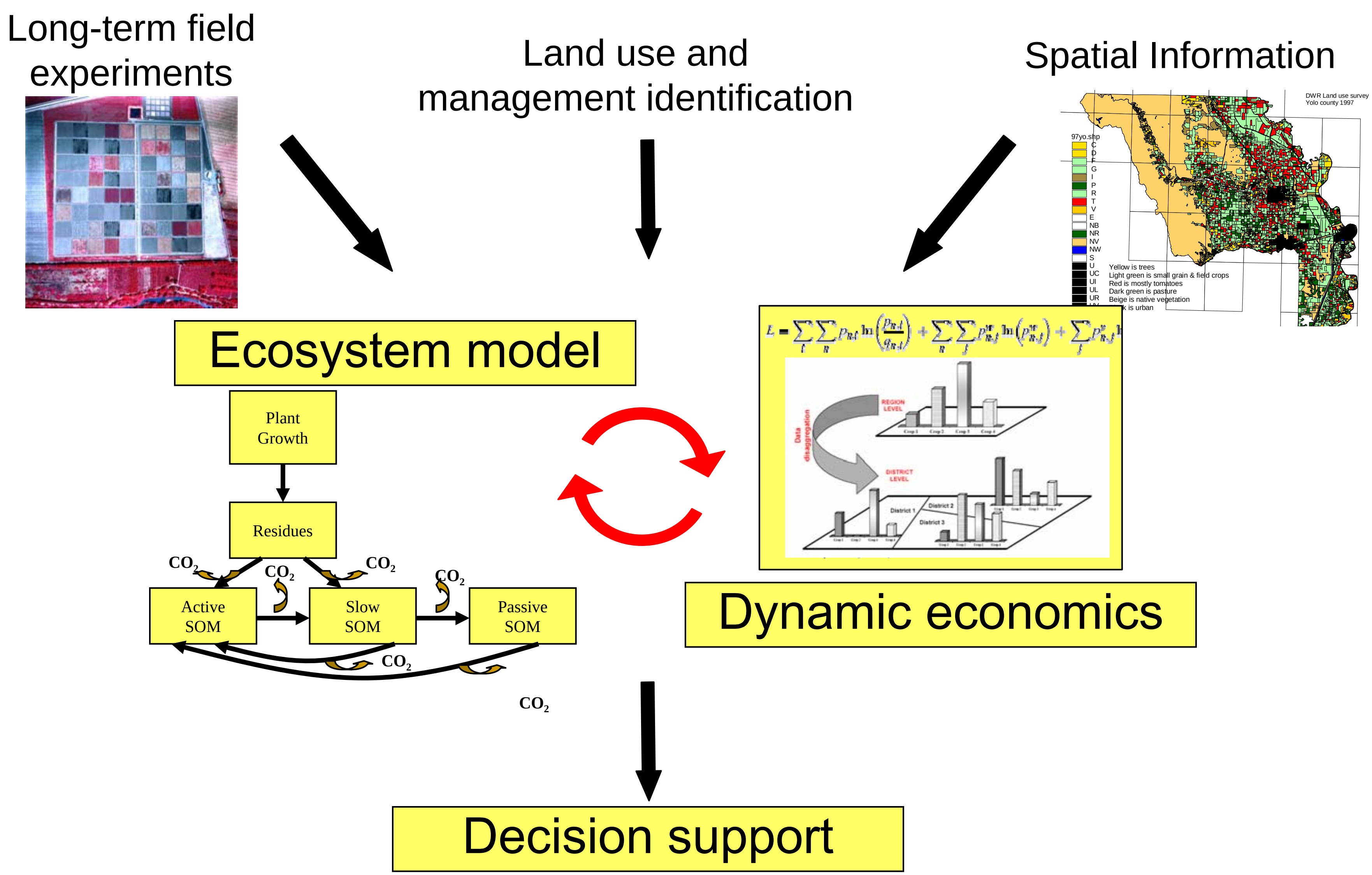
Source: Oenema *et al*. (2001)

Calculation of net GHG emissions

- Carbon dioxide equivalents
  - Calculated based on the mass and the global warming potential (GWP) of the GHGs

Gas	GWP (100-yr horizon)
CO_2	1
CH_4	23
N_2O	296

Integration of models



DayCent model

- A daily version plant-soil ecosystem model
  - Simulates plant production, soil nutrient dynamics, and soil water and temperature
  - simulates GHG fluxes (CO_2, CH_4 and N_2O)

Model structure - C Submodel

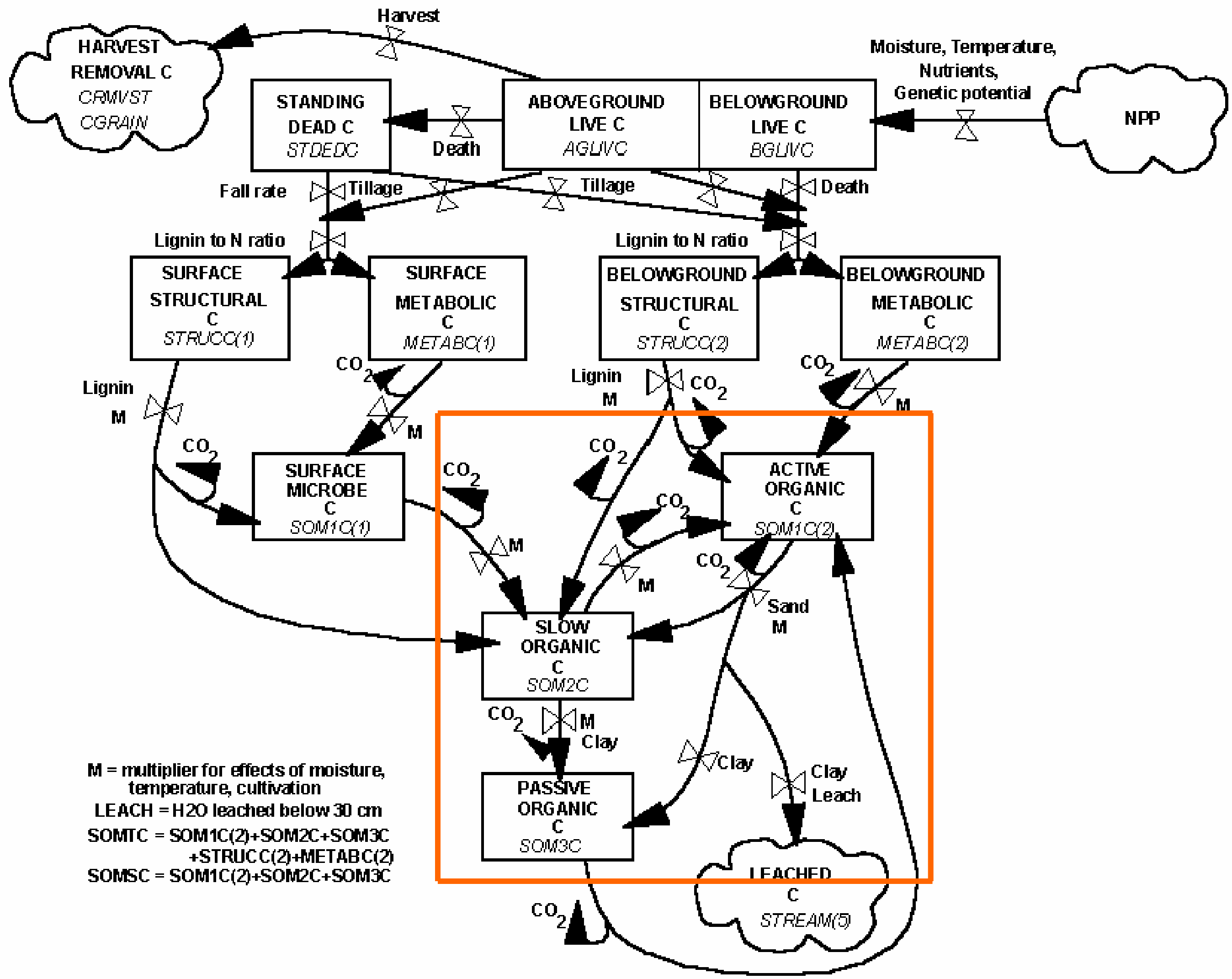
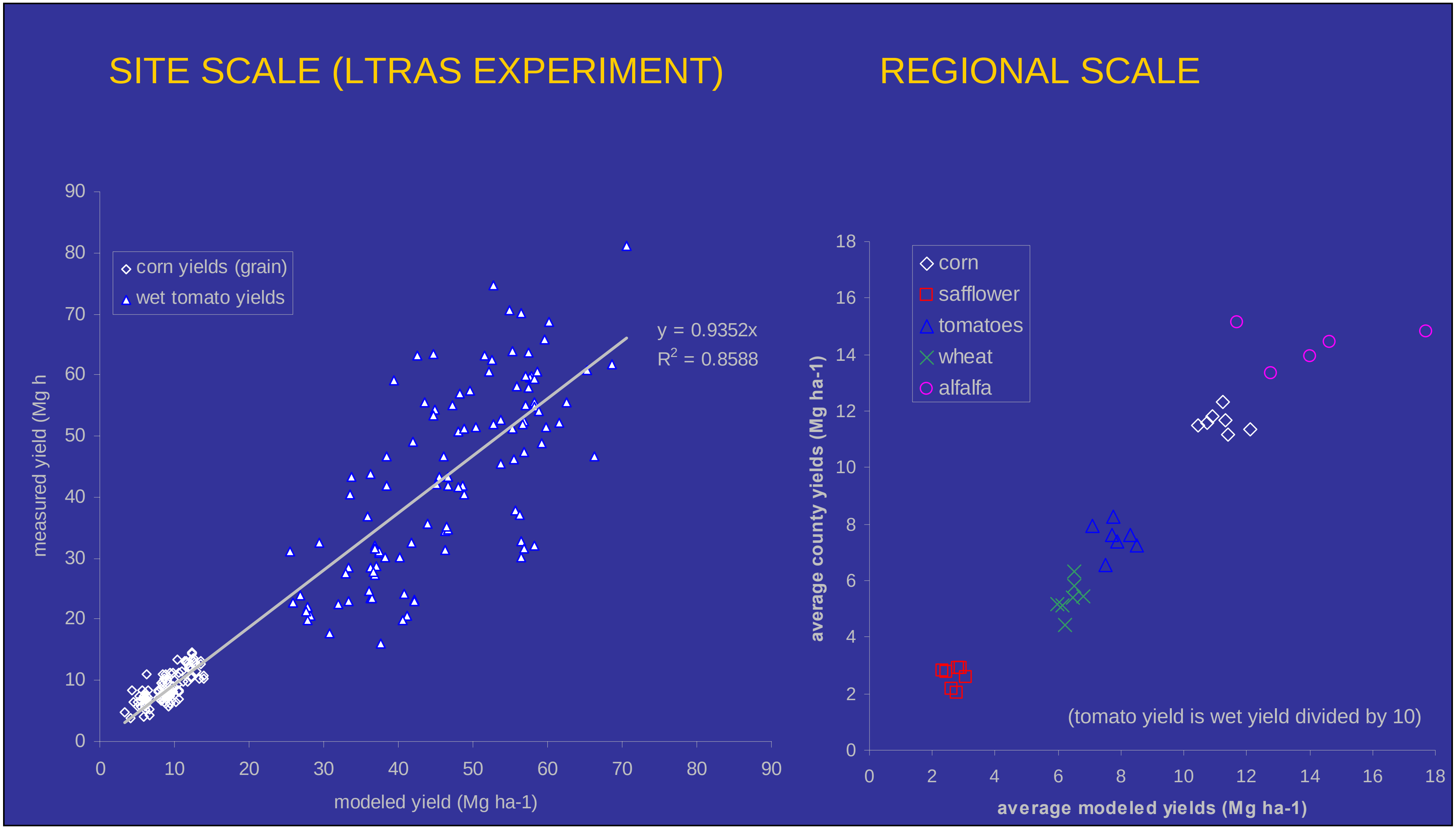


Figure 3-1: The pools and flows of carbon in the CENTURY model. The diagram shows the major factors which control the flows.

Source:

Parton et al. 1987

Validation: current yields



Yield changes

Fertilizer	Cover crop	Alfalfa	Corn	Rice	Safflower	Sunflower	Tomato	Wheat
mineral, 75%	no	0.35	-0.20	-0.03	-12.9	-0.04	-4.00	-0.10
mineral	no	0.01	3.10	0.14	0.07	0.16	-0.75	0.05
mineral	yes	0.30	-0.49	-0.44	4.48	-0.92	-1.31	0.10
mineral	yes	0.30	-0.58	-0.43	4.34	-1.02	-1.33	0.12
manure	no	0.28	-1.88	-0.50	-3.64	-0.09	-1.72	-4.13
manure	no	0.30	-2.99	-4.66	-0.60	-1.28	-4.39	-2.60
manure	yes	0.28	-2.45	-4.37	1.61	-0.97	-3.59	-2.37
manure	yes	0.40	-3.28	-0.66	-6.27	0.02	-2.63	-1.94

Management changes

Tillage	Fertilizer	Cover crop	GWP (Mg CO_2-eq ha^{-1} yr^{-1})		ΔSOC ($kg\ C\ ha^{-1}\ yr^{-1}$)		N_2O ($kg\ N\ ha^{-1}\ yr^{-1}$)	
			Sacramento Valley					
convent.	mineral, 75%	no	-0.89	± 0.76	-2	± 16	-1.92	± 1.59
conserv.	mineral	no	-0.68	± 0.36	103	± 34	-0.64	± 0.56
convent.	mineral	yes	-1.36	± 0.89	310	± 180	-0.48	± 0.94
conserv.	mineral	yes	-1.37	± 0.88	312	± 178	-0.48	± 0.94
convent.	Organic	no	-1.16	± 0.78	158	± 63	-1.23	± 1.51
conserv.	Organic	no	-1.94	± 1.03	288	± 88	-1.89	± 1.86
convent.	Organic	yes	-2.60	± 1.87	405	± 212	-2.38	± 2.81
conserv.	Organic	yes	-3.29	± 2.07	532	± 246	-2.86	± 2.98
			San Joaquin Valley					
convent.	mineral, 75%	no	-0.61	± 0.58	-4	± 14	-1.33	± 1.24
conserv.	mineral	no	-0.57	± 0.33	81	± 35	-0.59	± 0.55
convent.	mineral	yes	-1.35	± 1.07	284	± 170	-0.66	± 1.36
conserv.	mineral	yes	-1.38	± 1.08	287	± 169	-0.68	± 1.39
convent.	Organic	no	-0.49	± 0.89	154	± 54	0.16	± 1.96
conserv.	Organic	no	-1.14	± 0.90	255	± 79	-0.43	± 1.82
convent.	Organic	yes	-1.87	± 1.41	395	± 203	-0.89	± 2.41
conserv.	Organic	yes	-2.45	± 1.52	498	± 235	-1.32	± 2.41

Modeling Biofuel Cropping Systems

- Calibrate and validate DayCent for local conditions
- Simulate gas exchanges for different cropping systems, soils, climates and site management options
- Predict GHG fluxes at the plot and regional scale

Database for biofuel systems

- Species
  - C4 plants
    - Switchtgrass *(Panicum virgatum)*
    - Miscanthus *(Miscanthus giganteous)*
    - Bermudagrass *(Cynodon dactylon)*
    - Rhodesgrass *(Chloris gayana)*
    - Elephantgrass *(Pennisetum purpureum)*
  - C3 plants
    - Tall Fescue *(Fescuta arundinacea)*
    - Jose Tall Wheatgrass *(Agropirum elongatum)*
    - Alfalfa *(Medicago sativa)*

Preliminary results on biofuels

<table>
<tr><td colspan="3">Location</td><td>Rock Springs, PA</td><td>Davis, CA</td></tr>
<tr><td rowspan="5">Soil Property</td><td colspan="2">Soil Type</td><td>Hagerstown silt loam</td><td>Yolo silt loam</td></tr>
<tr><td rowspan="4">Soil Texture</td><td>Sand (%)</td><td>28.33</td><td>9.96</td></tr>
<tr><td>Silt (%)</td><td>33.44</td><td>65.40</td></tr>
<tr><td>Clay (%)</td><td>38.23</td><td>24.64</td></tr>
<tr><td>Organic Matter (%)</td><td>0.77</td><td>1.30</td></tr>
<tr><td rowspan="2">Management Events</td><td colspan="2">Fertilization ($kg\ N\ ha^{-1}\ yr^{-1}$)</td><td>56</td><td>56</td></tr>
<tr><td colspan="2">Harvesting</td><td>Every fall, 2001-2003</td><td>Fall, 2007</td></tr>
</table>

Preliminary results

Location	Year	Field trail yield (kg DM ha^{-1})	Simulated yield (kg DM ha^{-1})	% deviation
Rock Springs, PA	2001	6690	6304	-5.8%
	2002	6950	6857	-1.3%
	2003	7020	6721	-4.3%
Davis, CA	2007	10742	8666	-19.3%

Simulated GHG emissions

Location	year	N_2O emission (kg N_2O ha^{-1} yr^{-1})	CH_4 uptake (kg CH_4 ha^{-1} yr^{-1})	CO_2 emission (kg CO_2 ha^{-1} yr^{-1})	GWP (100-yr horizon) (kg ha^{-1} yr^{-1})
Rock Spring, PA	2001	4.09	1.14	776	2013
	2002	4.90	1.12	811	2287
	2003	6.13	0.91	748	2584
Davis, CA	2007	16.58	1.47	1298	6239

Thank you!

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