Integrated assessment of the biophysical and economic potential for greenhouse gas mitigation in CA agricultural soils

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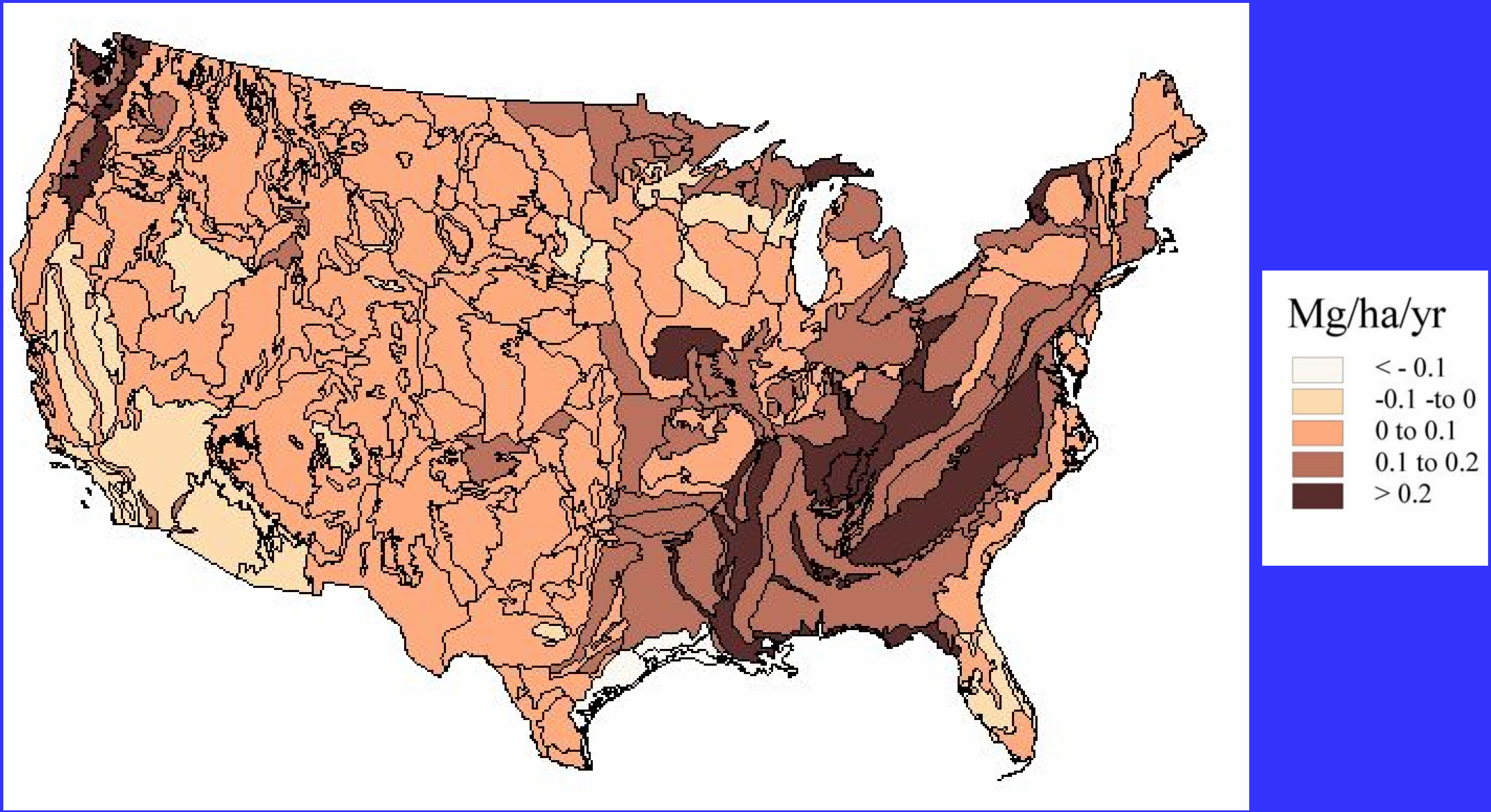
US National Carbon Inventory

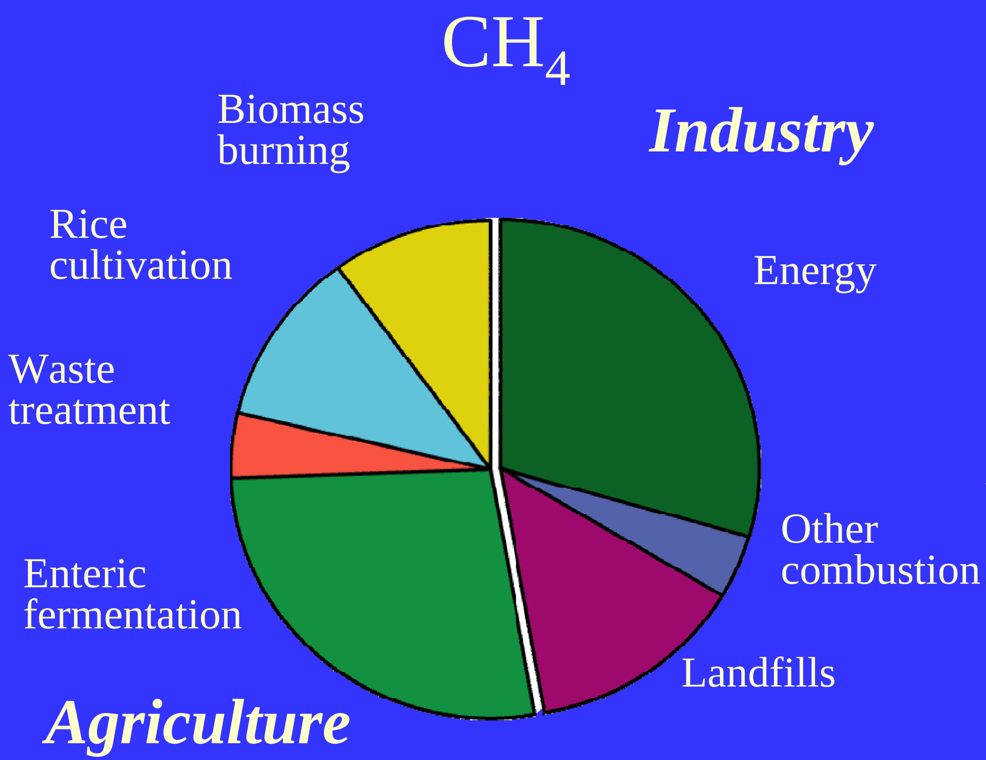


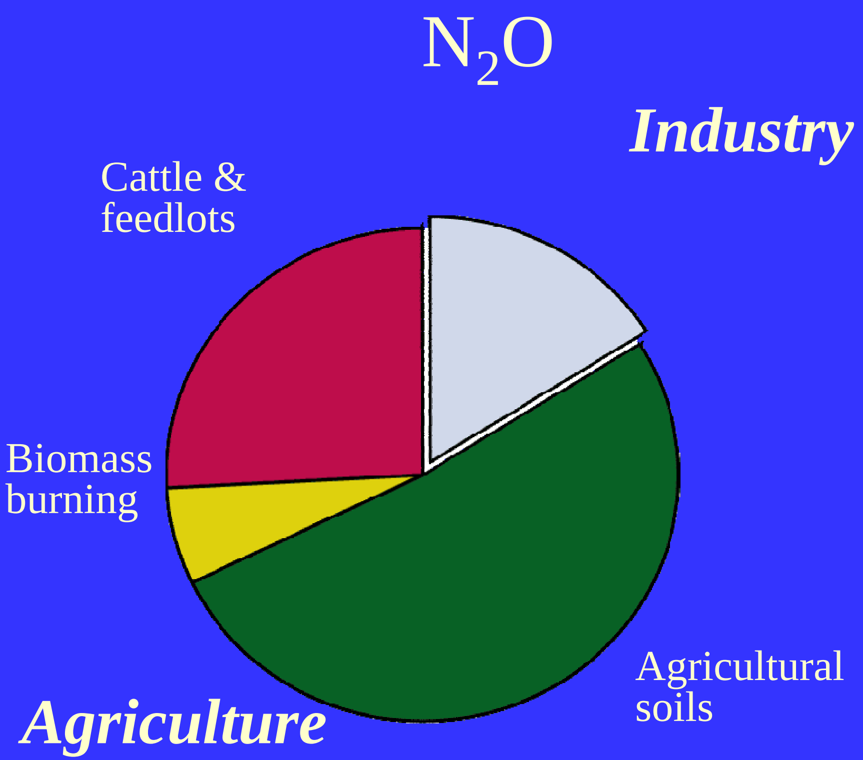
Mineral soils are sequestering ca. 15 million T C/yr

Slide courtesy of Ogle

Anthropogenic Sources of Methane and Nitrous Oxide Globally

Slide courtesy of
Robertson





Total Impact 2.0 Pg C_{equiv} 1.2 Pg C_{equiv}

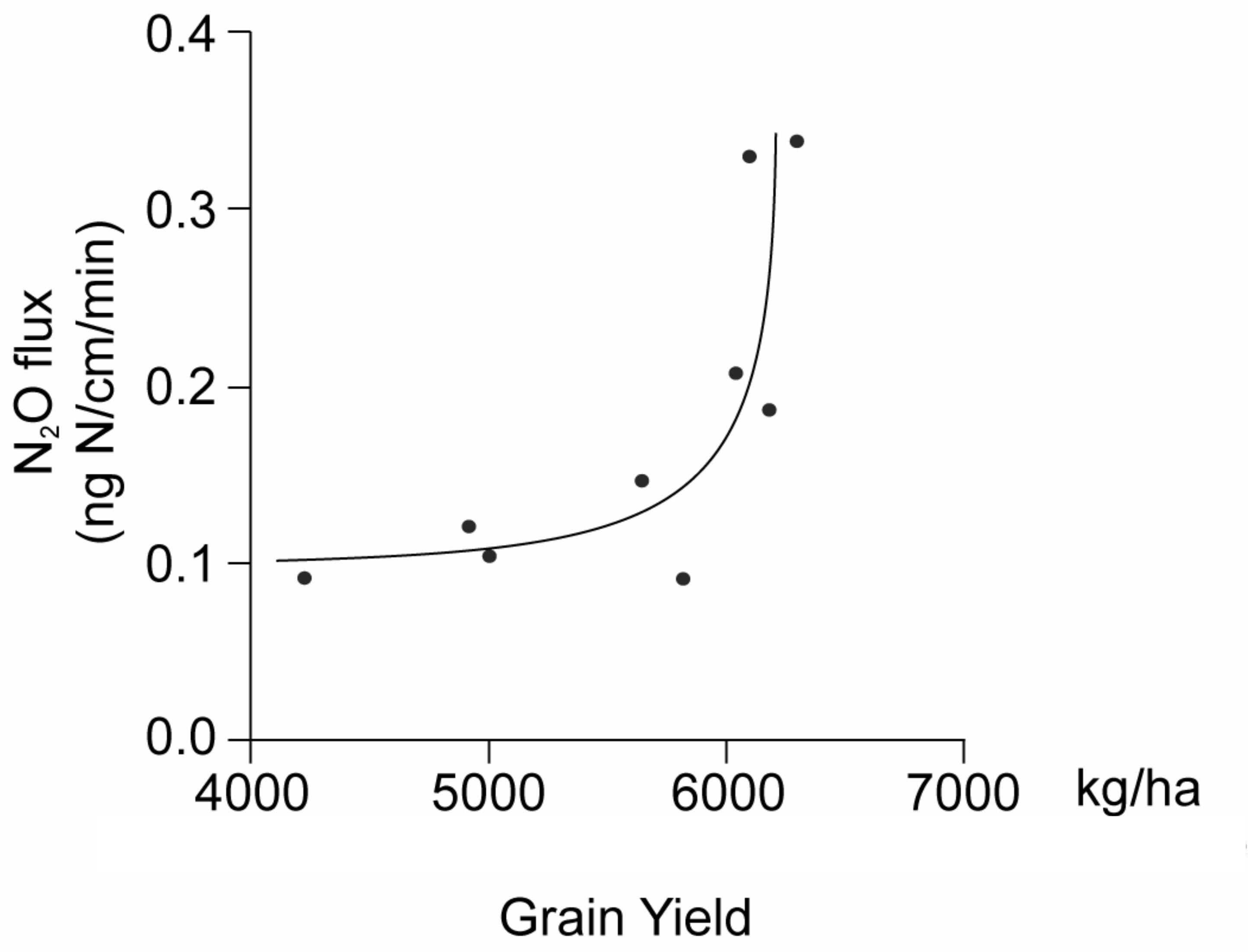
(compare to fossil fuel CO_2 loading = 3.3 Pg C per year)

(compare to soil C sequestration of 0.3-0.5 Pg C per year)

IPCC 2001; Robertson 2004

N_2O - Yield Threshold

Slide courtesy of Robertson



McSwiney and Robertson, submitted

Scoping study of Li and Salas (2004)

- Preliminary study of the potential for C sequestration and GHG mitigation in CA
- Large uncertainties in soil C dynamics due to uncertain initial conditions and crop residue management
- Recommendations
  - Improve spatial data on management practices including residue and manure management
  - Use updated SSURGO soils data base
  - Verify DNDC model for CA conditions
  - Evaluate alternative mitigation scenarios such as tillage, cover crops, optimal fertilization practices

Overall Objective

- Assess the biophysical potential and economic feasibility for soil C sequestration and reduction of trace gas emissions in CA agricultural soils

-Accomplished through integration of spatial databases on environmental factors and land use data with ecosystem simulations models and economic analyses

Specific Objectives

1. Test DAYCENT and DNDC for simulations of crop productivity, C storage, and trace gas emissions for CA agroecosystems.
2. Integrate the ecosystems models with an economic model at the field and county level.
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Modeling

Obtain ecosystem models, determine input data required, evaluate inherent limitations

Find experiments with high detail
- Complete management details
- Yields
- SOC (and N_2O if possible)

(under a range of crops, soils and management)

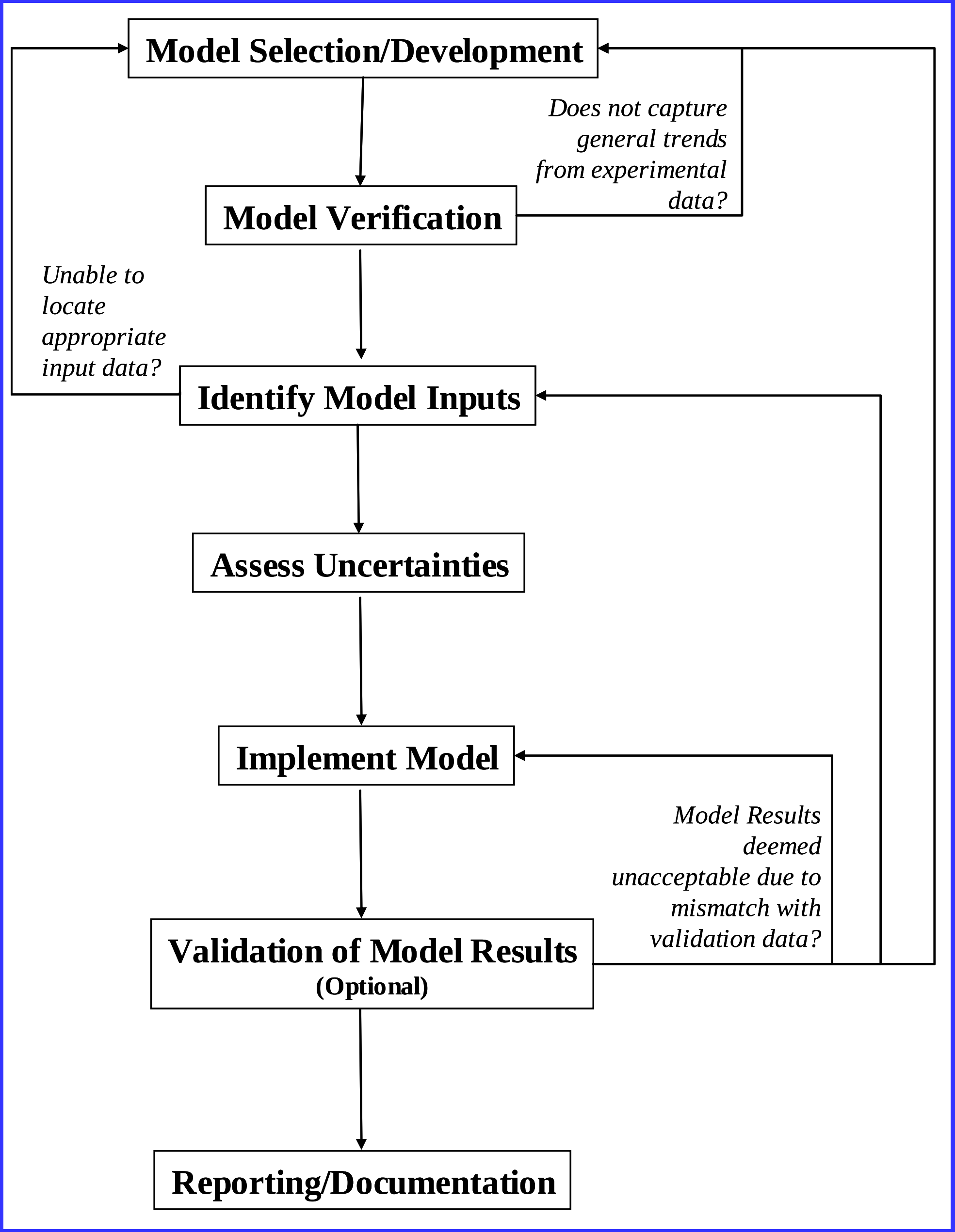
Simulate these experiments and see if yields are okay. Tune crop parameters till good fit to local genotypes.

Verify SOC and N_2O against any measurements.

Keep an eye on the big picture!

If it looks all-right, then we can simulate a variety of management options across a range of soil and climate, and use in a regional economic model

Steps in Dynamic Model-Based Approach



Model Selection/Development

Does not capture general trends from experimental data?

Model Verification

Unable to locate appropriate input data?

Identify Model Inputs

Assess Uncertainties

Implement Model

Model Results deemed unacceptable due to mismatch with validation data?

Validation of Model Results
(Optional)

Reporting/Documentation

Slide courtesy of Ogle

Two ecosystem models

DNDC	DayCent
Started as an N model requiring quick dynamics.	Started as a C model using slow dynamics.
Added crop and soil C pools	Added daily water and N model
Legacy: Only 1 year rotations possible Less legit for slow C dynamics	Legacy: More flexibility in crop systems Less legit for fast N dynamics

Major ecosystem processes to check

Crop Yield

Accurate simulated crop yield is critical because it is used in the economic model, and is the main part of the C cycle.

Soil Carbon

Accurately modeled changes in soil carbon stocks are key

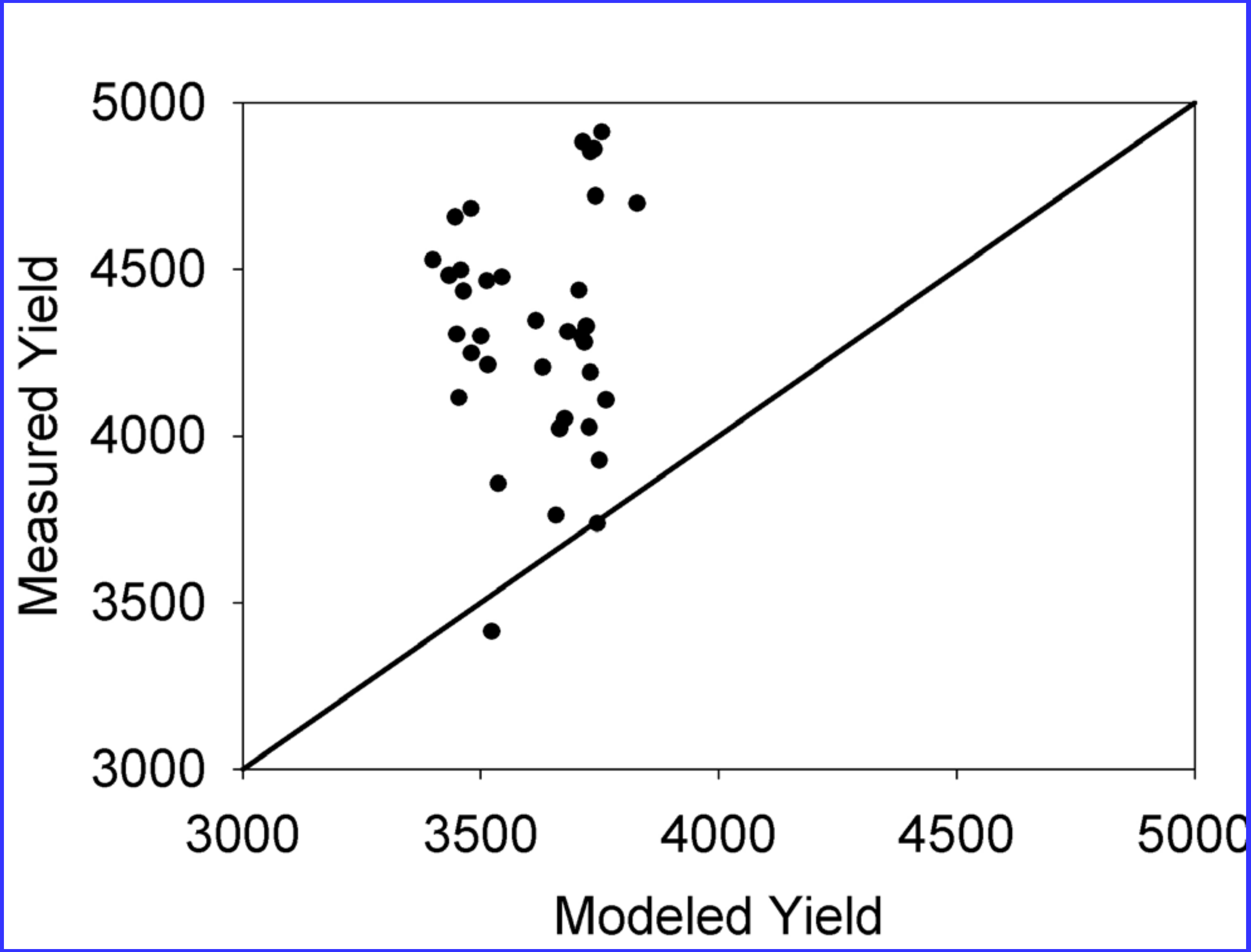
N_2O efflux

N_2O efflux may be the major greenhouse gas component of California agricultural systems.

Fuel C

Major component of ancillary greenhouse gas mitigation

Initial test of model comparison of yield at Yolo field site



DNDC

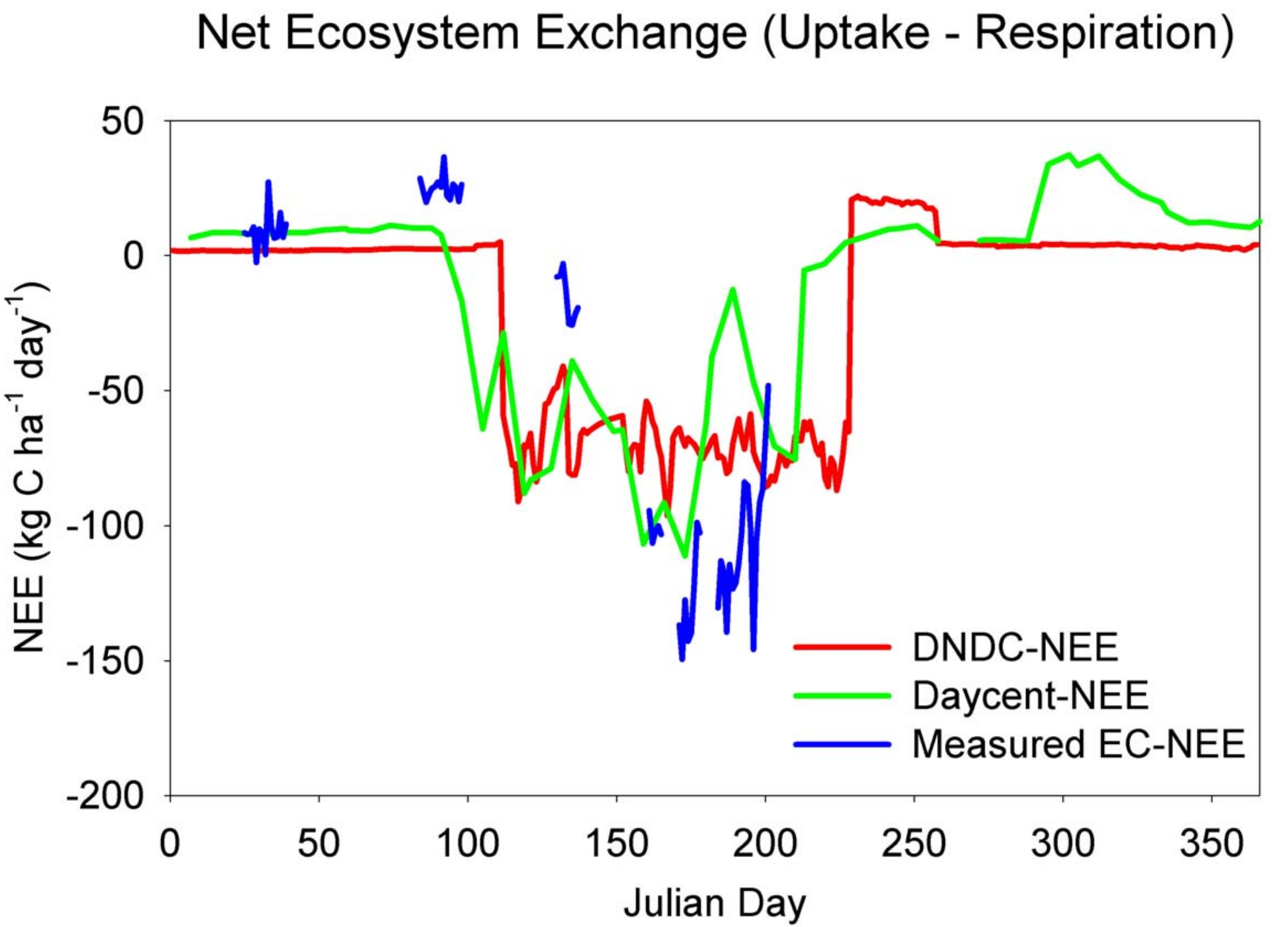
No calibration

See Wolf et al. poster for comparisons at other CA sites

Testing against field results

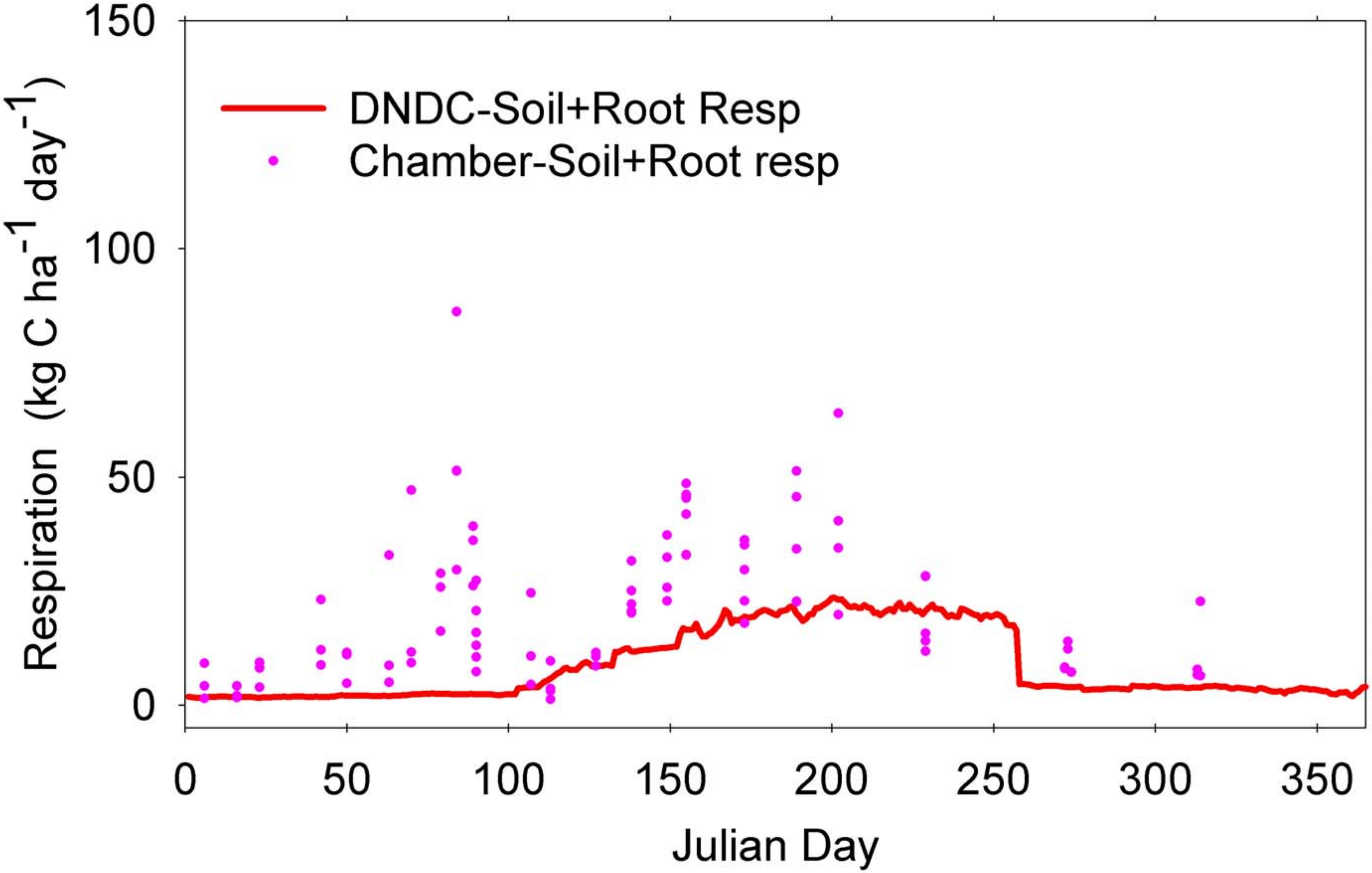
DayCent and DNDC

Yolo site



For measurement details, see King et al. and Paw U et al. posters

Respiration components

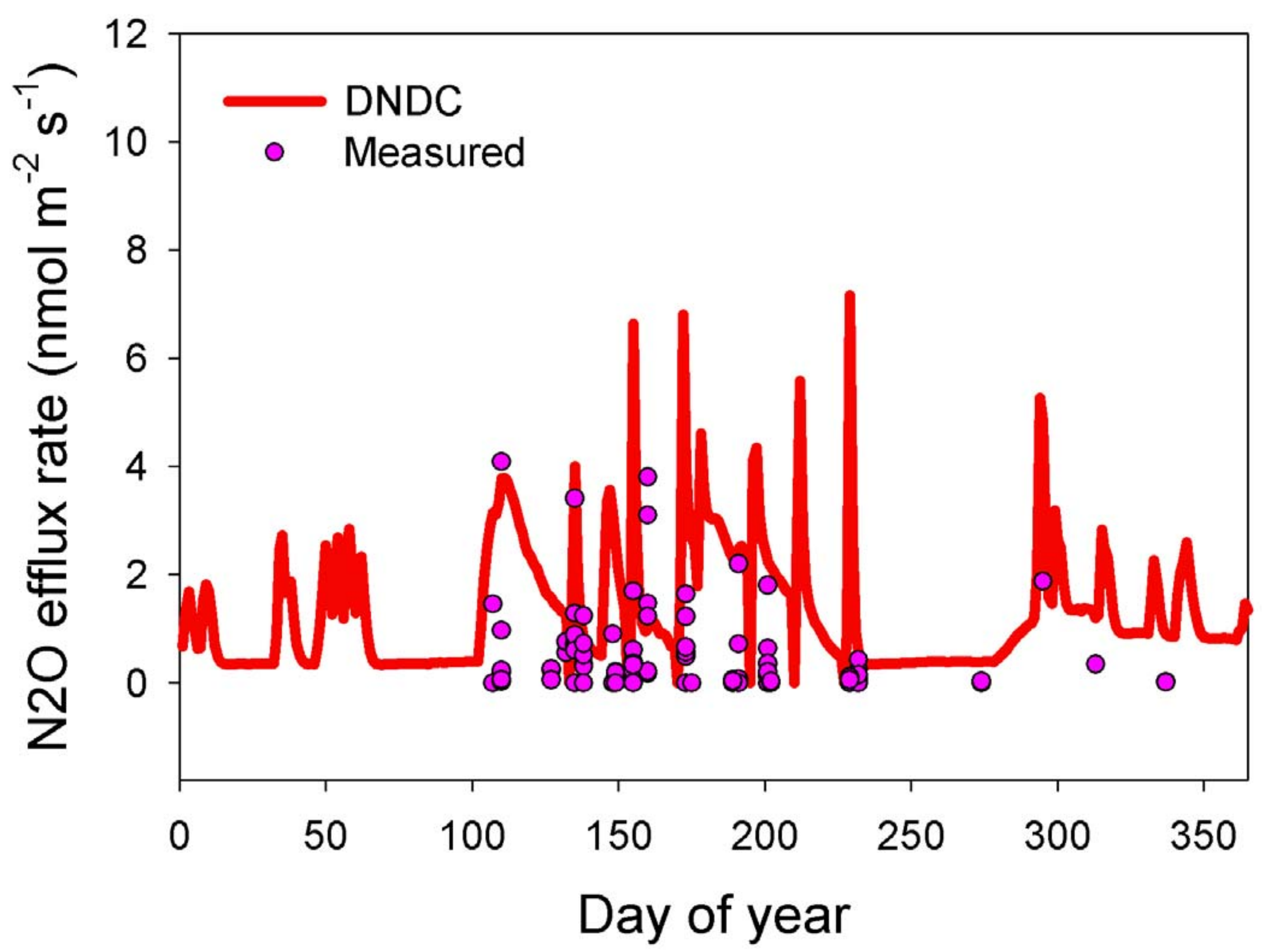


Test against field results

DNDC

Nitrous oxide

Yolo site

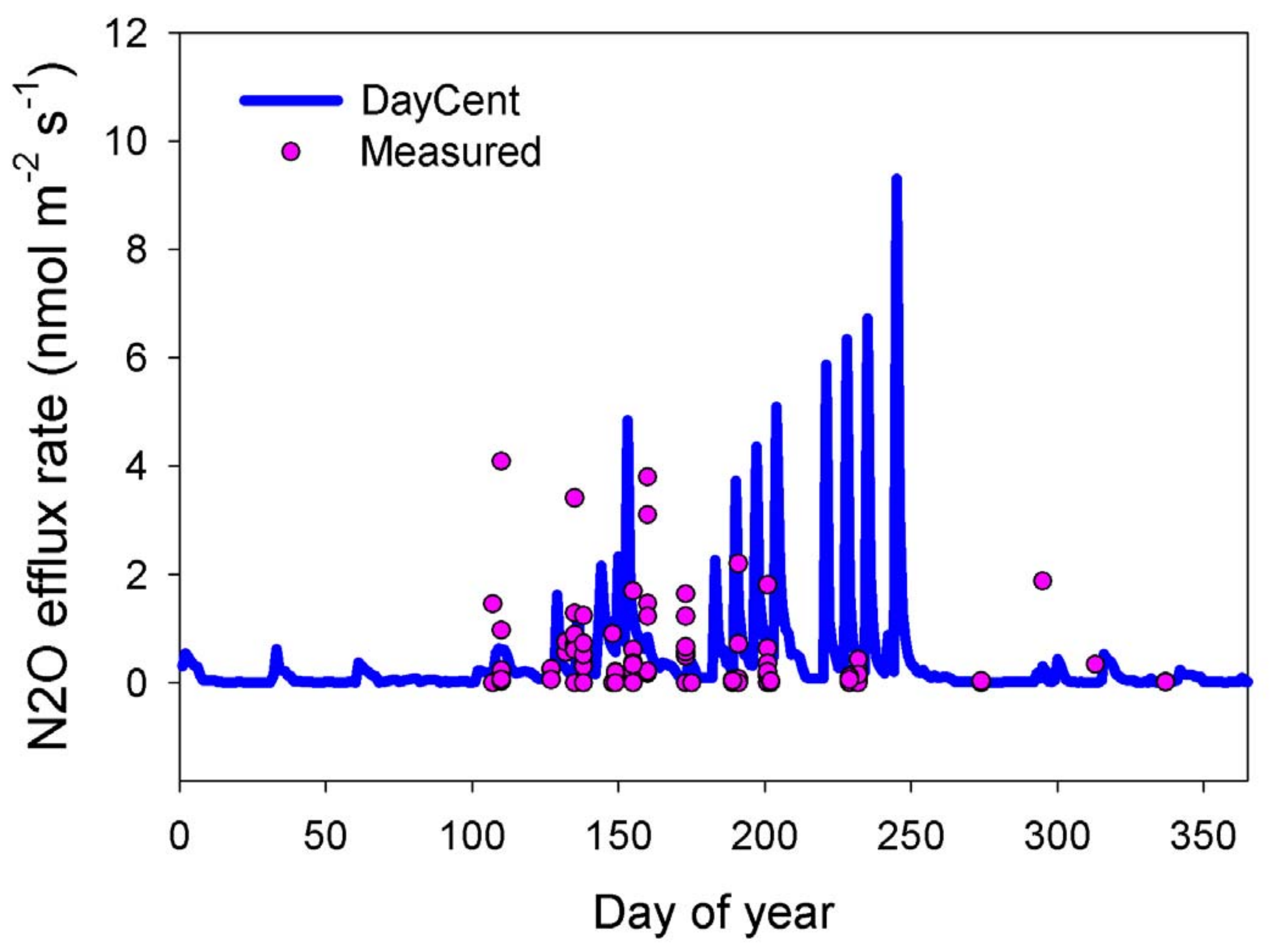


Test against field results

Yolo site

Nitrous oxide

DayCent

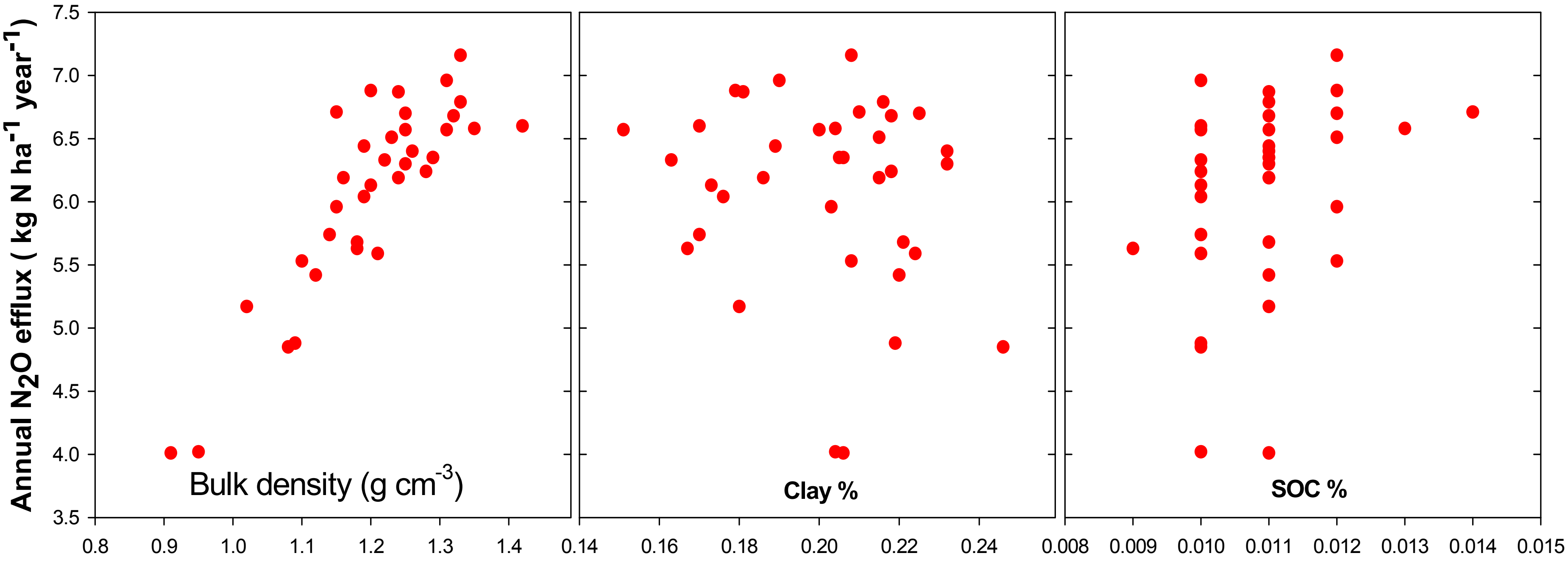


Model Sensitivity at field scale

DNDC

-Modeled 72 sample locations at Yolo field site

-Soil texture and SOC have little consistent effect on modeled N_2O efflux, but bulk density exerts a major control.



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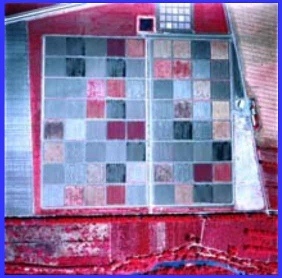
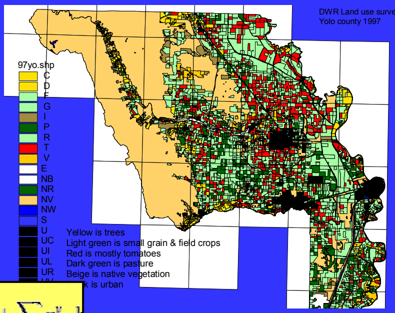
Integrated modeling approach

Field experiments

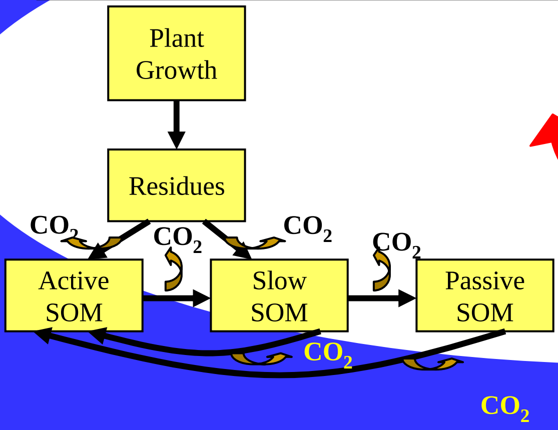


Land use and management identification

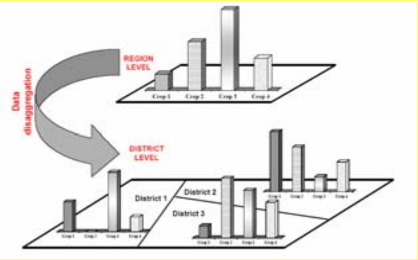
Spatial Information



Ecosystem model



$$L = \sum_i \sum_n p_{n,i} \ln\left(\frac{p_{n,i}}{q_{n,i}}\right) + \sum_n \sum_j p^w_{n,j} \ln\left(p^w_{n,j}\right) + \sum_j p^v_{n,j}$$

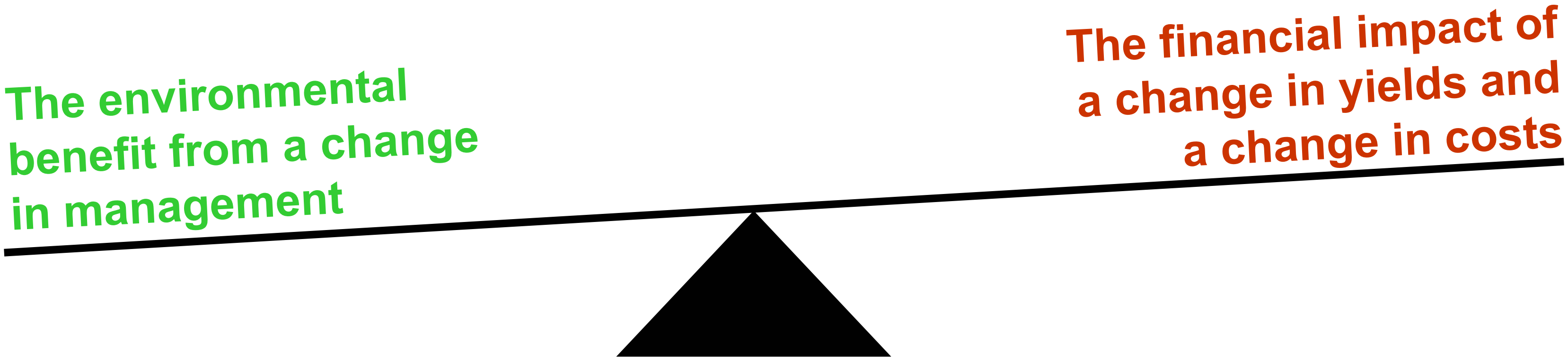


Dynamic economics

Decision support

With uncertainty estimates

Economic Tradeoffs



The environmental benefit from a change in management

The financial impact of a change in yields and a change in costs

$$\$/tCO2e = \frac{\Delta\$ \text{ (alternate – baseline)}}{\Delta tCO2e \text{ (alternate – baseline)}}$$

For greenhouse gas emissions in agriculture, this tradeoff changes:

- **For different soils (eg sand versus clay)**
- **For different farming systems (eg winegrapes vs wheat)**
- **For different climatic/economic regions (eg Chico vs Coachella)**
- **For different management changes (eg reduced tillage or cover crops)**

Coupling ecosystem and economic models

- Ecosystem models give predictions of yield and global warming potential as input into economic model
- Economic model predicts how growers may adapt their practices to maximize profit
- Change in practices from economic model then input back into ecosystem models

To a first approximation this exercise requires:

- **Identifying all cultivated lands in a county**
- **Summarizing the variability in soil properties for each map unit**
- **Identifying standard "baseline" land management practices**
- **Identifying management changes to reduce greenhouse gases**
- **Running the model for every combination of soil characteristics and land management over a range of historical weather conditions *just to get the environmental part of the equation*.**

**For 100 map units, a range of clay in each map unit,
and only 4 management scenarios, over 5 years of weather conditions:**

100 * 2 * 4 * 5 = 4000 model runs !

At a typical computation speed of 1 year s^{-1}, this equals 13 hours . . . .

When we start talking about many management scenarios, with changes in variable input usage (i.e. fertilizer) it all grows exponentially . . .

Grower adaptation and coupled modeling

- When farmers face a constraint or incentive, they can shift crop mix

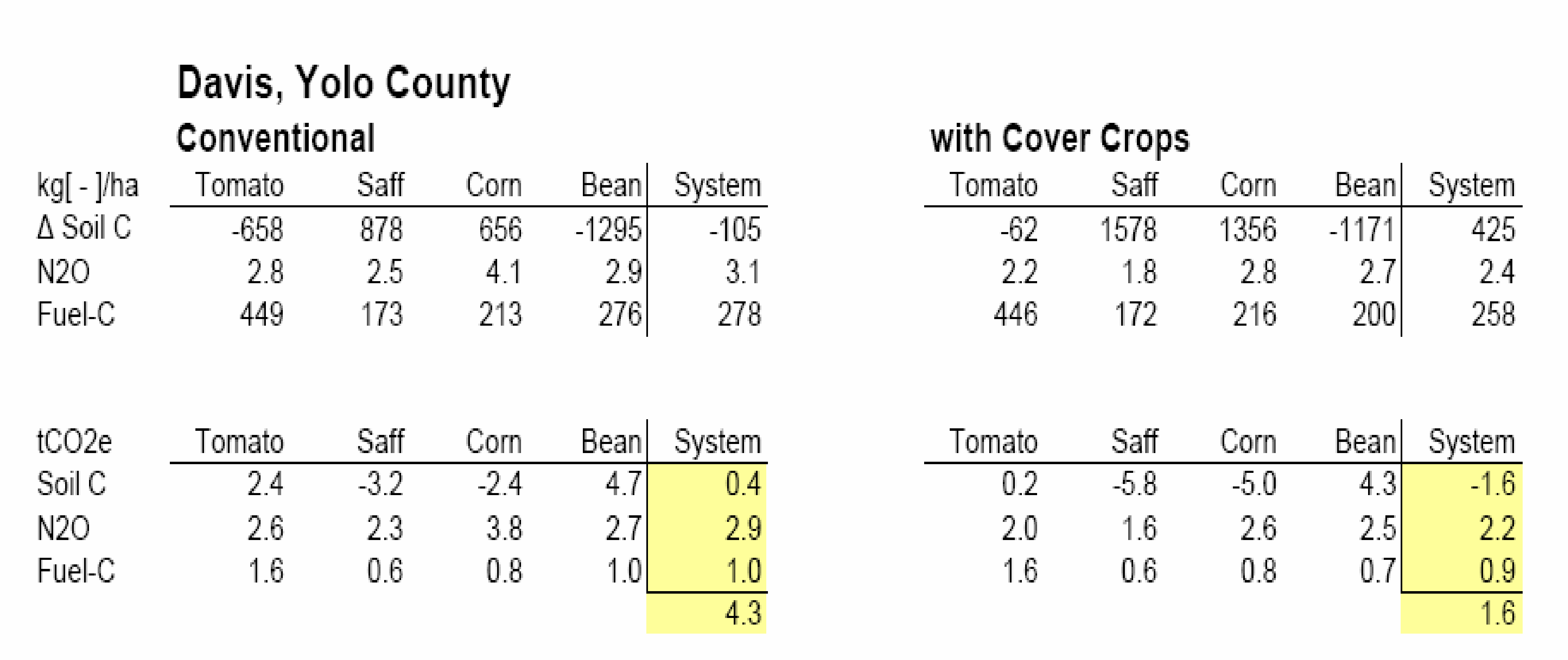
- Some crops and soils will be preferentially suited to reduce greenhouse gas emission, based on their biophysical potential, and the opportunity costs embodied with their place in the crop mix

  example: when faced with a water shortage, farmers do not cut back on irrigation, but switch to crops which demand less water

- This requires true interaction between biophysical & economic models at county and state levels to predict agriculture's aggregate response to efforts to curb greenhouse gas emissions

Greenhouse gas budget

- N_2O is the MAJOR component of the GHG budget
- Fuel C emissions exceeds soil emissions
- Cover crops can substantially mitigate GHG emission



Davis, Yolo County

Conventional

kg[-]/ha	Tomato	Saff	Corn	Bean	System
Δ Soil C	-658	878	656	-1295	-105
N2O	2.8	2.5	4.1	2.9	3.1
Fuel-C	449	173	213	276	278

tCO2e	Tomato	Saff	Corn	Bean	System
Soil C	2.4	-3.2	-2.4	4.7	0.4
N2O	2.6	2.3	3.8	2.7	2.9
Fuel-C	1.6	0.6	0.8	1.0	1.0
					4.3

with Cover Crops

kg[-]/ha	Tomato	Saff	Corn	Bean	System
Δ Soil C	-62	1578	1356	-1171	425
N2O	2.2	1.8	2.8	2.7	2.4
Fuel-C	446	172	216	200	258

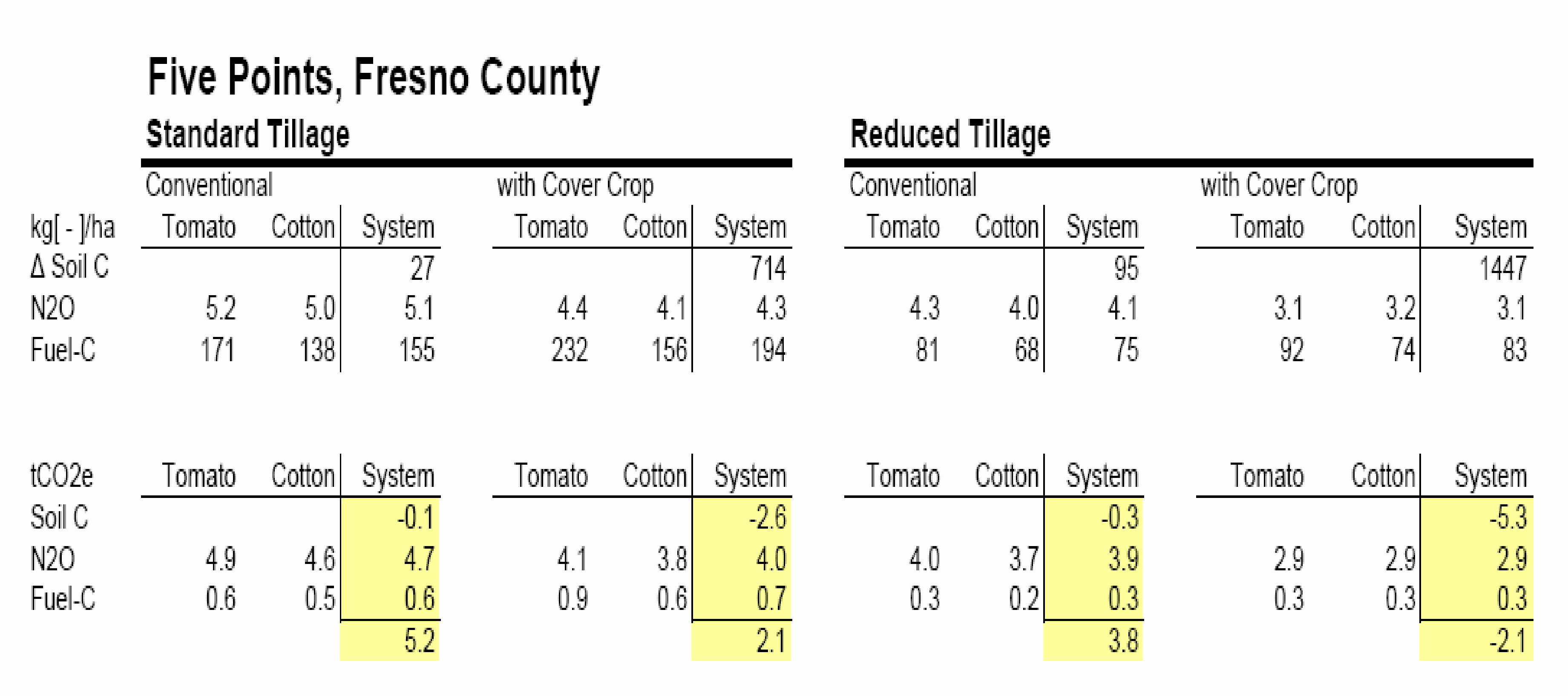
tCO2e	Tomato	Saff	Corn	Bean	System
Soil C	0.2	-5.8	-5.0	4.3	-1.6
N2O	2.0	1.6	2.6	2.5	2.2
Fuel-C	1.6	0.6	0.8	0.7	0.9
					1.6

N_2O and soil C are simulated

Source: SAFS

Greenhouse gas budget

- Reduced tillage can cut fuel-CO_2 emissions by half
- Integration of reduced tillage with cover cropping!



Five Points, Fresno County

	Standard Tillage						Reduced Tillage					
	Conventional			with Cover Crop			Conventional			with Cover Crop		
kg[-]/ha	Tomato	Cotton	System	Tomato	Cotton	System	Tomato	Cotton	System	Tomato	Cotton	System
Δ Soil C			27			714			95			1447
N2O	5.2	5.0	5.1	4.4	4.1	4.3	4.3	4.0	4.1	3.1	3.2	3.1
Fuel-C	171	138	155	232	156	194	81	68	75	92	74	83

tCO2e	Tomato	Cotton	System	Tomato	Cotton	System	Tomato	Cotton	System	Tomato	Cotton	System
Soil C			-0.1			-2.6			-0.3			-5.3
N2O	4.9	4.6	4.7	4.1	3.8	4.0	4.0	3.7	3.9	2.9	2.9	2.9
Fuel-C	0.6	0.5	0.6	0.9	0.6	0.7	0.3	0.2	0.3	0.3	0.3	0.3
			5.2			2.1			3.8			-2.1

Soil C measured, N_2O simulated **See Wolf et al. poster**

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Major sources of variation

- Inherent errors in model predictions
- Large differences in properties between and within soil types
- Differences in current and historic cropping affects soil C now, and land use history is generally unknown
- Uncertainties in weather and climate

Uncertainty in model predictions

- Most Sensitive Factor Method (Li et al., 2004) (Sensitivity of input variables)
  - Run models for minimum and maximum values of each input variable
- Monte Carlo approach (Structural uncertainties of model)
  - Randomly selecting values from PDFs and running the models to produce an ensemble of results
  - Data intensive

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Mitigation potential – Central Valley

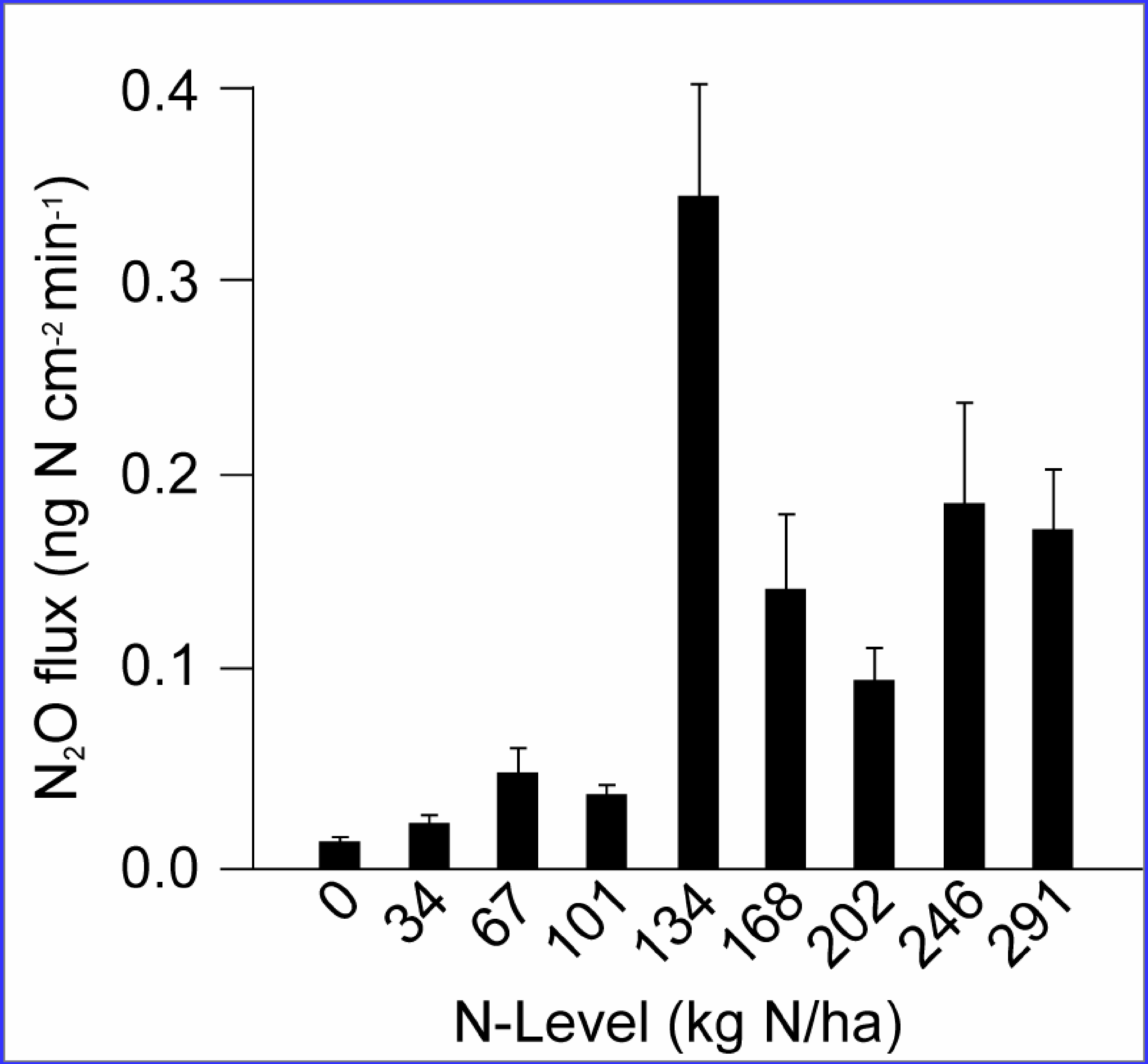
- Repeat ecosystem and economic modeling process for rest of the counties
- Assess multiple management scenarios in order to determine mitigation potential for policy analysis

Summary and Conclusions

- Testing DNDC and DAYCENT with data from CA field experiments
  - Accurate predictions of field-scale yield is mixed
  - DNDC better predicts N_2O emissions than DAYCENT
  - Models seem comparable for CO_2
  - Cover cropping and/or reduced tillage seem to offer some mitigation potential in CA
  - Fuel C and N_2O will be major player in greenhouse gas budgets in CA
- Currently assembling county-wide data sets for Yolo, Fresno, and Kings and beginning to make model runs for input to economic model

Thanks for your attention

N_2O Flux x N-fertilizer Level



McSwiney et al.

20 Year Cumulative GWP (NT - CT)

Humid Climate	Estimate	s.e.[2]
CO_2	-16296	(88)
N_2O	5027	(3706)
CH_4	-258	(46)
Soil-derived GWP	**-11526**	**(3707)**
Ancillary GHG changes	-2273	
Total GWP	**-13799**	

Dry Climate		
CO_2[1]	-7128	(115)
N_2O	5105	(5814)
CH_4	-258	(46)
Soil-derived GWP	**-2281**	**(5815)**
Ancillary GHG changes	-2273	
Total GWP	**-4554**	

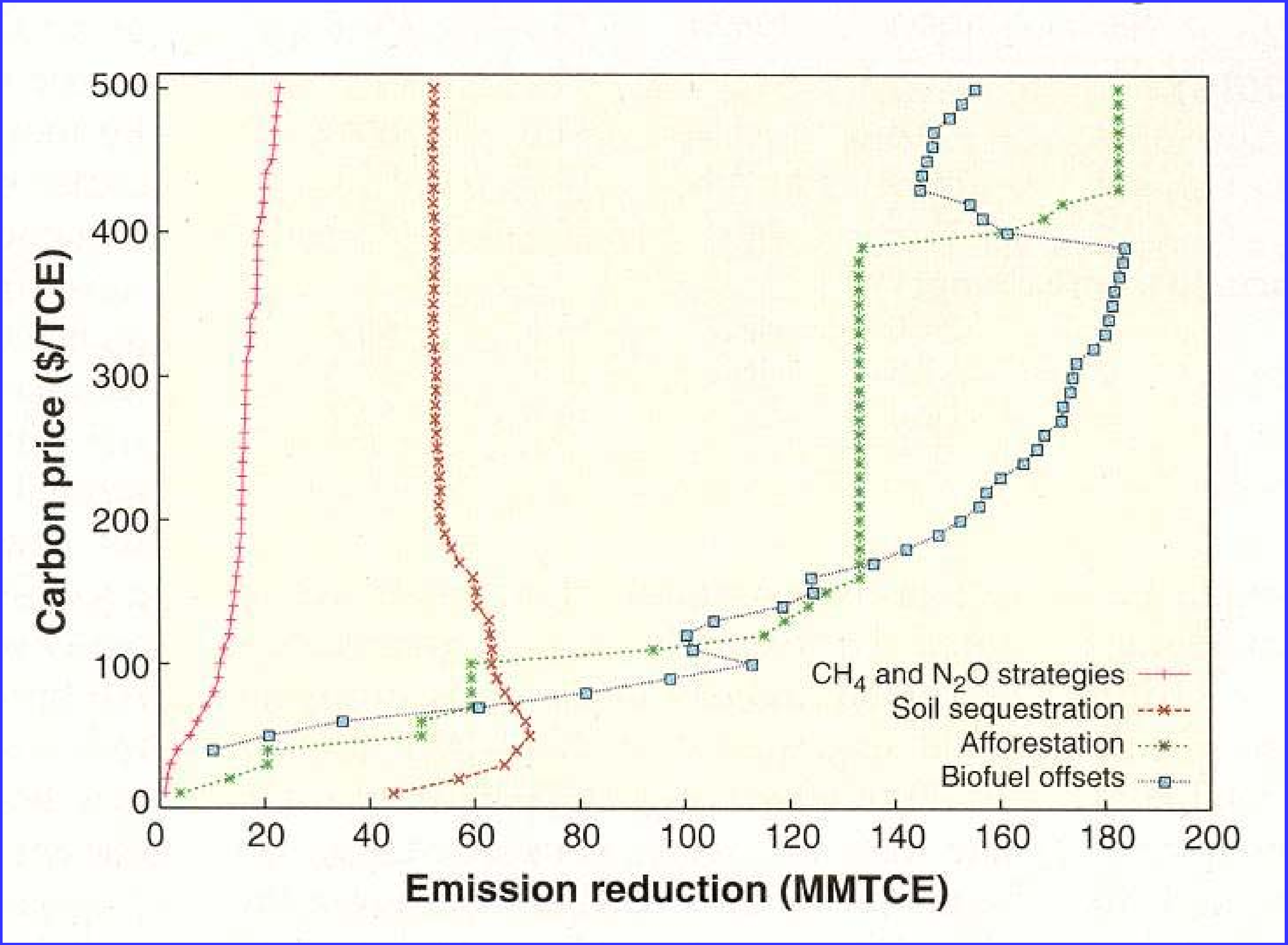
[1] GWP = in CO_2 equivalents

[2] s.e. = standard error

Six et al., 2003

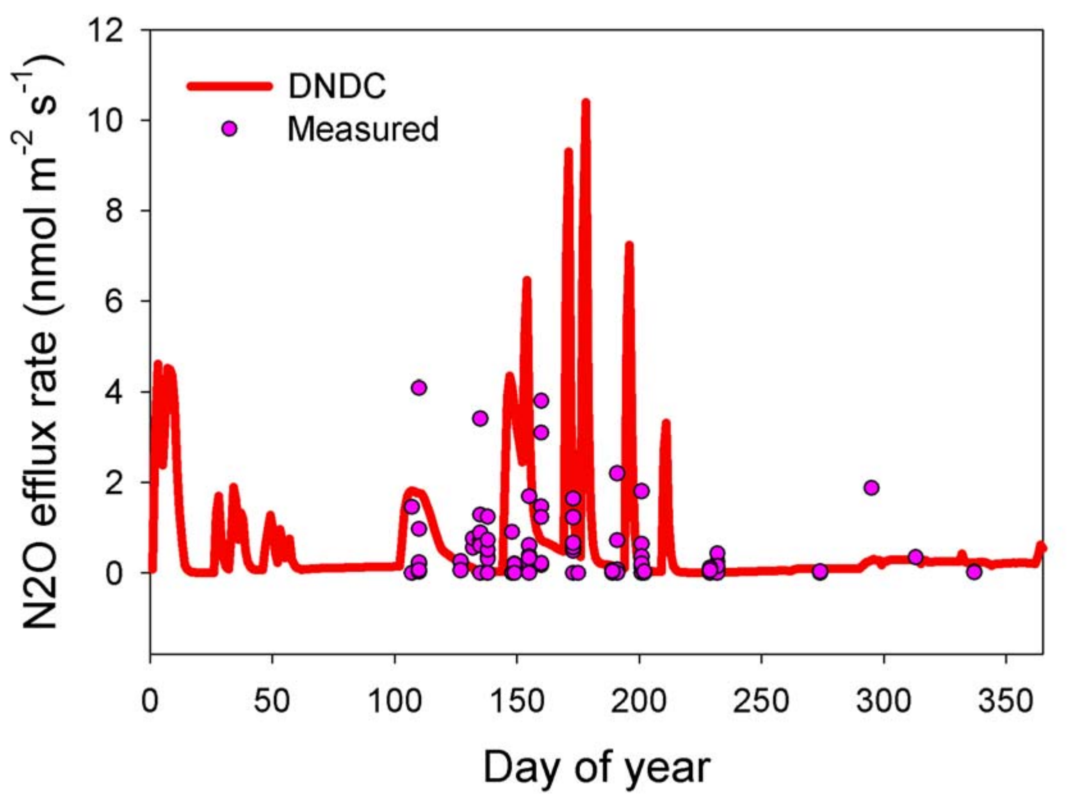
ΔSOC in U.S. Agricultural Lands 1990-1997

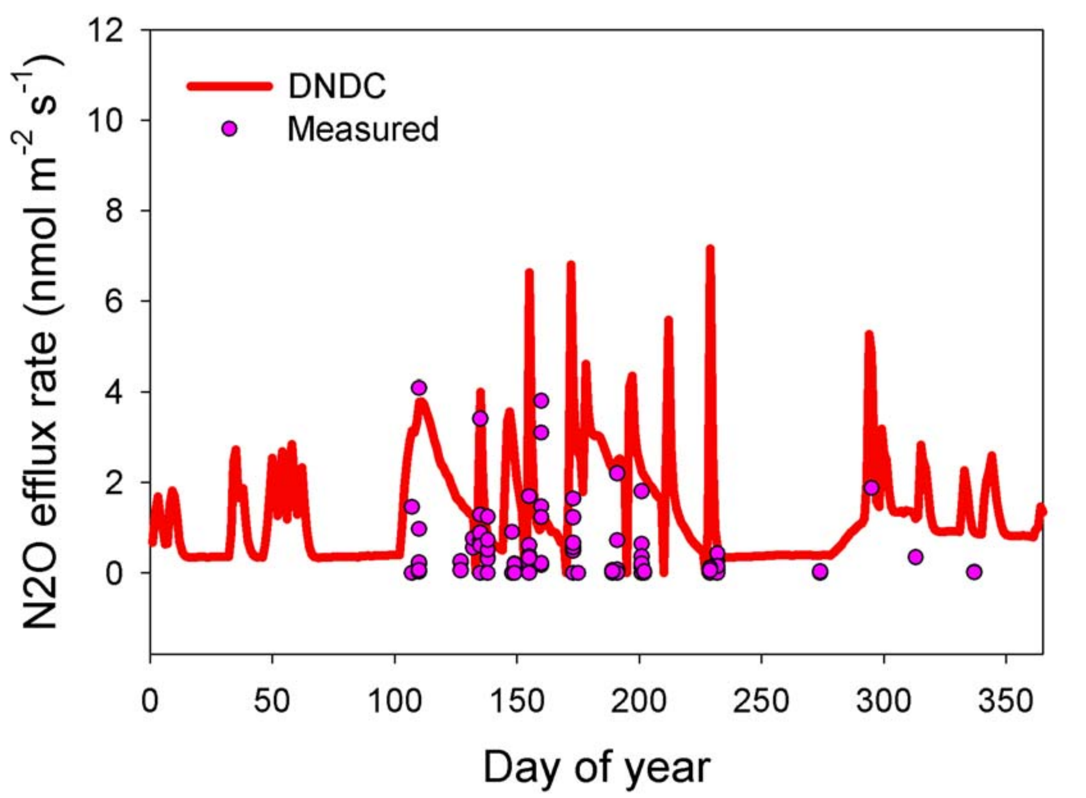
	1990-92 (Tg C yr^{-1})	1993-97 (Tg C yr^{-1})
Mineral Soils	9.76 (3.8 to 16.0)	9.65 (5.7 to 13.7)
Organic Soils	-9.36 (-6.3 to -13.2)	-9.47 (-6.4 to –13.4)
Total	0.41 (-6.6 to 7.4)	0.18 (-5.3 to 5.3)



McCarl and Schneider 2001

Slide courtesy Paustian

N2O efflux rate (nmol m^{-2} s^{-1})
Day of year
DNDC
Measured
12
10
8
6
4
2
0
0
50
100
150
200
250
300
350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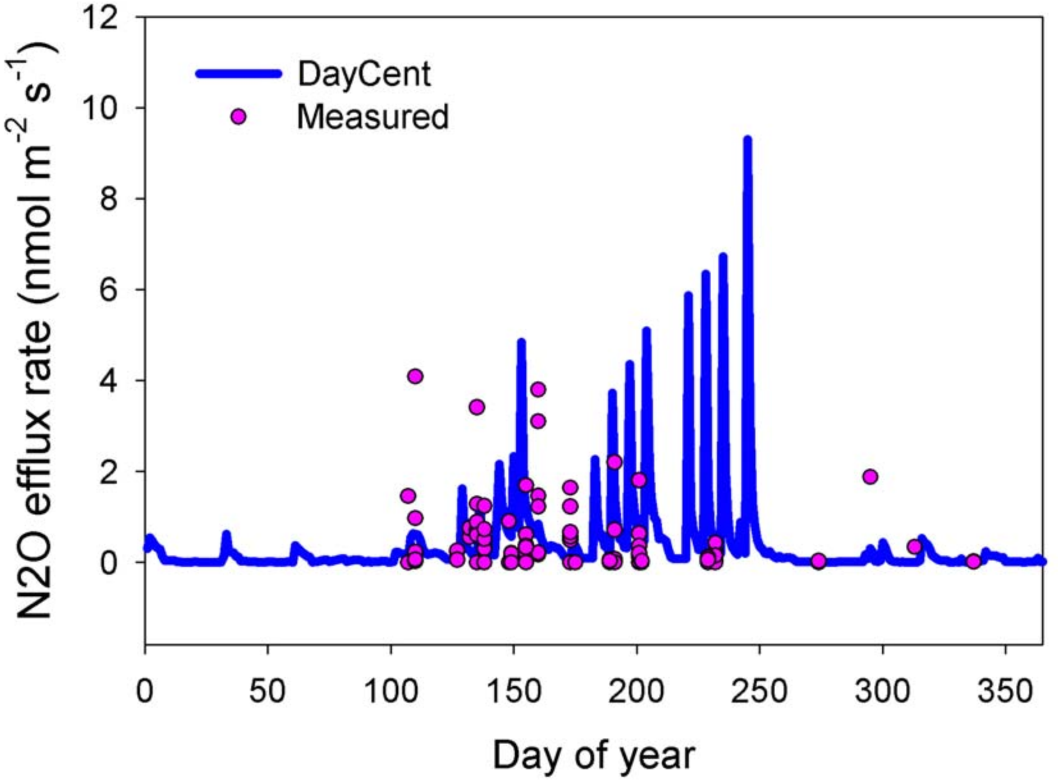
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12
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Measured
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150
200
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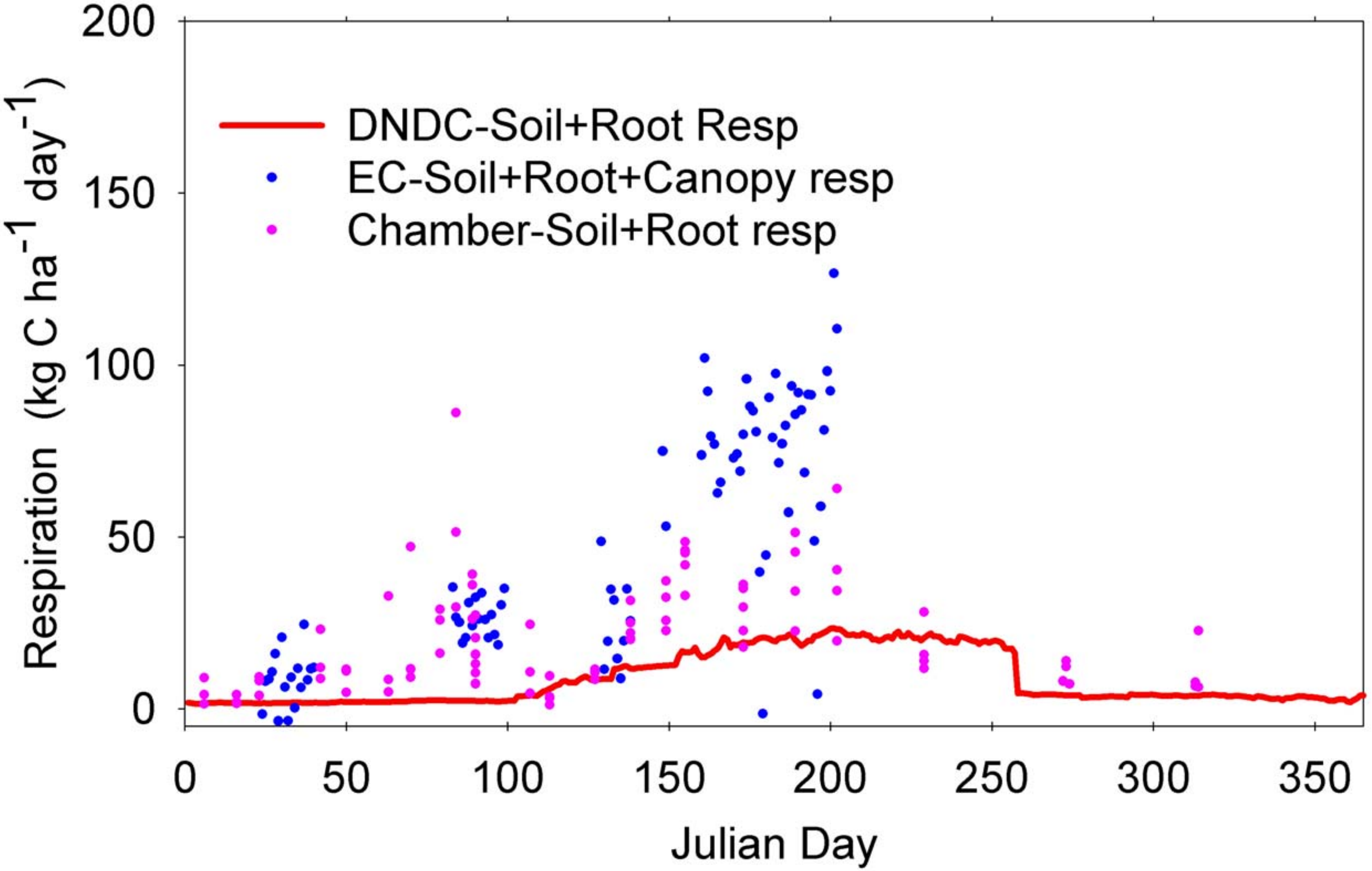
Day of year

Respiration components



Minimum payment needed to cover expenses