Ecological Intensification of Corn-Based Cropping Systems

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Today's Presentation

Adviento-Borbe et al. 2007 . Global Change Biology 13:1972-1988
Verma et al. 2005. Agric. and Forest Meteorology 131:77-96

- Compare the Global Warming Potential of "*normal*" irrigated and rainfed corn-based systems against "*intensified*" production regimes.

Global Warming Potential

- GWP Represents the effect of the cropping system on total greenhouse gas emissions including:
  - net carbon sequestration
  - trace gas emissions (N_2O and CH_4) and
  - CO_2-C from fossil fuel use

- In a sense (a *lower*) GWP is also a measure of *improved* resource use efficiency, *minimized* environmental impact and *higher* production efficiency.

Common Assumptions

- Corn – soybean rotation is a more sustainable system then continuous corn

- Conservation tillage (no-till) is required to accumulate soil organic matter (sequester C and reduce GWP)

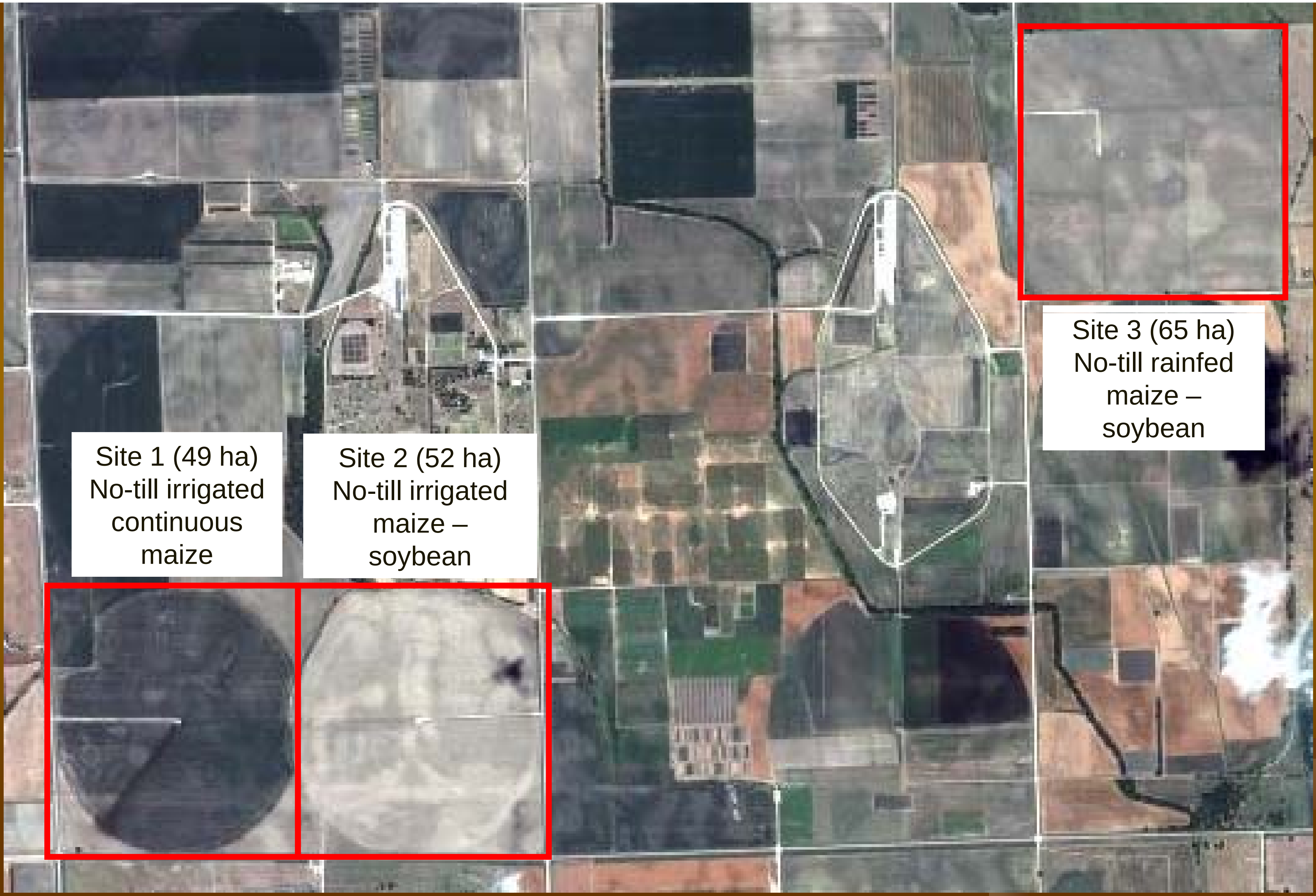
- Any attempt to intensify corn systems leads to increased N losses and GHG emissions

GWP of ***"Normal"*** Irrigated and Rainfed Corn Systems

- Four years of data showing full 365 day carbon balance, fuel use and trace gas emissions
- Irrigated yield averages are 65% of yield potential
- Rainfed yield averages are 48% of yield potentail

Carbon Sequestration Research Facility

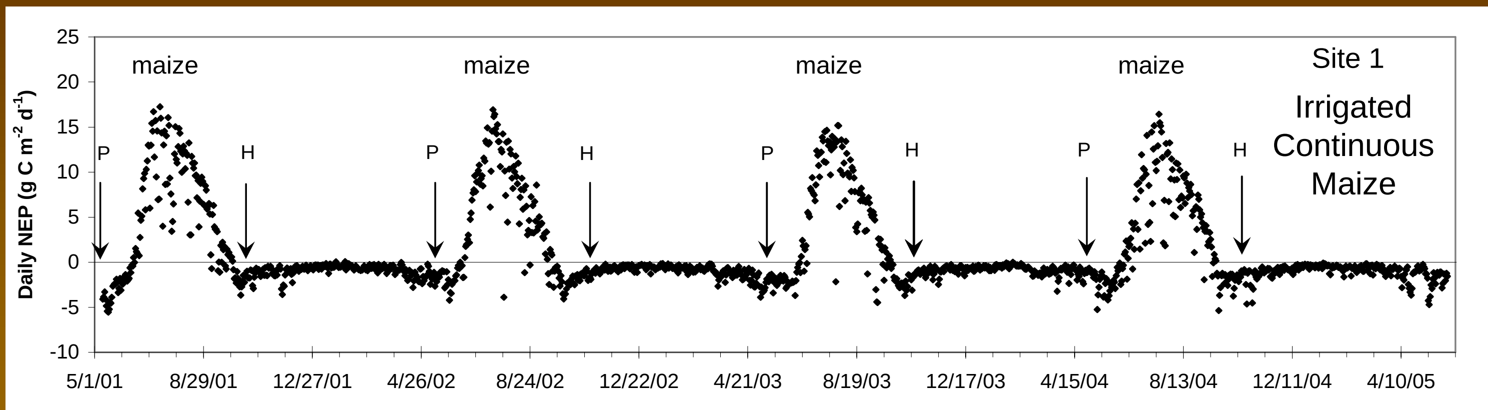
at the UNL Agricultural Research and Development Center, Mead, NE

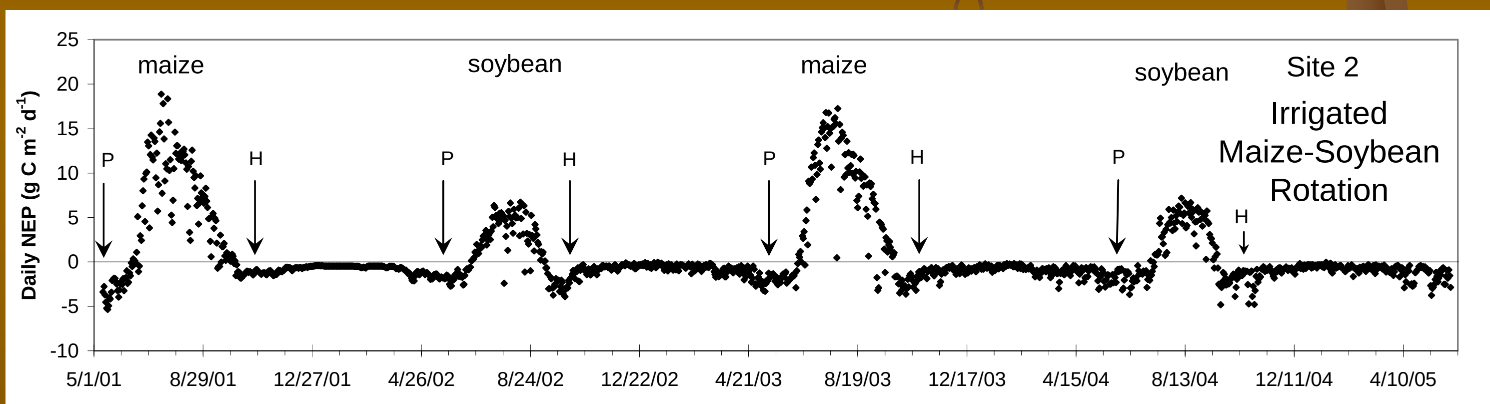


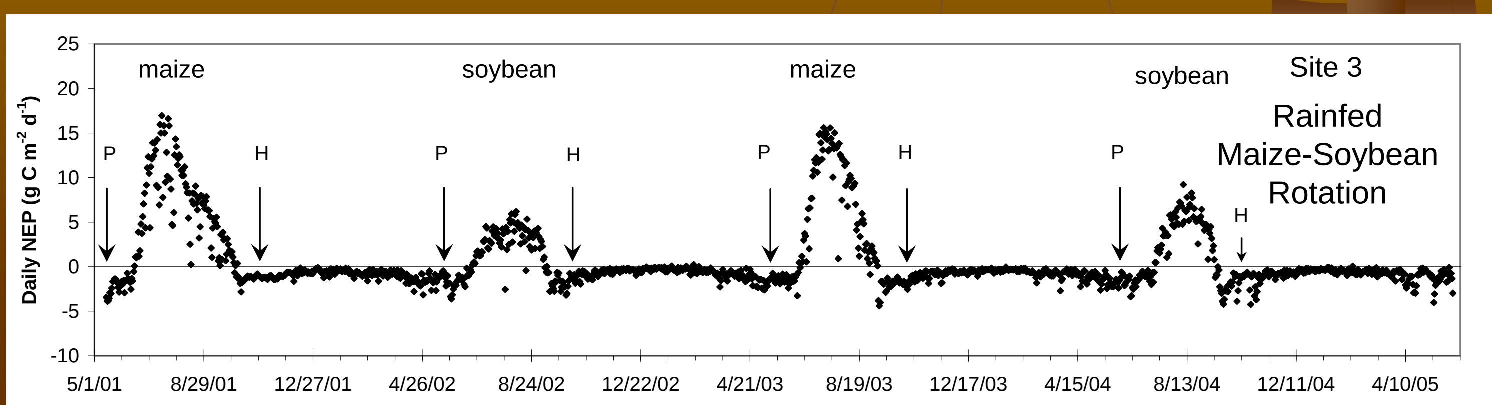
Definitions

- **NEE** = **N**et **E**cosystem **E**xchange of CO_2-C
  - Represents net overall balance of CO_2-C for the system or [Carbon in – Carbon out]
  - [Photosynthesis – $Resp_{soil}$ – $Resp_{plant}$]
- **NBP = N**et **B**iome **P**roductivity
  - equivalent to Net Carbon Sequestration
  - [NEE – Grain C removal]
- **GWP** = **G**lobal **W**arming **P**otential
  - Represents the effect of the cropping system on total greenhouse gas emissions including trace gas emissions (N_2O and CH_4) and CO_2-C from fossil fuel use

Daily Net Ecosystem Exchange







UNL Carbon Sequestration Project

A positive value indicates flux of CO_2-C to the surface

Net Biome Productivity, g C m^{-2}
Site 1 – **Continuous Irrigated Corn**

Average annual Net Carbon Sequestration = -51 g C m^{-2} yr^{-1}

	Year 1 2001-02	Year 2 2002-03	Year 3 2003-04	Year 4 2004-05
	Maize	**Maize**	**Maize**	**Maize**
Annual Net Ecosystem Exchange (NEE)	517	424	381	361
Grain C removal at harvest (C_g)	-521	-503	-470	-470
Est. CO_2–C release in irrig. water	43	39	49	30
Net Biome Productivity	7 to 28	-69 to -50	-77 to -52	-102 to -87

Range in Net Biome Productivity assumes that 25% or 75% of CO_2-C emission from Irrigation water is undetected by the eddy covariance tower.

Net Biome Productivity, g C m^{-2}

Site 2 – <u>**Irrigated Corn/Soybean**</u>

Average annual Net Carbon Sequestration = -92 g C m^{-2} yr^{-1}

	Year 1 2001-02	Year 2 2002-03	Year 3 2003-04	Year 4 2004-05
	Maize	**Soybean**	**Maize**	**Soybean**
Annual Net Ecosystem Exchange (NEE)	529	-48	572	-76
Grain C removal at harvest (C_g)	-518	-183	-538	-171
Est. CO_2-C release in irrig. water	41	26	45	21
Net Biome Productivity	21 to 42	-225 to -212	45 to 68	-241 to -231

Range in Net Biome Productivity assumes that 25% or 75% of CO_2-C emission from Irrigation water is undetected by the eddy covariance tower.

Net Biome Productivity
Site 3 – Rainfed Maize/Soybean

Average annual Net Carbon Sequestration = -16 g C m^{-2} yr^{-1}

	Year 1 2001-02	Year 2 2002-03	Year 3 2003-04	Year 4 2004-05
	Maize	**Soybean**	**Maize**	**Soybean**
Annual Net Ecosystem Exchange (NEE)	510	-18	397	-12
Grain C removal at harvest (C_g)	335	153	297	157
Net Biome Productivity	175	-171	100	-169

Contribution of Crop Production Fossil Fuel Inputs to CO_2-C Emissions

Annual Average, 2001 – 2004

Source	Site 1 Irrigated Corn		Site 3 Rainfed Corn		Site 2 Irrigated SB		Site 3 Rainfed SB	
	g C m^{-2}	%	g C m^{-2}	%	g C m^{-2}	%	g C m^{-2}	%
Nitrogen	**16.9**	***32.0***	**9.3**	***39.1***	**0.1**	***0.6***	**0.1**	***1.5***
Irrigation	13.3	*25.5*	-	-	7.7	*51.3*	-	-
Drying	11.0	*21.2*	6.7	*28.1*	-	-	-	-
Machinery	3.6	*7.0*	2.5	*10.4*	2.5	*16.9*	1.8	*30.4*
Depreciable[1]	1.4	*2.7*	0.8	*3.4*	1.2	*8.2*	0.7	*11.9*
Seed	4.8	*9.2*	3.5	*14.5*	2.2	*14.3*	2.2	*35.9*
Herbicide	1.3	*2.4*	1.0	*4.4*	1.3	*8.8*	1.2	*20.4*
Insecticide	0.03	*0.1*	0.003	*0*	-	-	-	-
TOTAL	**52.1**		**23.8**		**15.1**		**6.0**	

[1]Depreciable energy is the annual proportion of emissions associated with the manufacture of machinery used in production operations

Average Annual Global Warming Potential (GWP) g C m^{-2}

(Average 2001-2004 or 4 cropping seasons)

	Site 1 Irrigated continuous corn	Site 2 Irrigated corn-soybean rotation	Site 3 Rainfed corn-soybean rotation
(1) Annual NEE	421	244	219
(2) Grain C removal during harvest (C_g)	-491	-353	-235
(3) Estimated CO_2-C from irrigation water (I_c)	-40	-33	---
(4) Site C balance = (1) + (2) + (3)	**-80 to -100**	**-117 to -134**	**-16**
(5) N_2O flux (g CO_2-C eq.)	-51	-49	-40
(6) CH_4 flux (g CO_2-C eq.)	-1	5	4
(7) Production C-costs	-54	-33	-15
(8) Net GWP = (4) + (5) + (6) + (7)	**-186 to -206**	**-194 to -211**	**-67**

A negative number indicates a net source of CO_2-C to the atmosphere

GWP of "Intensive" Irrigated Corn Systems

Ecological Intensification Project – Lincoln NE

Ecological Intensification

- Central hypothesis: an optimal balance of high productivity, sustainability and minimal environmental impact can be achieved by fine-tuning of management towards better exploitation of crop yield potential.

Site: Lincoln, NE, UNL East Campus (1999 – 2005)

Crop rotation (main plots)

CC	Continuous corn
CS	Corn – Soybean (corn in odd years)
SC	Soybean – Corn (corn in even years)

Plant Population (subplots)

P1	Corn: 30k	28-31,000 plants/acre
P2	Corn: 37k	35-41,000 plants/acre
P3	Corn: 44k	38-47,000 plants/acre)

Management Intensity (sub-subplots)

M1	recommended fertilizer management based on soil testing. Maize: UNL recommendation for 200 bu/acre yield goal
M2	intensive management aimed at yields close to yield potential. Maize yield goal 300 bu/acre, higher NPK rates, micronutrients, N in 3-4 splits

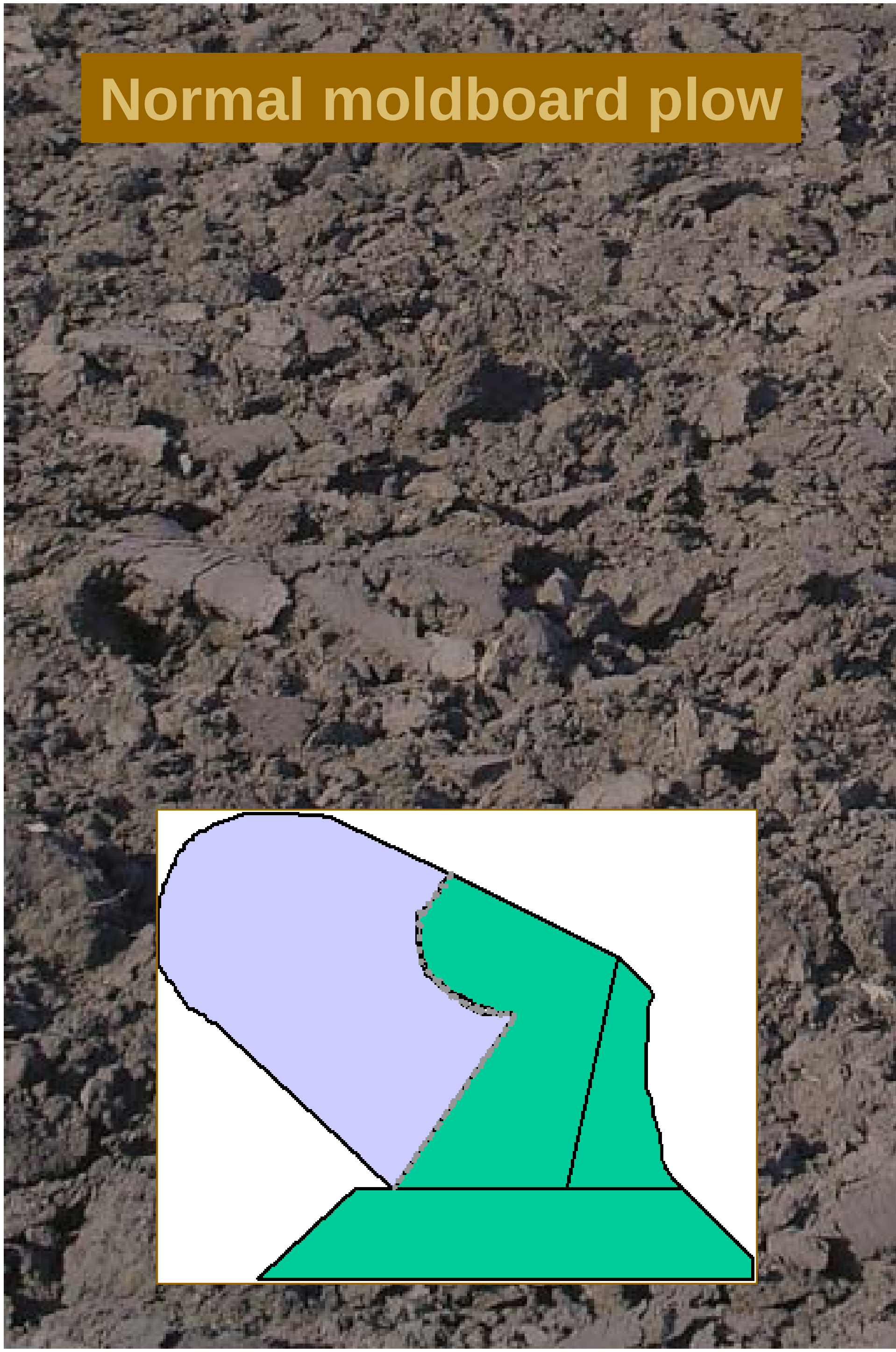
CC & CS systems: Corn yields

Treatments		Corn grain yield (bu/acre)[2]							
Density[1]	**Fertilizer**	**Avg[3]**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Continuous Corn									
P1	**M1**	**223**	-	214	223	178	255	**247**	**221**
P2/3	**M2**	**244**	-	229	252	242	265	**266**	**208**
Corn / Soybean									
P1	**M1**	**235**	219	225	230	221	268	**261**	**223**
P2/3	**M2**	**256**	257	248	249	243	285	**287**	**220**

[1] M2 treatment with highest yielding plant density: P2 in 2000, 2003 and 2005;
P3 in 1999, 2001, 2002 and 2004.

[2] Hybrid: P33A14 (113 d) in 1999-2000
P33P67 (114 d) in 2001-2002
P31N28 (119 d) in 2003-2004
P31G68 (119d) in 2005

[3] Average of 2000-2005


Normal moldboard plow

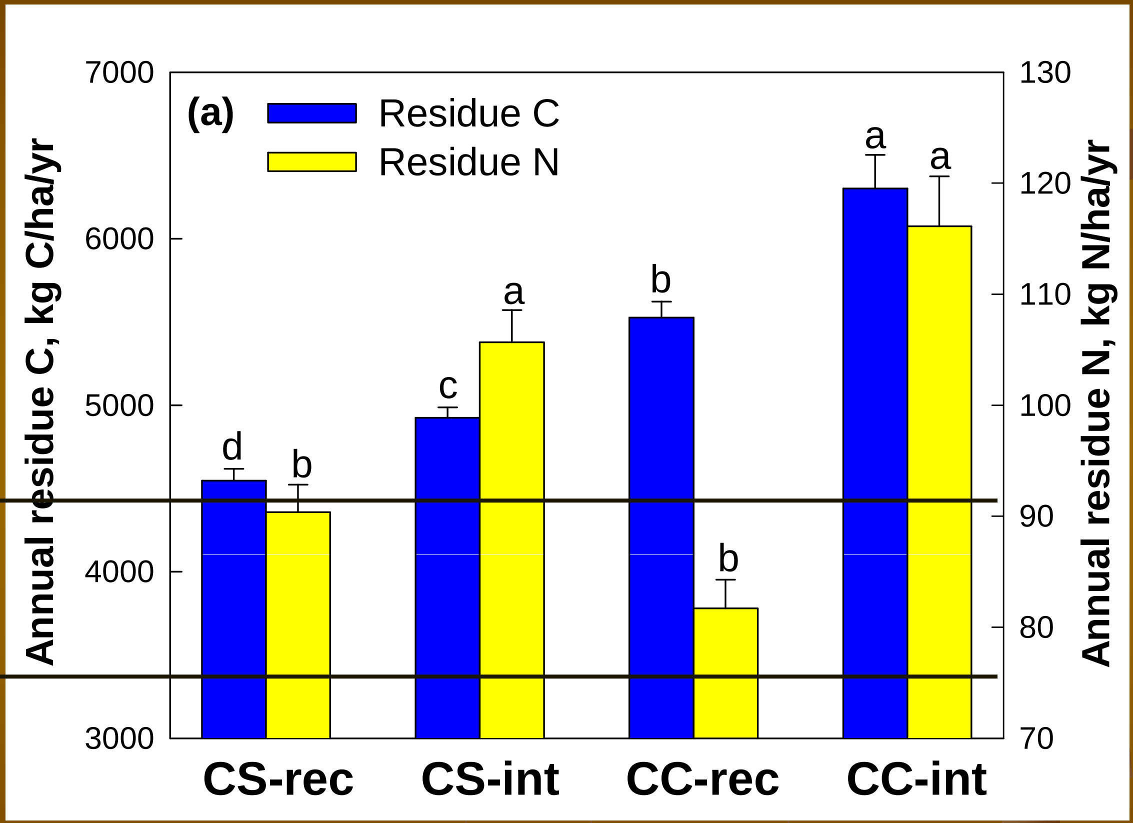

Conservation tillage plow

C & N input with crop residues, Lincoln, NE

C input "normal"

4380 kg C ha^{-1}
CC

3380 kg C ha^{-1}
CS



Averages for corn and soybean crops grown during 2000-2005

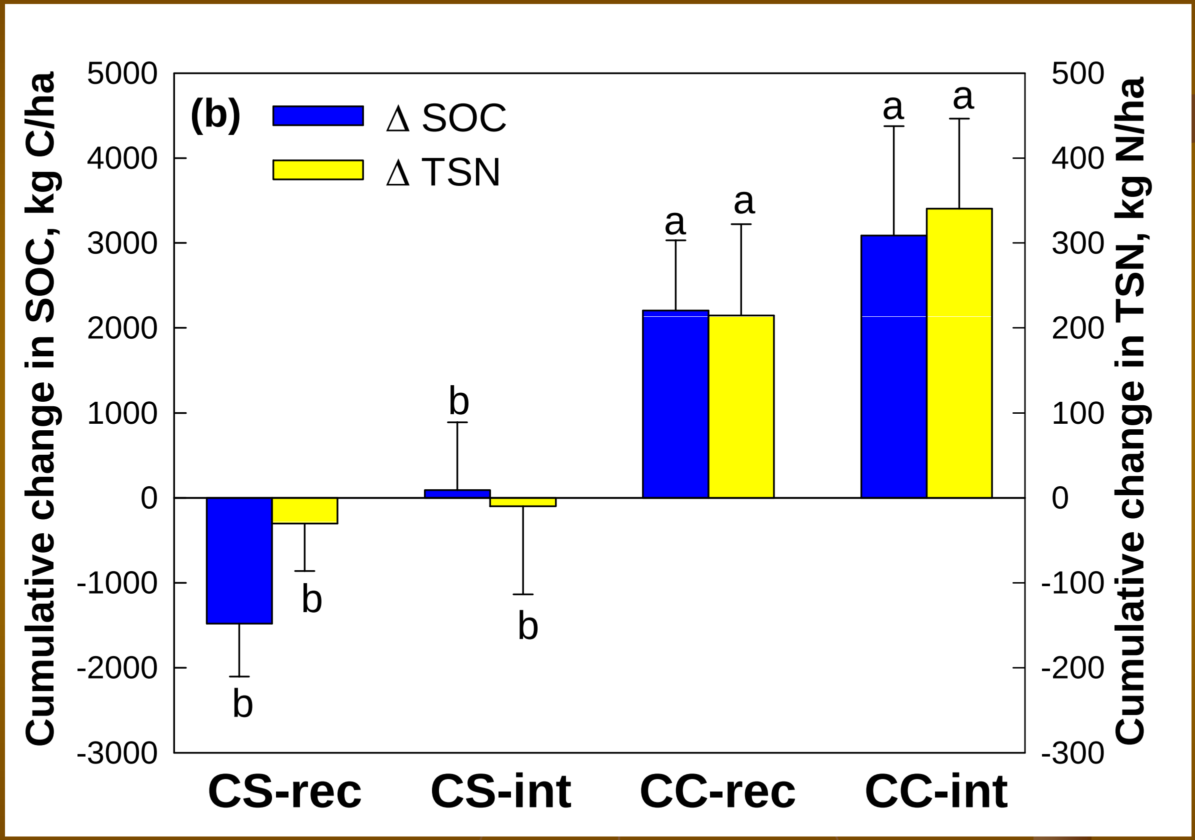
CS-rec corn-soybean rotation, recommended management

CS-int corn-soybean rotation, intensive management

CC-rec continuous corn, recommended management

CC-int continuous corn, intensive management

Change in soil C and N, Lincoln, NE



Soil samples collected in June 2000 and 2006, 0-30 cm

CS-rec corn-soybean rotation, recommended management
CS-int corn-soybean rotation, intensive management
CC-rec continuous corn, recommended management
CC-int continuous corn, intensive management

System-level N use efficiency, Lincoln, NE

	CS-Rec	CS-Int	CC-Rec	CC-Int
Annual fertilizer N input, lb N/a	64	156	183	272
Annual N removal with grain, lb N/a	208	216	160	176
Change in total soil N, 0-12", lb N/a	-27	-9	195	309
Nitrogen use efficiency				
lb N in C&S grain/lb N applied	3.25	1.38	0.87	0.65
lb grain N + change in soil N/lb N applied	2.83	1.33	1.94	1.78

corn and soybean grown during 2000-2005

CS-rec corn-soybean rotation, recommended management

CS-int corn-soybean rotation, intensive management

CC-rec continuous corn, recommended management

CC-int continuous corn, intensive management

Global warming potential, Lincoln, NE

GWP components		Continuous corn		Corn-soybean	
		Recom.	Intensive	Recom.	Intensive
		g CO_2-C equivalents m^{-2} yr^{-1}			
Agricultural production[a]	N fertilizer	22	33	8	18
	P, K, fertilizer	0	6	0	6
	Lime	6	9	6	9
	Seed, pesticides	5	6	5	6
	Machinery	2	3	2	3
	Diesel	9	9	8	8
	Irrigation	14	14	11	11
	Grain drying	11	12	9	10
Total		-69	-92	-49	-71
Soil C[b]		44	62	-30	2
Soil N_2O[c]		-32	-57	-25	-34
Soil CH_4[c]		3	3	2	1
GWP[d]		-54	-84	-102	-102

Averages for corn and soybean crops grown during 2000-2005.
GWP = Agricultural production + ΔSOC + soil N_2O + soil CH_4
(Adviento-Borbe et al., 2007. Global Change Biol. 13:1972-88)

Summary

- Intensification does not necessarily increase GHG emissions and the overall GWP when crops are grown with best management practices at near yield potential levels

- Overall impact of soybean was to decrease soil C sequestration and increase GWP of these corn systems.

Summary

- Corn yield potential varies across locations, from year to year and within a year (planting date). Variation must be understood to exploit yield potential through management.

- Interactions between climate, plant density, and nutrient status determine yield potential and how much of it can be achieved under field conditions.

Reported NEE of Other Ecosystems

Annual NEE g C m^{-2}	Biome and location	Reference
300 to 500	Irrigated Maize, Nebraska	Verma, et al., 2005
200	Harvard Forest, Massachusettes	Barford, et al., 2003
174	Howland Forest, Massachusettes	Hollinger et al., 2004
80 to 170	U. Michigan Biological Station Forest	Schmidt et al., 2003
-50 to 200	Wind River Canopy Res. Facility, Wash.	M. Falk, 2004
270 to 420	Douglas Fir forest, West Coast Canada	Morgenstern, et al., 2004
50 to 275	Tallgrass prarie, Oklahoma	Suyker et al., 2003
-18 to 20	Temperate grassland, Alberta, Canada	Flanagan et al., 2002
-30 to 130	Mediterranean grassland	Xu and Baldocchi, 2003