Ecological Intensification of Corn-Based Cropping Systems
Soil quality changes impact yield

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INTRODUCTION

Meeting the projected global demand for food and fuel from corn systems while conserving natural resources and improving environmental quality can only be achieved by the intensification of existing corn systems (Cassman, 1999; Cassman et al., 2003). Since 1999 we have been experimenting with optimizing corn management systems to exploit corn yield potential. To date, our experience has shown that considerable yield increases are realized by choosing the right combination of adapted varieties, planting date and plant populations to maximize crop productivity. In addition, more intensive N management strategies that focus both on improving crop N use efficiency and residue carbon management also contribute to reducing nitrogen input over the longer-term through increases in soil organic matter and N storage that can increase the indigenous soil N supply capacity. Significant increases in soil organic matter and N storage have resulted from intensification of crop management practices. Intensification has not caused significant increases in the global warming potential of these cropping systems (Adviento-Borbe, 2007).

MATERIALS AND METHODS

The UNL research program on *Ecological intensification of irrigated maize-based cropping systems* has the following objectives: (i) improve the understanding of the yield potential of corn and soybean and how it is affected by management, (ii) develop a scientific basis for evaluating yield potential at different locations, (ii) develop practical technologies for managing intensive cropping systems at 70-80% of the yield potential, and (iv) conduct an integrated assessment of productivity, profitability, input use efficiency, soil carbon sequestration, energy and carbon budgets, and trace gas emissions.

Experimental details are as follows:

Soil: Kennebec sil (fine-silty, mixed, mesic Cumulic Hapludoll)

pH (limed to 6.0), 2.7% OM, 67 ppm Bray P1, 350 ppm extractable K.

Field experiment conducted at Lincoln, NE from 1999 through 2003

Treatments:

•3x3x2 factorial experiment conducted in a split-split plot randomized complete block design

•*Main-plot*: **Irrigated crop rotations** (**CC**-continuous maize, **CS**-maize-soybean)

•*Sub-plot*: **Plant population density** (**P1**-33; **P2**-37, **P3**-44 1000pl./acre)

•Maize hybrid Pioneer 33A14 (Bt) planted in 1999 and 2000; Pioneer 33P67 (Bt) planted in 2001 and 2002; Pioneer 31N28 planted in 2003.

•*<u>Sub-sub-plot</u>*: **Fertilizer nutrient management** as (M1-recommended NPK rates for a yield goal of 200 bu/acre, M2-intensive NPK management for 300 bu/acre yield goal.

- **M1**: 107-123 lb N/a for corn after soybean, 161-181 lb N/a for corn after corn, using UNL N recommendations; no P and K applied (high soil test values). Nitrogen split into two applications (pre-plant and V6 stages)
- **M2**: 193-266 lb N/a for maize after soybean, 223-324 lb N/a for maize after maize; 92 lb P_2O_5/a, 93 lb K_2O/a, 10 lb S/a per crop. Nitrogen split into 4 applications (pre-plant, V6, V10 and VT stages)

Nitrogen fertilizer application rates have been made on the basis of yield goal, spring residual soil nitrate to a depth of 4 feet, organic matter content and credit for previous crop of soybean as outlined in the UNL nitrogen algorithm (Shapiro, et al., 2001). ***<u>In 2006-7</u>***, the corn population treatment was changed to P1=30k/acre 2 30"rows, P2=40k/acre @ 30" rows and P3=40k/acre @15"rows. In 2007, no yields were taken as the corn crop was taken by a severe wind storm that made it impossible to harvest corn to determine yield. The crop was salvaged by combine harvest and soil prepared for planting in 2008. No fall application of n ***<u>In 2008,</u>*** rotation sequences were continued, but corn was planted in all plots at a population of 34k/acre without the application of P or K (no M1 or M2 treatments). A single blanket application of 50 lb N/acre was made prior to planting. Corn was irrigated as in the past and harvested to determine the impact of recorded changes in soil quality on grain yield and nutrient uptake. Herein we will report on corn yield, N use efficiency (NUE) and changes in both soil C and N over the course of the experiment and the residual effect of changes in soil quality on corn yield in 2008.

RESULTS

<u>Summary of long-term results</u>

Table 1. Crop management practices and grain yields in continuous corn (CC) and corn/soybean rotation (CS) systems with recommended (-rec) or intensive (-int) management (2000-2005).

	CS-Rec	**CS-Int**	**CC-Rec**	**CC-Int**
Yield goal (% of yield potential)	80-90	90-100	80-90	90-100
Plant density, corn (1000 pl/a)	30	35-40	30	35-40
N applied to corn (lb/a)	118-127	209-227	164-218	227-281
no. of N applications to corn	2	4	2	4
N on corn residue in fall (lb/a)	0	45	0	45
N applied to soybean (lb/a)	0	70	0	70
P & K applications (lb/a)	0	40/75	0	40/75
Avg. annual N application (lb/a)	64	156	183	272
Range in corn yield (bu/a)	221-268	220-287	178-255	208-266
Average corn yield (bu/a)	238	255	223	244
Average soybean yield (bu/a)	72	75	-	-

Average crop yields in this experiment were close to the yield potential of soybean and corn at this location and significantly higher than the national or state average. Corn yields were generally in the 215 to 287 bu/a range or within 84 to 97% of the simulated yield potential. Corn following soybean yielded about 5 to 11% higher than continuous corn primarily due to fewer problems with stand establishment and fewer pest and disease problems.

<u>Changes in soil C, N and indigenous soil N supply</u>

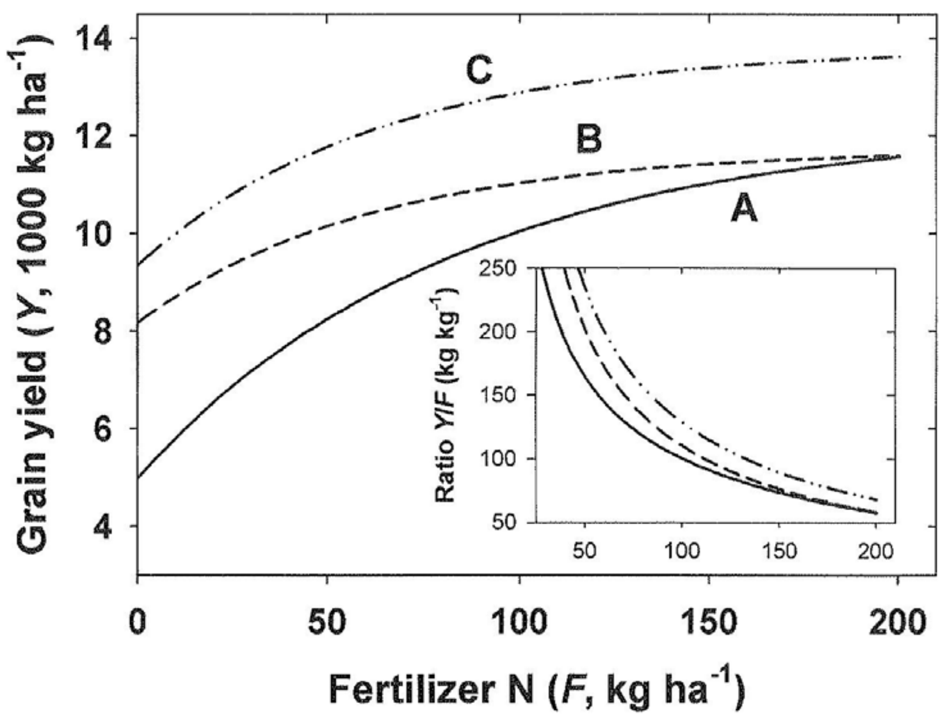

Figure 1. Hypothetical relationship between corn yield (Y) and N application rate (F) for average soil quality and average yield *(curve A)*, average yield and increased soil organic matter content and associated indigenous N supply *(curve B)*, and increased soil organic matter content and indigenous N supply with improved crop management to achieve greater N fertilizer efficiency at all rates of applied N *(curve C)*. Scenarios B and C assume an increase of 50 kg N ha-1 in indigenous soil N supply from the increase in soil organic matter. Insert shows the overall N use efficiency (Y/F) for each scenario. (From Cassman et al., 2003).

Soil organic matter (SOM) contributes to soil quality and ecosystem function through its influence on soil physical stability, soil microbial activity, nutrient storage and release, and environmental quality. Building soil organic matter requires increasing both C and N input to soil and increasing SOM becomes a function of N and C management through augmented plant productivity and increased return of crop residue. Since the C:N ration of SOC is

relatively stable,an increase in SOC decomposition should result in a greater indigenous N supply and a reduction in N fertilizer requirement (see scenarios B and C in Figure 1).
Since the start of this experiment, large amounts of crop residue have been returned to the soil in all four management systems, but with significant differences among them in terms of dry matter amounts and composition. Corn returned 75 to 100% more residue than soybean, but with a much wider C/N ratio. On a whole crop rotation basis, average annual C return with above-ground residue increased in the order CS-rec < CS-int (+8%) < CC-rec (+22%) < CC-int (+39%), whereas residue N inputs followed the order CC-rec < CS-rec < CS-int < CC-int. (Fig. 3). Both residue C and N input were highest in the CC-int system, exceeding the more commonly practiced CS-rec system by 30 to 40%.

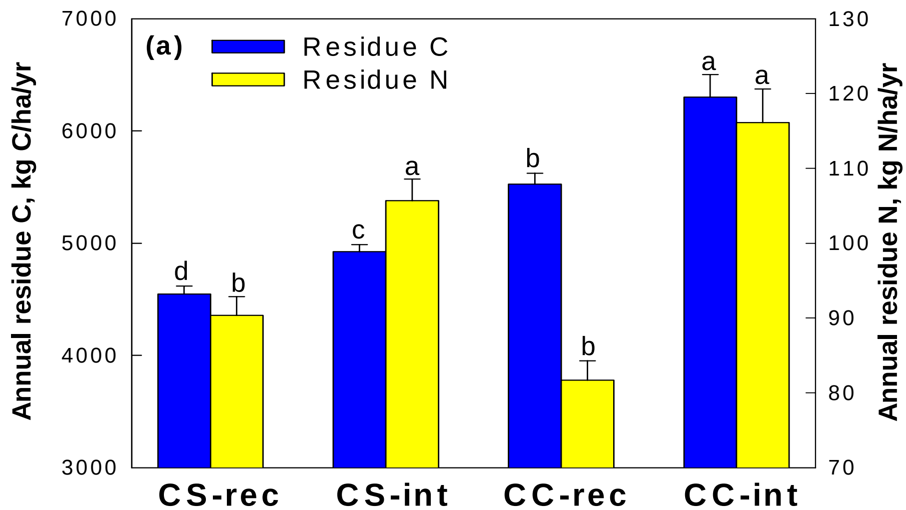

Figure 2. Average annual carbon and nitrogen input to soil in crop residues (2000 – 2006). CS = corn/soybean rotation; CC = continuous corn; rec = recommended nutrient management; int = intensive nutrient management.

In the intensive continuous corn systems, incorporation of large amounts of residue C and N has led to a significant build-up of SOM over just a few years. Although corn yields and N use efficiency were higher for the intensive corn-soybean rotation, this excellent performance was achieved at the cost of exploiting C and N reserves. Our results here confirm those of recent eddy covariance studies at other sites, showing that significant net C losses during the soybean phase of the CS rotation prohibit gains in SOC (Verma et al., 2005; Baker and Griffiths, 2005). These observations lead us to conclude that the N-credit attributed to corn-soybean rotations appears to be due to mining of soil N reserves. Significant potential for sequestration of atmospheric C therefore exists in intensively managed continuous corn systems. In the CC-int, 14% more crop residue C was returned to the soil than in the CC-rec treatment.

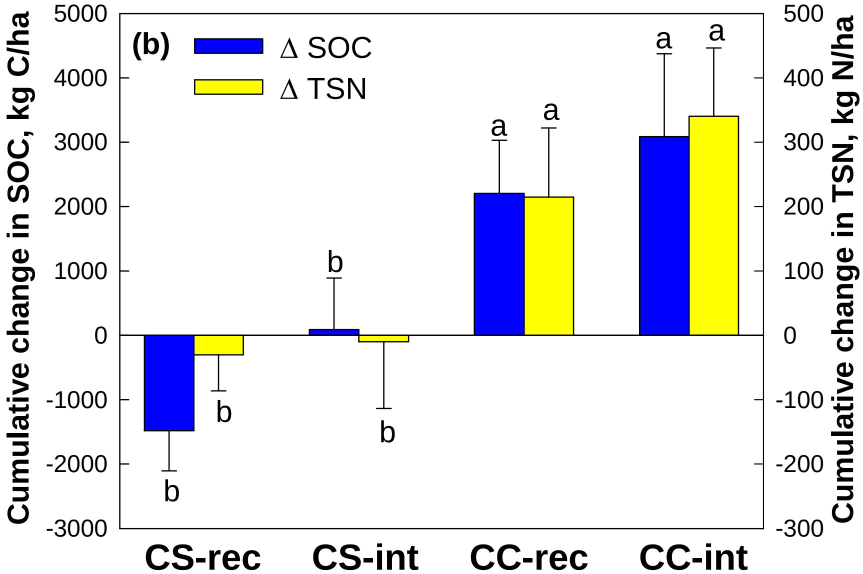

Figure 3. Cumulative change in soil carbon (SOC) and soil nitrogen (TSN) after six years of treatment. CS = corn/soybean rotation; CC = continuous corn; rec = recommended nutrient management; int = intensive nutrient management. Soil samples collected in June 2000 and 2006, 0-12"

In 2006, surface soil (0-12") was collected from CC and CS plots that had received the M1-P1 and M2-P3 treatments. Soil was sieved and incubated under aerobic conditions and periodically leached of inorganic N for a 90d period. Figure 4 shows the elevated indigenous N supply mineralized from the CC treatment that had received the M2 N rate as well as post-harvest fall applications of N to residue prior to plowing. Indigenous N supply was approximately 30% greater than the other (rotation * fertilizer management) treatments.

Nitrogen use efficiency

Table 2 presents the overall N balance and N use efficiency of the four systems. Without consideration of the change in soil TSN status, most researchers would calculate N use efficiency as the total amount of N in grain / N application rate. One can see that this calculation gives an artificially high N use efficiency for the CS-rec system compared to the CS-int or CC systems. It would seem more appropriate to calculate a system-level N use efficiency given the measured loss in TSN and SOC with soybean in rotation with corn.
Note that the additional sequestration of soil N in the CC systems has resulted in system-level N use efficiencies that are more than double those determined without soil improvement as a consideration. Conversely, the system level N use efficiency for the CS-rec system represented a 13% decline (from 3.27 to 2.84) with consideration of soil N loss.

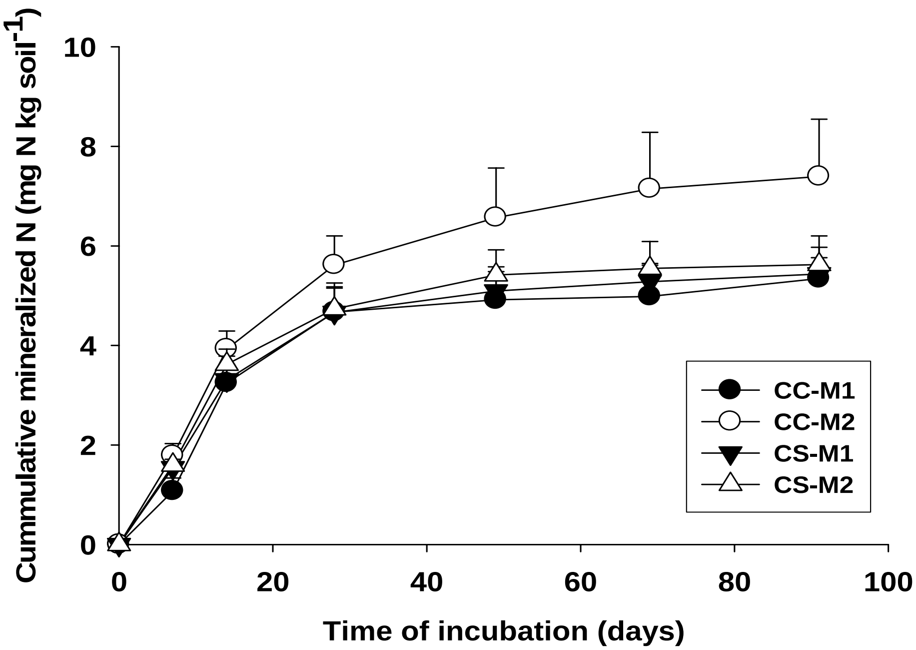

Figure 4. Cumulative mineralized nitrogen (N) in the upper 30 cm of soil after 90d of aerobic incubation (60% WFPS and 25°C).

Table 2. System level N use efficiency in continuous corn (CC) and corn/soybean rotation (CS) systems with recommended (-rec) or intensive (-int) management (2000-2005).

	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	3.27	1.38	0.88	0.65
lb grain N + change in soil N / lb N applied	2.84	1.33	1.95	1.79

2008 "Residual" corn yields

Corn yields illustrated in Figure 5 (upper panel) are those resulting from N supply in response to indigenous soil supply and the 50 lb N/acre applied to all corn plots in 2008. In the lower panel of Figure 5 are the levels of residual preplant soil nitrate in the upper 12"of soil. There was little difference in residual nitrate in the continuous corn treatments as a function of previous years treatment. In 2007, there were differential N applications applied to soybean plots and so soil nitrate levels were quite variable. Even so, there was no significant impact of soil nitrate in the CS rotation on subsequent grain yield in 2008. The most salient impact of previous management history on "residual" 2008 corn yield was the interaction of rotation*

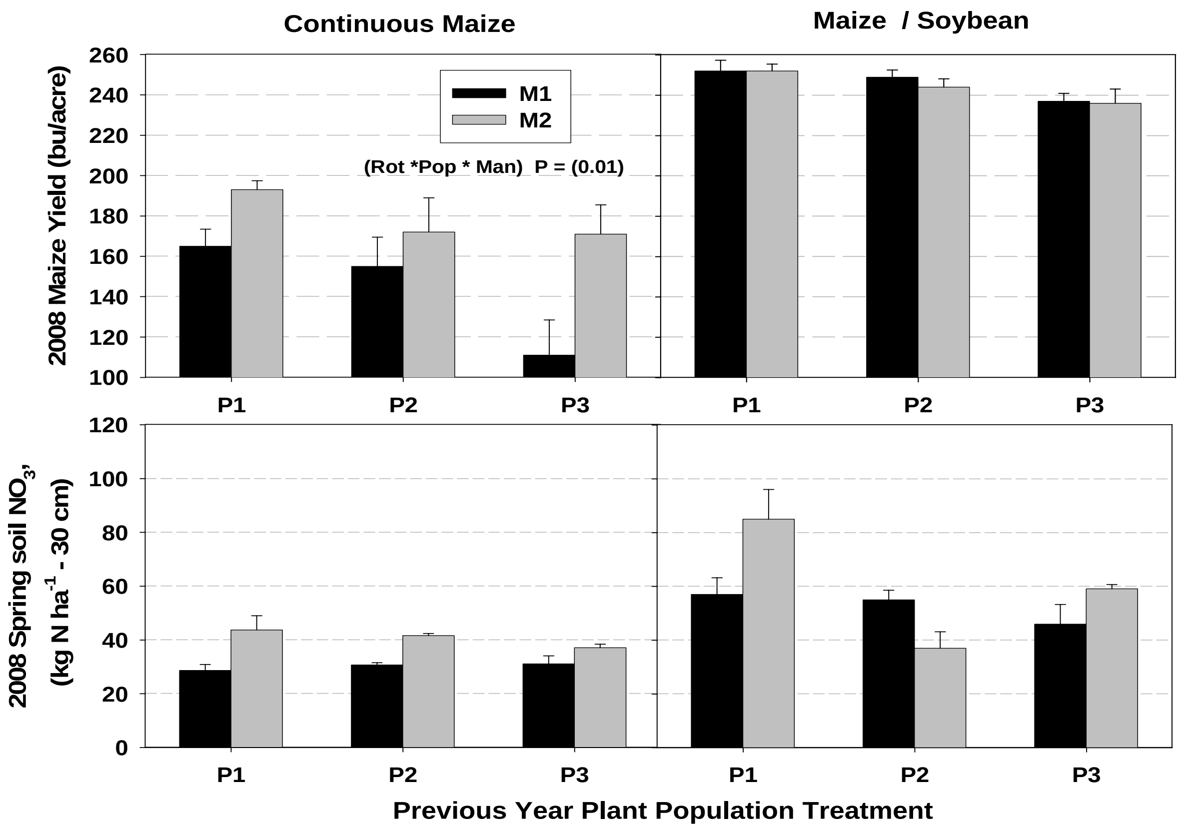

Figure 5. Upper graph: 2008 "residual" corn grain yield as a function of previous years plant population, previous crop and long-term fertility management. Corn population in 2008 was 34k/acre. There was no difference in soybean plant population in 2007. For corn, previous years plant populations were P1= 30k/acre, P2=37k/acre and P3=44k/acre (1999-2005) and P1=30k/acre, P2=40k @ 30"rows, and P3=40k @ 15"rows (2006-7). Corn received a blanket N application of 50 lb N/acre in 2008 but no M1 and M2 treatment applications. Lower graph: Spring 2008 soil nitrate N in the upper 30 cm of soil.

population * fertility management. Yields of corn after soybean were 150% of continuous corn on average apparently the result of elevated soil nitrate (in part) and lack of N immobilization pressure. As we have observed, however, the indigenous soil N supply experienced in CS rotation is the result of some degree of soil C and N loss (Figure 3 and Table 2). The increase in indigenous N supply under continuous corn was evident. Here we have observed significant increases in indigenous N supply under the long-term M2 treatment with soil N sequestration the result of increase in C input to soil with added N. Surprisingly, we observed a latent soil N immobilization pressure resulting from long-term input of high C:N residue under the CC-M1 treatment (Figures 2 and 5). The net effect of previous residue C and N input (population) was a decline in yield of 54 bu/acre from 165 to 111 bu/a under past CC-M1 treatments. Even though C inputs were significantly greater in the long-run under intensive (M2) management in CC (Figure 2), the sequestration of N and increase in indigenous N supply was evident in 2008 in that yield ranged from 193 bu/a under P1 history to a low of 171 bu/a under P3 history. Therefore, an augmented mineralization potential under M2 history (Figure 2) resulted in a difference of 60+ bu/a (Figure 5).

CONCLUSIONS

At a time when there is growing concern about the ability to produce adequate corn to meet demand for food, feed, and fuel (Cassman and Liska, 2007), the results from our research highlight several important points. First, there remains a large gap between average corn yields currently achieved by farmers and the yield potential ceiling that can be exploited through improved crop management practices. Second, intensification of cropping does not necessarily increase GHG emissions and GWP of agricultural systems provided that crops are grown with best management practices and near yield potential levels, resulting in high resource use efficiency. Managing at high yield levels creates large sinks for C and mineral N, thereby providing the prerequisite for sequestering atmospheric CO_2 and avoiding large N_2O emissions that could result from inefficient utilization of soil or fertilizer N.

Finally, the N credit associated with corn soybean rotations appears to be the result of soil N exploitation. Positive changes in soil quality and sytem level resource use efficiency can be achieved through intensification. Increase in C inputs to soil must also be accompanied by N additions to enhance indigenous N supply. Here we have demonstrated positive changes in indigenous soil N supply with intensification which translate to substantial yield responses and improvements in N use efficiency.

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