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Changes In Nitrogen Use Efficiency And Soil Quality After Five Years Of Managing For High Yield Corn And Soybean

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CHANGES IN NITROGEN USE EFFICIENCY AND SOIL QUALITY AFTER FIVE YEARS OF MANAGING FOR HIGH YIELD CORN AND SOYBEAN

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ABSTRACT

Average corn grain yields in the USA have increased linearly at a rate of 1.7 bu/acre over the past 35 years with a national yield average of 140 bu/acre. Corn yield contest winners and simulation models, however, indicate there is ~100 bu/a in exploitable corn yield gap. Four years (1999-2002) of plant development, grain yield and nutrient uptake were compared in intensive irrigated maize systems representing (a) recommended best management practices for a yield goal of 200 bu/acre (M1) and (b) intensive management aiming at a yield goal of 300 bu/acre (M2). For each management level, three levels of plant density (30000-P1, 37000-P2 and 44000-P3 seed/acre) were compared in a continuous corn and corn- soybean rotation. Over five years, the grain yields increased 11% as a function of management and this effect was manifest under higher plant densities. A high yield of 285 bu/acre was achieved at the M2, P2 treatment in 2003. Higher population resulted in greater demand for N and K per unit grain yield. Over the past five years, nitrogen use efficiency has steadily improved in the M2 treatment due to improvements in soil quality. Intensive management and population levels significantly increased residue carbon inputs with disproportionately lower soil respiration. Closing the yield gap requires higher plant population and improved nutrient management to maintain efficient and profitable improvement in maize production. Soil quality improvements and higher residue inputs under intensive management should make this task easier with time.

INTRODUCTION

Rainfed and irrigated systems in which corn is grown either in rotation with soybean or as continuous corn are the predominant cropping systems in the North American corn-belt. Average corn grain yields in the USA have increased linearly at a rate of 1.7 bu/acre over the past 35 years with a national yield average of 140 bu/acre. Results of corn-yield contest winners and data from well designed field experiments as well as simulation models indicate that the actual yield potential of corn in our temperate climate is > 300 bu/acre. Here we define yield potential (Ymax) as the maximum yield that can be obtained with no limitations in water or nutrient supply and potential crop growth is only limited by genetic characteristics, solar radiation, temperature and CO_2 concentration (van Ittersum et al., 2003). Given the apparent yield gap that exists in the US corn-belt, there are most probably significant changes in management practices that can be adopted to close this yield gap. However, there is a need to develop management systems that also preserve the integrity of the environment and that are profitable in practice. Given the lack of new agricultural lands to exploit and the ever growing need for increased productivity on existing land, intensification strategies must be developed that improve soil nutrient supply, nutrient use efficiency as well as soil nutrient supply (Cassman et al, 2002, 2003).

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.

•*Sub-sub-plot*: **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). 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.

RESULTS

Table 1 shows the trend in grain yield over the period 1999-2003. Maximum grain yields were achieved in each year of the study with plant populations of 37,000 plants/acre in 2000 and 2003 and 44, 000 plants/acre in 1999, 2001 and 2002 under intensive fertilizer management. When averaged over crop rotation, the M2 treatment resulted in an average yield gain of 11 % and this gain was manifest at higher plant populations. Although soil test values for P and K were in the very high range, current fertilizer recommendations (M1) were insufficient to supply the demand of higher biomass under the P2/3 plant populations. Yield loss at the P3 population in 2000 was due to severe heat stress in that year and a reduced period for grain fill. In 2003, the hybrid P31N28 was unresponsive to population density under the M2 treatment. This may be attributed to an excellent growing season (coolest in 30 years) where full expression of yield potential was realized regardless of population density. This could also be an artifact of the general characteristics of this hybrid, which had very erect leaf structure. We intend to use this same hybrid in 2004.

Table 1. Corn grain yield (15.5% moisture) trends in the Ecological Intensification study at Lincoln, NE as affected by crop rotation, fertility management and plant population density. Yields for the M2 treatment refer to the plant density with the highest yield in the given year (see footnote).

Treatments		**Corn grain yield 1999-2003 (bu/acre)**					
Density[¶]	**Fertilizer**	**Average**	**1999**	**2000**	**2001**	**2002**	**2003**
Continuous Corn							
P1	**M1**	**217**		241	223	178	255
P2/3	**M2**	**247**		229	252	242	265
Corn after Soybean							
P1	**M1**	**236**	219	225	230	221	268
P2/3	**M2**	**256**	257	248	249	243	285

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

Nitrogen application rates are adjusted as a function of projected yield potential, previous crop and spring residual soil NO_3-N (Table 2). Application rates have remained more consistent for the corn–soybean rotation owing in part to soybean impact on reducing residual soil NO_3-N (Table 3). Beginning in 2002, we began the practice of applying 45 to 65 lb N/a to the residue of the continuous corn M2 treatment prior to plow-down in the fall. This is meant to facilitate decomposition and humification of the high amounts of residue we have experienced under this treatment with the intent of decreasing the competition of decomposers for N resources during the early growing season. The elevated soil NO_3-N levels in the spring following these applications has resulted in a significant reduction in fertilizer rate (see table 2). The impact of these management changes on N fertilizer use efficiency (NUE) is given in Table 4. Average farm NUE is 1.03 bu/lb N. Although average NUE for the CC-M2 treatment is below this level, we have experienced a steady increase in NUE over the course of the study. This indicates the potential that exists for increasing NUE in maize based systems. We hypothesize that the increase in NUE we are observing is due to improvement in both soil quality from greater C inputs to the soil and concomitant sequestration of N with this carbon. The cumulative effect of crop residue C and N recycled in these systems is summarized in Figure 1. Over the four year period (1999-2002), 7.5 t C/a were recycled

Table 2. History of nitrogen fertilizer application to continuous corn and corn following soybean for the M1 (recommended) and M2 (intensive) fertilizer management treatments.

Treatments[¶]	Nitrogen rate 1999-2003 (lb N/acre)					
	Average	1999	2000	2001	2002	2003
Continuous Corn						
M1	**170**		181	179	161	161
M2	**268**		324	268	258*	223*
Corn after Soybean						
M1	**116**	116	123	116	107	116
M2	**224**	201	266	214	193	223

[¶]M1: pre-plant & V6, M2: Pre-plant, V6, V10, V12-VT.

**CC-M2 includes fall application of 65 lb N/acre (2001) and 45 lb N/acre (2002) on residue* prior to tillage.

Table 3. Residual soil NO3-N (spring) in the surface 4-feet of soil as affected by crop rotation, plant density and fertility managment.

Treatments		Average	Residual Soil NO_3-N in spring, 0-4 ft (lb N/acre)			
Density[¶]	Fertilizer		2000	2001	2002	2003
Continuous Corn						
P1	**M1**	58	-	50	56	67
P2/3	**M2**	130	-	105	261*	154*
Corn-Soybean (prev. crop corn)						
P1	**M1**	50	41	38	59	62
P2/3	**M2**	82	45	106	94	84
Corn-soybean (prev. crop soybean)						
P1	**M1**	70	49	76	95	60
P2/3	**M2**	87	70	96	115	67

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

in the recommended CS-P1-M1 treatment which is the most widespread rotation in the corn-belt. This amount increased to 9.1 t C/a in the intensified corn-soybean system (CS-P3-M2). Net C recycling in all of the continuous corn treatments was larger than in any of the CS treatments, reaching 9.3 t C/a in CC-P1 –M1 and a maximum of 11.7 T C/a in CC-P3-M2. This represents an increase of 48% in residue carbon inputs to soil over this four year period. Nitrogen recycled in crop residues was highest in the corn-soybean rotation with an average of 481 lb N/a vs. 356 lb N/a in the continuous corn treatment. Increased C inputs to soil can only build soil organic matter if there are not elevated losses of CO_2-C form soil respiration. We have been monitoring soil CO_2-C respiration since 1999 and have noted that fertility treatments have had a minor impact on CO_2-C losses. Figure 2 shows the CO_2-C losses during the 2003 growing season. Although losses were higher for CC (owing to the higher residue C input) fertility management did not result in soil CO2-C losses equivalent to C inputs. This suggests that increases in soil C and N should result.

Table 4. Trend in nitrogen fertilizer use efficiency as influenced by crop rotation, population density and fertility management (199-2003).

Treatments		Average 1999-2003				NUE 1999-2003				
Density¶	**Fertilizer**	**Nrate**	**Yield**	**NUE**		**1999**	**2000**	**2001**	**2002**	**2003**
		lb N/a	**bu /a**	**bu/ lbN**		---------------bushels / lb N-------------				
Continuous Corn										
P1	**M1**	170	217	**1.28**		-	1.18	1.25	1.11	1.59
P2/3	**M2**	268	247	**0.94**		-	0.71	0.94	0.94	1.18
Corn after Soybean										
P1	**M1**	116	236	**2.04**		1.89	1.83	1.98	2.06	2.31
P2/3	**M2**	224	256	**1.16**		1.28	0.93	1.16	1.26	1.28

¶¶M2 treatment with highest yielding plant density:
P2 in 2000 and 2003; P3 in 1999, 2001 and 2002.

Figure 1. Cumulative carbon and nitrogen inputs to soil in aboveground crop residues for a four-year period (1999-2002) as affected by crop rotation, plant density, and nutrient management.

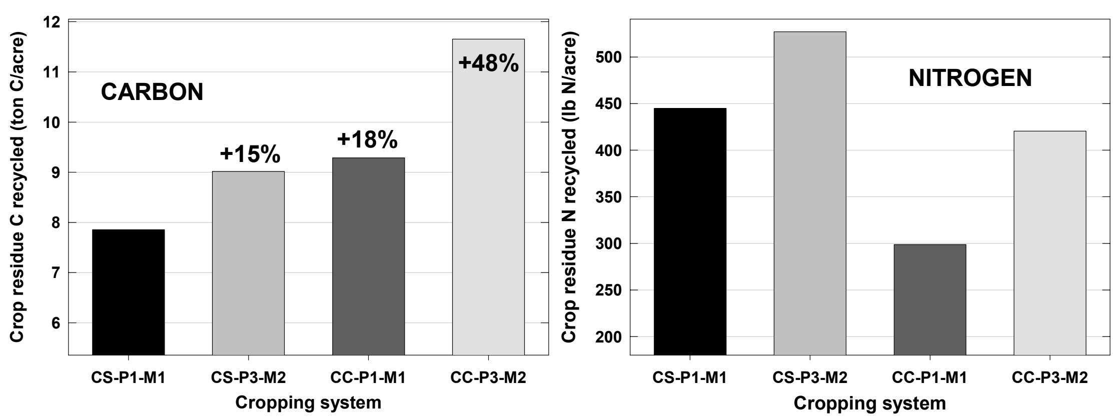


Figure 3 shows the change in both soil C and N between the period 06/2000 and 06/2003. Both soil C and N have increased over this time span and soil C has increased to a greater extent in the CS rotation relative to the CC-P1-M1 treatment. This is most likely due to the elevated residue N additions with soybean in the rotation and the impact this has in the creation of stabile humus. Highest soil C and N increases over this period have been observed for the continuous corn system under high population density and intensive fertility management. Stabilization of soil N in this system has most probably resulted in increase indigenous soil N supply and better synchrony of N supply during the growing season. This has probably been a major factor in the increase in NUE we have observed over the last five years. Studies on the nature of the changes in soil organic matter fractions and N storage and release form these fractions are underway.

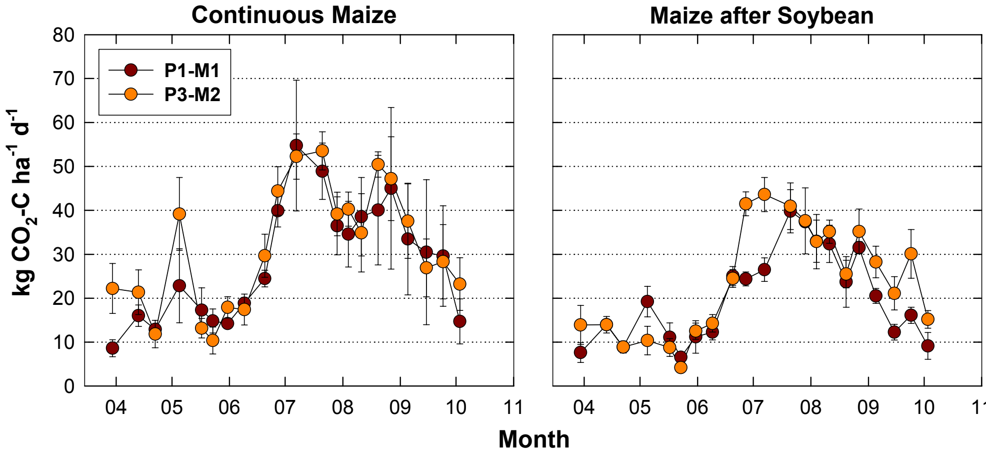
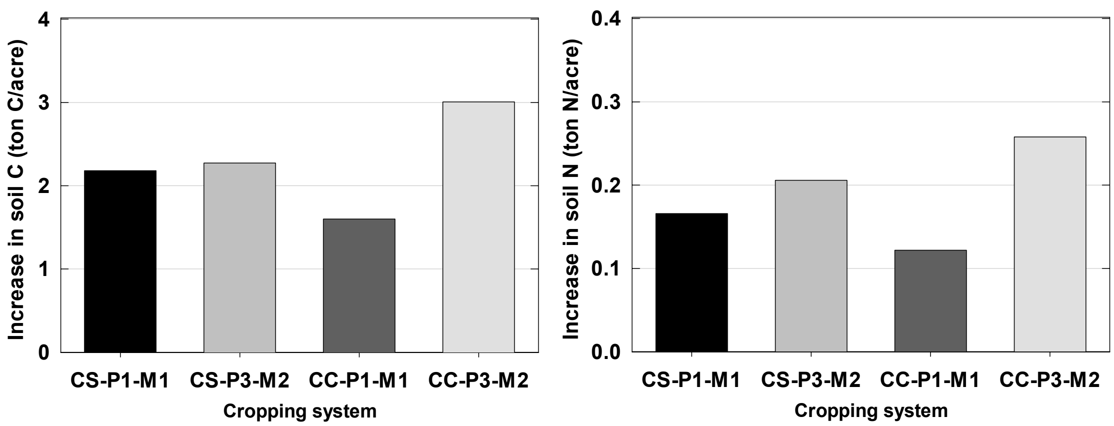


Figure 2. Soil CO2-C emissions in 2003. Cumulative emissions during the growing season:

CC-P1-M1	5200 kg C/ha	CS-P1-M1	3600 kg C/ha
CC-P3-M2	5600 kg C/ha	CS-P3-M2	4200 kg C/ha

Figure 3. Change in soil carbon and nitrogen in the upper 30 cm of soil from samples taken in the 06/2000 and 06/2003 as influenced by crop rotation, plant density, and nutrient management.



CONCLUSIONS

Average yields approaching 80% of the yield potential of corn have been routinely achieved in the Ecological Intensification project at Lincoln, NE. We have observed a trend toward improvement in nitrogen fertilizer use efficiency which, in part, is due to a gain in soil C and N storage as a result of intensive management. Closing the yield gap requires higher plant population and improved nutrient management to maintain efficient and profitable improvement in maize production. Soil quality improvements and higher residue inputs under intensive management should make this task easier with time.

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