Closing the Corn Yield Gap: Management Practices that Improve Soil Quality and Net Productivity but Reduce Global Warming Potential

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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. Yield analysis of the central U.S. Corn Belt indicates that there is a large exploitable yield gap for corn. 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 adopted varieties, planting dates, and plant populations to maximize crop productivity. In addition, more intensive N management strategies that cater, not only to improving crop N use efficiency but also residue carbon management, aid in reducing nitrogen input over the long-term. Significant increases in soil organic matter and N storage have resulted from intensification of crop management practices. In addition, intensification has not caused significant increases in the global warming potential of these cropping systems.

Yield Potential

Corn yield potential represents the maximum achievable grain yield of a cultivar or hybrid within a certain climate to which it is adapted when grown with minimal biotic or abiotic stresses. Here the only limitations are temperature, solar radiation, and genetics. How do we measure yield potential for a given region? That is best done by cultivating the crop in field experiments under optimal management with no nutrient or water limitations and careful control of diseases. An alternate and more convenient means of estimating yield potential is with well calibrated mechanistic simulation models.

Figure 1 shows a timeline of National Corn Growers Association yield contest winners for the irrigated and rainfed categories with both first and second place winners in each year. One can see that within a given year the first and second place yields are very similar and that the gap between irrigated and rainfed yields has narrowed owing to better-adapted, more stress-resistant cultivars. The yield potential for the irrigated category hovers around the 300-320 bu/A range which identifies this as the probable yield ceiling. Figure 2 shows a similar exercise whereby yield potential is estimated with the Hybrid-maize model (Yang et al., 2004) over a wide range of sites within the U.S. Corn Belt. Based upon these simulations, the Hybrid-maize model has also determined a ceiling for corn yield potential in the same range as the NCGA contest winners. The model simulation, however, indicates that a minimum of 60 days of reproductive growth is needed to achieve yield potential. This would suggest that abnormally hot years (rapid GDD accumulation) would limit corn yield. Based upon the average rainfed and irrigated corn yields, these data would suggest that limitations in our

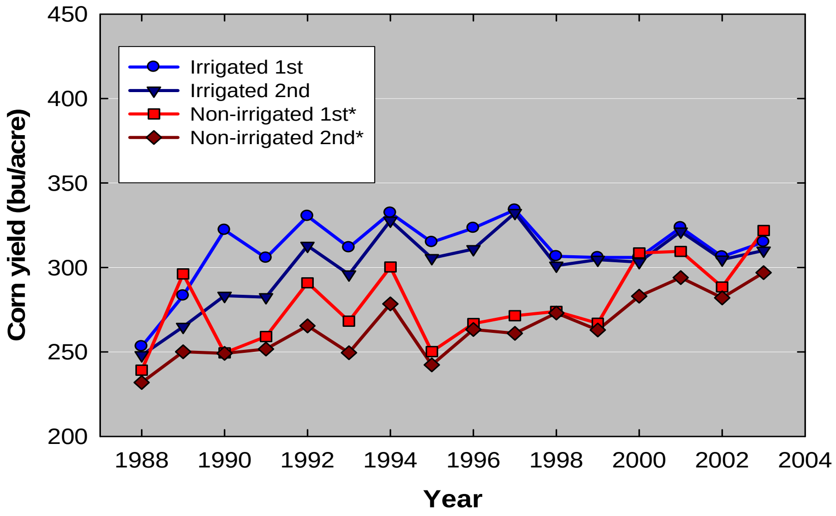

Figure 1. Yield trend for irrigated and non-irrigated corn yield contest winners of the NCGA through 2003. Average corn yields irrigated ≈ 170 bu/a , rainfed ≈ 110 bu/A.

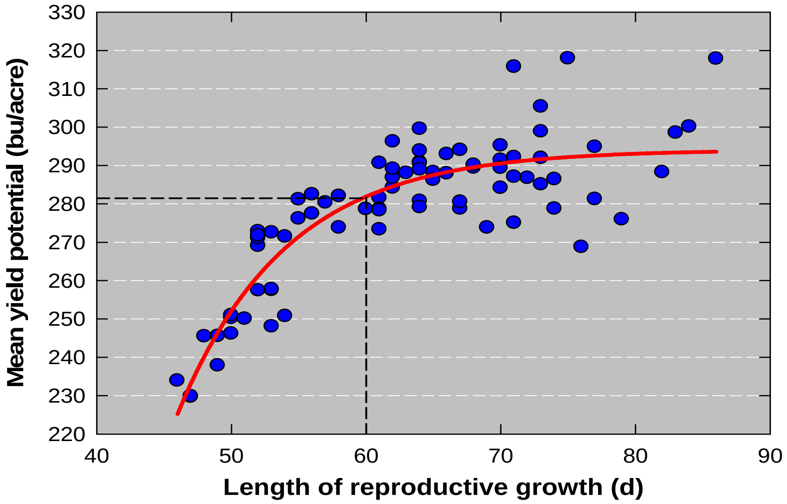

Figure 2. Hybrid-Maize simulated corn yield for 80 locations across the U.S. Corn Belt within Lat 32.7-42.7 N; Long 88-102 W; Elev. 130 – 1390 m. Hybrid: 2650 GDU (110 d CRM); Planting date: May 1, 40,000 plants/A. Management: no limitations by water or nutrients.

nutrient management, plant population, and disease suppression have limited us to 60% of yield potential. At issue is whether closing this yield gap can be achieved in a sustainable fashion with minimal environmental impact and without increasing GHG emissions from agricultural land. To assess such options requires full accounting of the global warming potential (GWP) of agricultural systems including the net changes in soil organic carbon (SOC), the energy consumed in crop production and the trace gas emissions (notably N_2O) associated with N management.

The Ecological Intensification Experiment

In order to address these questions, a long-term experiment was established in 1999 in Lincoln, NE. The primary objective of this experiment is to evaluate resource-efficient management concepts for achieving crop yields that approach the climatic yield potential. The soil at this site is a deep Kennebec silty clay loam with high soil fertility status (pH 6 to 6.5, 2.5% to 3% organic matter, 300 to 400 ppm K, and 60 to 80 ppm Bray P-1 P) The experiment is conducted with three crop rotations as main plots (CC=continuous corn, CS or SC=corn soybean rotation with an entry point into each crop in each year), three plant populations densities as sub-plots and two levels of nutrient management (recommended and intensive) as the final split. For this paper, four management systems are evaluated, CC-recommended management, CC-intensive management, CS-recommended, and CS-intensive. Table 1 summarizes the range in nutrient management, population and yield for these treatments through 2005.

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
Average corn yield (bu/A)	234	249	223	239
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.

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 (Figure 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%.

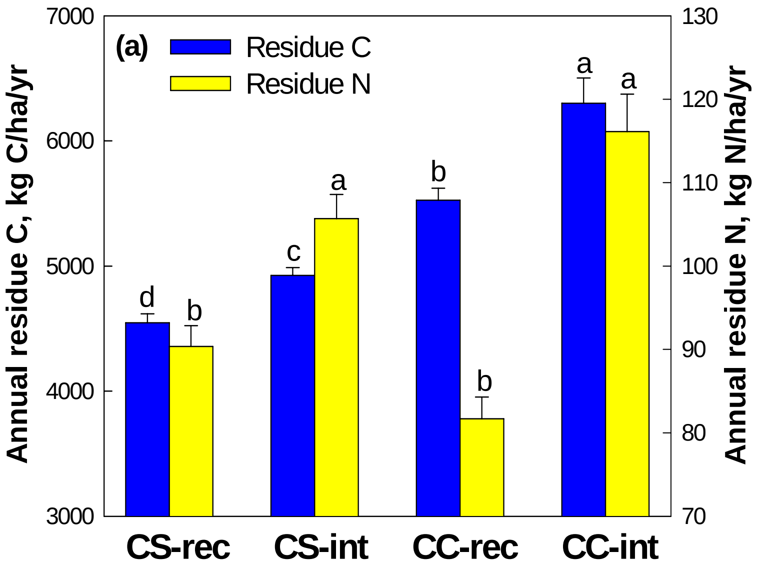

Figure 3. Average annual carbon and nitrogen input to soil in crop residues (2000-2006). CS=corn/soybean rotation; CC=continuous corn; rec=recommended nutrient management; int=intensive nutrient management.

Changes in Soil Organic Carbon and Nitrogen

Despite the large biomass production in our high yielding corn systems, peak growing season (about 36 to 55 lb C/A/day) soil CO_2 efflux was within typical ranges for arable crops. In a complete 2-year crop rotation with flux measurements conducted in corn and soybean, soil CO_2 efflux (respiration) in the continuous corn systems was 22% larger than in corn-soybean rotations at both levels of management intensity. Within each crop rotation, intensified fertility management did not cause a significant increase in soil CO_2 emissions as compared to the recommended practice. As a result, both SOC and total soil N (TSN) increased in the two CC systems, but decreased in the CS-rec or remained unchanged in the CS-int system. On average, SOC *declined* at an average rate of 275 lb/A/yr in the CS-rec, whereas it *increased* at a rate of 565 lb N/A/yr in the CC-intensive (0- to 12-inch depth). Similar trends were observed for TSN (Figure 4).

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.

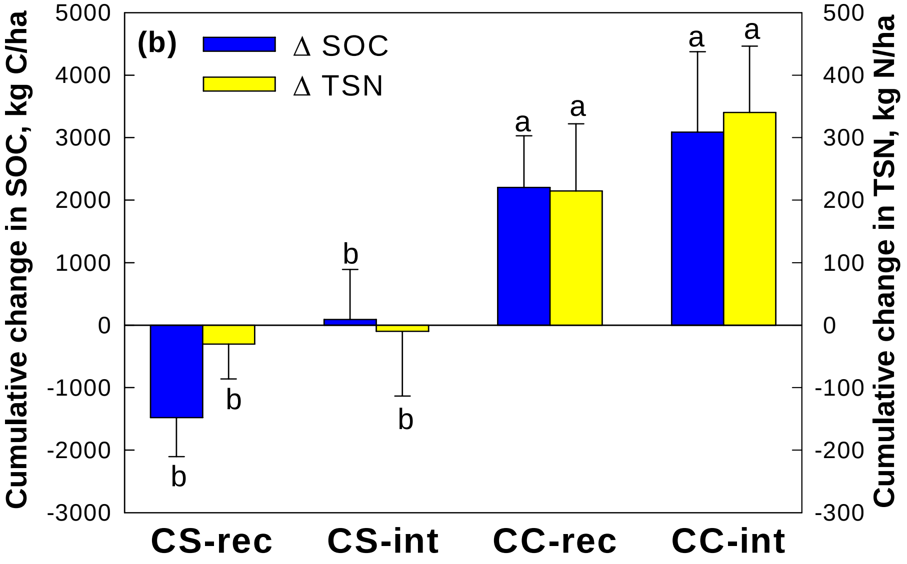

Figure 2. Cumulative change in soil carbon (SOC) and soil nitrogen (TSN) after six years of treatment. CS=corn/soybean rotation; CC=continuous corn; rec=recommended nutrient management; int=intensive nutrient management. Soil samples collected in June 2000 and 2006, 0-12".

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.

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 , 0-12Ó, 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

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 (form 3.27 to 2.84) with consideration of soil N loss.

Global Warming Potential

When fossil fuel consumption, CO_2-C losses, and trace gas emissions are factored into total GWP of these systems, all four cropping systems were net sources of GHG, with GWP ranging from 0.54 to 1.02 tons of CO_2-C/acre/year. Positive or negative changes in SOC, intrinsic C costs associated with crop production, and soil N_2O emissions were major contributors to the net GWP. The oxidation of CH_4 (methane) by these soils gave only a small mitigation capacity (Table 3). Nitrogen fertilizer (16% to 36%), energy used for irrigation (15% to 22%), electricity for grain drying (13% to 18%), diesel (10% to 16%), and lime (9% to 13%) were the major components of the C costs associated with agricultural production. Despite higher C costs associated with agricultural production and also higher N_2O emissions, net GWP in the continuous maize systems was lower than that of the corn-soybean systems because sequestration of atmospheric CO_2 in SOC was observed only in the CC systems. Although the amount of N fertilizer N applied to corn grown in the intensive cropping systems was 40% (CC) or 64% to 92% (CS) greater than the recommended treatments, N_2O losses were not directly related to the level of N input only. Significant N_2O losses were observed during the soybean year especially after soybean harvest.

Table 1. Global warming potential (GWP) expressed as CO_2-C equivalents for continuous corn and corn-soybean rotation. Averages for corn and soybean grown during 2000-2005. GWP = Agricultural production + ΔSOC + soil N_2O + soil CH_4 . A negative number indicates sequestration of C from the atmosphere.

GWP components		Continuous Corn		Corn-Soybean	
		Recomm.	Intensive	Recomm.	Intensive
		Tons CO_2-C equivalents / A/ yr			
Agricultural Production	N fertilizer	0.22	0.33	0.08	0.18
	P,K, fertilizer	0	0.06	0	0.06
	Lime	0.06	0.09	0.06	0.09
	Seed, pesticides	0.05	0.06	0.05	0.06
	Machinery	0.02	0.03	0.02	0.03
	Diesel	0.09	0.09	0.08	0.08
	Irrigation	0.14	0.14	0.11	0.11
	Grain drying	0.11	0.12	0.09	0.10
Total		0.69	0.92	0.49	0.71
Soil C		-0.44	-0.62	0.30	-0.02
Soil N_2O		0.32	0.57	0.25	0.34
Soil CH_4		-0.03	-0.03	-0.02	-0.10
GWP		**0.54**	**0.84**	**1.02**	**1.02**

Conclusions

These results suggest that 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. High-yielding continuous corn systems have significant potential for GHG mitigation, particularly if corn grain is converted to bioethanol. 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.

The N credit associated with corn-soybean rotations appears to be the result of soil N exploitation. Net soil C loss was recorded for the conventional corn-soybean rotation. Other studies utilizing eddy covariance techniques confirm that the total gross C fixation (GPP) by corn is twice that of soybean. Ecosystem respiration of corn, however, is only 60% of corn GPP but is 85% of GPP for soybean. Thus the net C sequestration potential of corn is four times as great as soybean. The great differences in corn and soybean C sequestration potential suggest that continuous corn systems may indeed hold greater promise for mitigation of global warming than the conventional corn soybean rotation.

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