

Achieving 300 Bu/A Corn Sustainability

Involves agricultural intensification that pursues higher yields, biofuel production potential, and preservation of our soil and water resources.

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Summary: As the world's greatest producer of corn, U.S. agriculture is obligated to pursue both higher yields and sustainable production practices. The United Nations predicts that the global human population will increase by more than 30 percent to 9 billion by 2050. Agricultural researchers and policy makers estimate that grain yields must increase by 70 to 200 percent to meet demands of a growing population that is increasingly demanding a meat-based diet. While low-input, low-intensity farming systems preserve soil resources and meet most definitions of agricultural sustainability, these systems often sacrifice yield potential. For the world's three staple food crops (rice, wheat, and corn) we must find ways to increase, not decrease the yield per unit of cropped land. Based on increased net primary productivity, improved nutrient use efficiency (NUE) and suitable conservation practices, high-population corn systems may be more environmentally sustainable than current production systems when managed appropriately and when restricted to the most suitable land. By assessing agricultural sustainability in terms of the energy resources embodied in long- and short-term energy/carbon plant fractions, we present a research approach to agricultural intensification that pursues higher yields, biofuel production potential, and preservation of our soil and water resources.



Based on United Nations predictions that the human population will increase by 30 percent by 2050, scientists and policy makers conclude that we will need to increase 2009 grain yield levels by up to 200 percent to meet demands of a growing population that is increasingly demanding a meat-based diet. According to the USDA's October 2010 Grain World Market Report, the United States produced 55 percent of the world's corn last year. Over 40 percent of American-grown corn came from Iowa, Illinois, Nebraska, and Minnesota. As the world's greatest producers of corn, we are obligated to pursue both higher yields and sustainable production practices. Academic thought regarding sustainable farming of staple crops is shifting from a low-input, low-intensity philosophy to a system of intensification. The low-input, low-intensity method preserves soil resources, yet sacrifices yield potential. This may be acceptable for most commodities, but for the world's three staple food crops (rice, wheat, and corn) we must find ways to increase, not decrease, the yield per unit of cropped land. The new philosophy of intensification pursues higher yields

exclusively on land best suited for crop production and uses agricultural practices that protect the soil resource and enhance efficiency of nutrient uptake.

Our research approach in this report evaluates corn grain for feed and food, stover for feed and biofuel production, and below ground root and exudates to return soil organic matter and support a larger soil biological community (bacteria, fungi, nematodes, earthworms, etc.).

Improving efficiency

It is widely recognized among growers that losing agricultural inputs via leaching, denitrification, erosion, and runoff is wasteful economically, agronomically, and environmentally. Research shows that improved NUE and other agricultural inputs are well within our grasp. As Tilman, et al., (2003) point out, U.S. corn yields increased by nearly 40 percent from 1980 to 2000 without any increase in nitrogen (N) fertilizer application. Tilman, et al. go on to predict that advances in plant breeding, biotechnology, and crop and soil management will account for future increases in global crop production without negative environmental consequences.

Doubling yields? Edgerton (2009) predicts that the combination of marker-assisted breeding, biotechnological traits, and continued advances in agronomic practices will make it possible for the U.S. to double corn yields over the next two decades. This advancement in yield entails a 10-ton/ha (167 bu/A) yield increase over the current U.S. corn yield average. Edgerton estimates that about 80 percent of the increased yield gain will be the result of introducing new biotechnological traits and marker-assisted breeding practices. New corn hybrids with genetic traits that offer greater tolerance to herbicides, insect feeding, pathogens, drought, low soil fertility, and other plant stressors will create the potential for yield increases.

Plant population. To realize the full potential of new genetics, modern hybrids must be grown at higher plant populations than their predecessors. Increasing corn plant populations has been shown to improve N and phosphorous (P) use efficiency as well as uptake of other agricultural inputs such as sulfur (S), fungicides, and insecticides. Evidence also suggests that increasing corn plant populations using narrower corn rows

may produce more corn stover than traditional 30-inch rows as well as greater below ground plant biomass.

Biomass. Corn root biomass is substantially more effective at increasing soil organic matter and sequestering carbon (C) than corn stover. Most models estimating sustainable levels of stover removal also fail to include the substantial mass of C released to the soil in the form of root exudates. Despite frequently voiced concerns about removal of corn stover as an agent for reducing soil organic matter, we suggest (based on previous soil physical, chemical, and biological property analysis) that a percentage of corn stover is most judiciously used to promote the increasingly more efficient biofuel industry. A primary directive of the 2007 Energy Independence and Security Act is to promote ethanol production with a goal of 36 billion gallons by 2022, of which 21 billion gallons are to derive from cellulosic feedstock. When viewed from the landscape scale, we believe supporting the biofuel industry with harvested stover can be environmentally sustainable while also serving to help meet governmental directives regarding national energy independence and reducing dependence on fossil fuels.

Organizing

Ranking. By compiling research data from the past 20+ years at the Crop Physiology Laboratory (CPL) at the University of Illinois, we have ranked the factors that appear to have the greatest impact (both positive and negative) on corn yield. The seven factors are shown in Table 1.

Prerequisites. In our quest for 300 bu/A corn, we determined an average bushel per acre value provided by each factor along with specific prerequisites such as drainage, fertility, and weed control. Included in the prerequisites were:

- Proper soil pH and adequate levels of soil P and potassium (K)
- Other soil fertility considerations such as sulfur (S) and micronutrients
- Adequate weed, insect, and disease control

Omission plot

Based on our compiled research data, an omission plot experimental design was conceived to test five of the seven identified factors (N, other fertility, genetic traits, population, and growth regulators) for their individual and cumulative effects on corn yield:

Table 1. Seven wonders of the corn yield world.

Rank	Factor	Value	
		Bu/A	%
1	Weather	70+	27
2	Nitrogen	70	26
3	Hybrid	50	19
4	Previous crop	25	10
5	Plant population	20	8
6	Tillage	15	6
7	Growth regulators	10	4
Total =		260 bu/A	100%

Given key prerequisites

Table 2. Greater nutrient removal with grain as a result of biotechnology traits.

Nutrient	Non RW	Root worm	Difference
	bu/A or lbs/A removed		%
Yield	179	205	15
N	110	126	14
P	17	21	24
K	26	31	19
S	8.9	10.4	17
Zn (oz)	2,2	2,8	27

Champaign, IL (2008) average of two hybrid pairs

1. No P or K versus 100 lbs P₂O₅ with S and Zn for balanced nutrition like MESZ (12-40-0-10[S] – 1[Zn])
2. 180 lbs UAN preplant versus 100 additional lbs of N sidedressed as a stabilized N source (like Super-U)
3. RR refuge hybrid versus insect-protection-traited hybrid like DKC 61-19 (both with soil insecticide at planting)
4. 32,000 plants/A versus 45,000 plants/A (both in 30-inch rows and twin rows in 2010)
5. No fungicide versus Headline or Quilt-Xcel (@ R1)

Table 3 shows a comparison of high-tech versus standard practices ('Traditional') over two years and the resulting difference in corn yield.

The yield enhancement from the use of the five high-yield factors was compared to the traditional system and the value of each individual factor was determined using the omission plot approach where each factor is either added (one at a time) to the traditional system or removed (one at a time) from the high-technology system. For instance, in the traditional

package with a plant population of 32,000 plants per acre, the yield was 193 bu/A (second column, first row of Table 3); when the population was increased to 45,000 plants per acre while all other factors were maintained the same as the traditional package, yield decreased by 6 bu/A (to 187 bu/A; second column, row 5 of Table 3). In the high-tech package with all of the optimized inputs and plant population of 45,000 plants per acre, the measured yield was 245 bu/A (column 4, row 1 of Table 3). When the population was decreased to 32,000 plants per acre while all other factors were maintained the same as in the high-tech package, yield was reduced by 7 bu/A (to 238 bu/A; column 4, row 5 of Table 3). Based on data for 2008 and 2009, it was determined that population is an integral factor for high yield; however, we also recognized the need for plant density management at high populations to avoid interplant competition, which can decrease per-plant yield. We identified twin-row planting technology as a potential way to manage high plant populations that also allows for fertilizer application at planting near the seed.

Table 3. Traditional vs. high-tech, two years.				
	Traditional		High-tech	
Factor	Yield	*	Yield	**
	Bu/A ⁻¹			
None or all	193		245	
Fertility	197	+4	236	-9
Nitrogen	198	+5	232	-13
Genetics	202	+9	225	-20
Population	187	-6	238	-7
Fungicide	198	+5	218	-27

Data from Champaign and Dixon Springs
* Difference when changed to high-tech level
** Difference when changed to traditional level
*** Adapted from Ruffo, Henninger, and Below. A new experimental design to analyze the value of management factors contributing to high corn yield. *Am. Soc. Ag. Mtg. Oct 31-Nov 4, 2010.*

Expanding study

Based on the data collected from two years of high-yield studies, we propose to expand the study design to include conservation practices and sustainability measurements. In 2011, we will add three additional factors to the omission plot experimental design: crop rotation, partial stover removal, and tillage intensity. Research and conventional wisdom provide evidence that corn following soybean produces greater yields than following corn. Research by the CPL has indicated that the primary agent of yield reduction in corn-corn rotations is corn residue, although the mechanism is not fully understood. A number of studies have shown that with proper management and additional organic inputs, stover removal can be performed without degrading soil quality or reducing soil organic matter content. We propose that partial stover removal in the high-yield corn environment cannot only be performed in a sustainable manner, but that the use of stover for biofuel or animal feed is a more environmentally sustainable application for corn stover than allowing it to slowly decompose at the soil's surface. Another benefit of partial stover removal is that less corn residue greatly facilitates strip tillage activities from a mechanical perspective, thus promoting conservation tillage in the high-yield environment. We will assess the effects of removing corn stover for reducing soil organic matter and for reducing the continuous corn yield penalty. We will also conduct plant tissue analyses of removed stover to estimate soil carbon and plant nutrients removed at various stover harvest rates. This will result in information

that can be used to create appropriate fertilizer recommendations based on how much stover is removed.

Strip tillage is a relatively new reduced tillage system that protects soil from erosion, retains plant-available water later in the growing season, and allows banding of fertilizers for more efficient plant uptake and reduced erosional losses associated with broadcast fertilization. Although strip tillage has been used exclusively in single-row cropping systems to date, we propose that strip tillage can also be used with twin-row corn systems and that pairing strip tillage with twin-row technologies will result in improved plant nutrient uptake, reduced soil erosion, and increased soil organic matter retention.

Anticipated results

Yield results. In the previously described high-yield study investigating the individual and combined use of five "high-tech" factors versus "traditional" practices, the combined "high-tech" treatment yielded 14 to 66 bu/A more grain than the treatment combining only "traditional" inputs and practices (Table 3). Although there was variation in the data set influenced by site and weather, in all cases the value of a given high-yield factor was more influential on yield when combined with other high-yield factors, rather than provided alone. These trials show that single production factors used alone do not guarantee high corn yields; rather, it is the positive interaction among multiple complementary factors that will optimize the production potential of each plant and result in higher corn yields. We will implement the same treatment design using combinations of complementary high-yielding management practices to

assess the effect of the practices both on yield and sustainability metrics.

Environmental results. We define agricultural sustainability as a system of crop and animal production that, over the long term:

- Satisfies human, food, fiber, forage, and fuel needs
- Sustains the economic vitality of farm operations
- Maintains or improves soil organic matter, soil structure, and water quality (modified from the 1990 Farm Bill).

Looking ahead

We propose to maintain or improve soil organic matter by reducing tillage and increasing plant populations, thus creating more below ground root biomass and exudates. We will maintain and improve soil structure both with strip tillage and the addition of below ground plant biomass to increase soil organic matter. Finally, we will maintain or improve water quality by optimizing the use of every agricultural input that is applied to the crop.

Specifically, we will achieve this by improving N uptake efficiency with split N application, slow-release N inputs, and optimum placement of inputs by banding P and S fertilizer with the strip tiller. Finally, by creating a favorable rooting environment with strip tillage, banding nutrients, and using the most advanced suitable crop hybrids, we will optimize the corn root system for maximal fertilizer recovery and increased below ground carbon sequestration.

We will evaluate sustainability in a number of ways, primarily focusing on nutrient uptake efficiency and the validity of removing corn stover based on additional root production in the high-yield environment. Less tangible and quantifiable sustainable outcomes (e.g., improved water availability and soil structure, reduced soil erosion, and fossil fuel combustion) will be observed and recorded whenever possible.

From an environmental perspective, the outcome of this project will be highly beneficial, resulting in preservation of our soil and water resources for future generations.

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