ACHIEVING 300 BUSHELS-PER-ACRE CORN SUSTAINABLY: A PROCEEDINGS OF THE 2011 FLUID FERTILIZER FOUNDATION SYMPOSIUM – CROPPING INTENSIFICATION ON THE FARM

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ABSTRACT

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% to 9 billion by 2050. Agricultural researchers and policy makers estimate that grain yields must increase by 70-200% 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 foodcrops (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, greater nutrient use efficiency, 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.

INTRODUCTION

Based on United Nations predictions that the human population will increase by 30% by 2050, scientists and policy makers conclude that we will need to increase 2009 grain yield levels by up to 200% 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% of the world's corn last year. Over 40% 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 foodcrops (rice, wheat, and corn) we must find ways to increase, not decrease, the yield per unit of cropped land. This new philosophy of intensification pursues higher yields exclusively on the land best-suited for crop production and utilizes agricultural practices that protect the soil resource and enhances efficiency of nutrient uptake (Cassman et al. 2002). Our research approach evaluates corn grain for feed and food, stover for feed and biofuel production, and belowground roots and exudates to return soil organic matter and support a larger soil biological community (bacteria, fungi, nematodes, earthworms, etc.).

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 use efficiency of nitrogen and other agricultural inputs is well within our grasp. Tilman et al. (2002) point out that U.S. corn yields increased by nearly 40% from 1980-2000 without any increase in nitrogen fertilizer application and they predicted that advances in plant breeding, biotechnology, and crop and soil management will account for future increases in global crop production without negative environmental consequences. Edgerton (2009) states that the combination of marker-assisted breeding, biotechnology 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 tonne/ha yield increase over the current U.S. corn yield average; Edgerton estimates that about 80% of the increased yield gain will be the result of introducing new biotechnology traits and marker-assisted breeding practices. New corn hybrids with genetic traits that confer greater tolerance to herbicide, insect feeding, pathogens, drought, low soil fertility, and other plant stressors create the potential for yield increase.

However, to realize the full potential of new genetics, modern hybrids must be grown at higher plant populations than their predecessors (Tollenaar 1989; Tokatlidis and Koutroubas 2004).

Increasing corn plant populations has been shown to improve N and P use efficiency (Boomsma et al. 2009; Clay et al. 2009) and may also improve water-use efficiency (Kuchenbuch et al. 2009) as well as uptake of other agricultural inputs such as sulfur, fungicides, and insecticides. Additionally, evidence suggests that increasing corn plant populations using narrower corn rows may also produce more corn stover than traditional 30-inch rows (Hammer et al. 2009) and greater belowground plant biomass (Kuchenbuch et al. 2009). Additionally, corn root biomass is substantially more effective at increasing soil organic matter and sequestering carbon than corn stover (Balesdent & Balabane 1996; Hooker et al. 2005; Johnson et al. 2007). Most current models estimating sustainable levels of stover removal also fail to include the substantial mass of carbon released to the soil in the form of root exudates (Wilts et al. 2004; Amos & Walters 2006). 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 (Hooker et al. 2005, Johnson et al. 2006, Wilhelm et al. 2007) 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.

WORK PLAN

The Crop Physiology Laboratory at UIUC has conducted experiments over the last 20 years to identify the principle factors that result in increased corn yields. The seven factors (sometimes referred to as the "Seven wonders of the corn yield world") that were found to have the greatest impact on high yielding corn production are: 1. Weather; 2. Nitrogen; 3. Hybrid; 4. Previous Crop; 5. Population; 6. Tillage; and 7. Growth Regulators. Based on this information, an omission plot experimental design was conceived to test five of the identified factors (nitrogen, other fertility, genetic traits, population, and growth regulators) for their individual and cumulative effects on yield. This highly-managed, systematic approach to yield factor identification is described in Table 1. Based on data from 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 inter-plant competition which can decrease per-plant yield (Boomsma et al. 2009). We identified twin row planting technology as a method to manage high plant populations that also provides the opportunity to make a fertilizer application at planting near the seed.

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: rotation, partial stover removal, and tillage. Research and anecdotal evidence show that corn following soybean produce greater yields than following corn. Research by the Crop Physiology Lab 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 (e.g. Fronning et al. 2008) 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 can not only be performed in a sustainable manner, but that the use of stover for biofuels or animal feed is a more environmentally sustainable application for corn stover than allowing it to slowly decompose at the soil 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 extensive plant tissue analyses of removed stover to estimate soil nutrients removed at various stover removal rates. This will result in information that can be used to create appropriate fertilizer recommendations at variable stover harvest rates.

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 and 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 yield" factors vs. traditional practices, the combined "high-tech" treatment yielded 14-66 bushels per acre more grain than the treatment combining only "traditional" inputs and practices. Although there was variation in the dataset influenced by site and weather, in all cases the value of a given high-yield factor was more influential for increasing 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 highest corn yields possible. We will implement the same treatment design of Below and colleagues utilizing 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
- And maintains or improves soil organic matter, soil structure, and water quality.

(Modified from the 1990 Farm Bill)

Specifically, we propose to maintain or improve soil organic matter by increasing plant populations, thus creating more belowground root biomass and exudates, and reducing tillage using strip tillage. We will maintain and improve soil structure with strip tillage and addition of 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 added to the crop. Specifically, we will achieve this by improving nitrogen uptake efficiency with split N application and optimizing placement of inputs by banding P and S fertilizer with the strip tiller. Finally, by creating a favorable rooting environment with strip tillage and banding nutrients and using the most advanced suitable crop hybrids, we will optimize the corn root system to optimize fertilizer recovery and increase belowground soil 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.

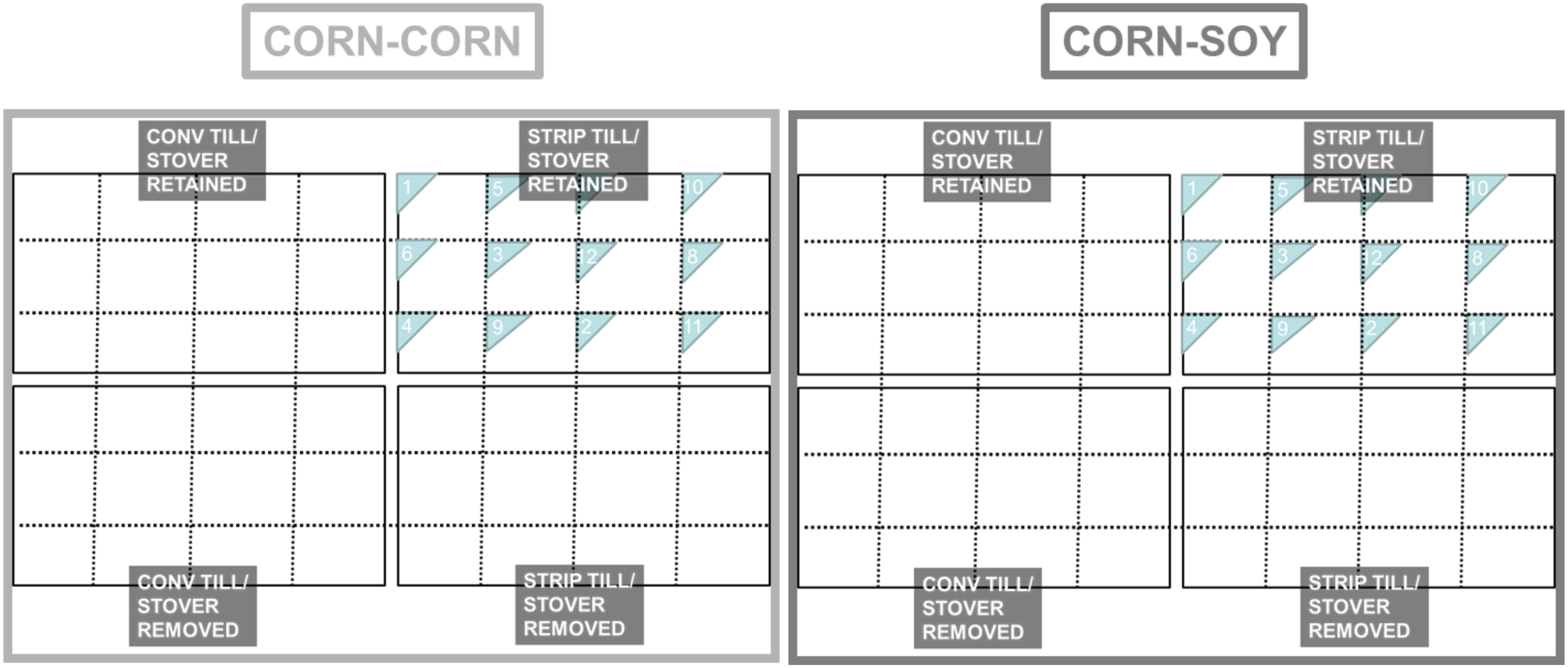

Figure 1. Experimental design of one replication of the 2011/2012 proposed project. The 12 treatments are repeated in each quadrat of each rotation (corn-corn or corn-soy) plot. The eight split plots (conventional tillage+stover, conventional tillage-stover, strip tillage+stover, strip tillage-stover) assess residue management concerns in high-yielding corn systems. The 12 split-split plot treatments are described in Table 1.

Table 1. Subplot treatments evaluated in the 2011/2012 Sustainability Omissions Plot Design. The six subplot treatments are plant population, hybrid traits, N rate, other nutrients, and crop protection inputs (fungicide).

Trt. No.	Trt.	Pop	Hybrid	N	Fert.	Fungicide
1	HIGH YIELD	45K	MULTI-TRAIT	BASE+SLOW REL	MESZ	STROBILURIN
2	-POPULATION	32K	MULTI-TRAIT	BASE+SLOW REL	MESZ	STROBILURIN
3	-HYBRID TRAIT	45K	REFUGE	BASE+SLOW REL	MESZ	STROBILURIN
4	-NITROGEN	45K	MULTI-TRAIT	BASE	MESZ	STROBILURIN
5	-FERTILITY	45K	MULTI-TRAIT	BASE +SLOW REL	NONE	STROBILURIN
6	-FUNGICIDE	45K	MULTI-TRAIT	BASE +SLOW REL	MESZ	NONE
7	TRADITIONAL	32K	REFUGE	BASE	NONE	NONE
8	+POPULATION	45K	REFUGE	BASE	NONE	NONE
9	+HYBRID TRAIT	32K	MULTI-TRAIT	BASE	NONE	NONE
10	+NITROGEN	32K	REFUGE	BASE+SLOW REL	NONE	NONE
11	+FERTILITY	32K	REFUGE	BASE	MESZ	NONE
12	+FUNGICIDE	32K	REFUGE	BASE	NONE	STROBILURIN

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