Project
NE-11F

Ecological Intensification of Irrigated Corn and Soybean Systems

Will agriculture be able to meet future global demands for food? How much can we increase our level of food production? What effects does more intensive production have on the environment? Can we use crops to reduce the concentration of harmful greenhouse gases in the atmosphere? To begin to answer these questions, science must start with small, highly controlled studies, then move to progressively larger scales as discoveries are made. This research project, begun in 1999, investigates these important questions, beginning with irrigated corn and soybeans in eastern Nebraska.

Sponsors:

FAR

IMC Global

University of Nebraska Lincoln

Investigators

Name	Title	Research Areas	Contact Information
Timothy J. Arkebauer	Associate Professor	Environmental crop physiology	106 KCR Department of Agronomy and Horticulture University of Nebraska PO Box 830817 Lincoln, NE 68583-0817 Email: tarkebauer1@unl.edu Phone: (402) 472-2847 Fax: (402) 472-7904
Robert M. Caldwell	Assistant Professor	Cropping systems, soybean physiology	306 Keim Hall Department of Agronomy and Horticulture University of Nebraska PO Box 830915 Lincoln, NE 68583-0915 Email: rcaldwell1@unl.edu Phone: (402) 472-4792 Fax: (402) 472-7904
Kenneth G. Cassman	Professor and Head	Soil fertility and plant nutrition	279 Plant Science Department of Agronomy and Horticulture University of Nebraska PO Box 830915 Lincoln, NE 68583-0915 Email: kcassman1@unl.edu Phone: (402) 472-1555 Fax: (402) 472-7904
Rhae A. Drijber	Associate Professor	Soil microbial ecology	121 Keim Hall Department of Agronomy and Horticulture University of Nebraska PO Box 830915 Lincoln, NE 68583-0915 Email: rdrijber1@unl.edu Phone: (402) 472-0770 Fax: (402) 472-7904
Achim Dobermann	Associate Professor	Soil fertility and plant nutrition	279 Plant Science Department of Agronomy and Horticulture University of Nebraska PO Box 830915 Lincoln, NE 68583-0915 Email: adobermann2@unl.edu Phone: (402) 472-1501 Fax: (402) 472-7904
John L. Lindquist	Assistant Professor	Weed/crop ecophysiology	201 KCR Department of Agronomy and Horticulture University of Nebraska PO Box 830817 Lincoln, NE 68583-0817 Email: jlindquist1@unl.edu Phone: (402) 472-2771 Fax: (402) 472-3654
John P. Markwell	Professor	Biochemistry	Department of Biochemistry University of Nebraska N251 The Beadle Center PO Box 830664 Lincoln, NE 68588-0664 Email: markwell2@unl.edu Phone: (402) 472-2924 Fax: (402) 472-7842

Lenis A. Nelson	Professor	Plant breeding and crop production	342 Keim Hall Department of Agronomy and Horticulture University of Nebraska PO Box 830953 Lincoln, NE 68583-0953 Email: lnelson1@unl.edu Phone: (402) 472-1489 Fax: (402) 472-7904
William L. Powers	Professor	Soil physics	131 Keim Hall Department of Agronomy and Horticulture University of Nebraska PO Box 830915 Lincoln, NE 68583-0915 Email: wpowers1@unl.edu Phone: (402) 472-1529 Fax: (402) 472-7904
W. Ken Russell	Assistant Professor	Plant quantitative genetics (corn)	326 Keim Hall Department of Agronomy and Horticulture University of Nebraska PO Box 830915 Lincoln, NE 68583-0915 Email: krussel3@unl.edu Phone: (402) 472-1562 Fax: (402) 472-7904
James E. Specht	Professor	Soybean genetics	322 Keim Hall Department of Agronomy and Horticulture University of Nebraska PO Box 830915 Lincoln, NE 68583-0915 Email: jspecht1@unl.edu Phone: (402) 472-1536 Fax: (402) 472-7904
Madhavan Soundararajan	Lecturer	Biochemistry	Department of Biochemistry University of Nebraska N256 The Beadle Center PO Box 830664 Lincoln, NE 68588-0664 Email: soundararajan1@unl.edu Phone: (402) 472-2939 Fax: (402) 472-7842
Daniel T. Walters	Professor	Soil Fertility, carbon sequestration	261 Plant Science Department of Agronomy and Horticulture University of Nebraska PO Box 830915 Lincoln, NE 68583-0915 Email: dwalters1@unl.edu Phone: (402) 472-1506 Fax: (402) 472-7904

Background

Summary

Low commodity prices and environmental concerns about global climate change caused by carbon dioxide enrichment of the atmosphere provide strong justification for increasing both farm profits and the storage of carbon (C) in agricultural soils. The working hypothesis of this research is that achieving increased profit and C storage will require innovative new crop management practices that improve soil quality, increase yields, and decrease unit production costs. Moreover, we believe that these three goals are both feasible and complementary.

Soil productivity can be defined as the degree to which a soil permits the optimization of crop yield, input use efficiency, and profit while minimizing the potential for environmental hazards from the application of agricultural inputs. **Crop yield potential** is defined as the yield that can be obtained with an adapted variety or hybrid when grown with minimal possible abiotic or biotic stress. **Carbon sequestration** is the accumulation of C in soil organic matter that occurs when the annual C inputs from crop residues and roots exceed the amount of C released from soil by decomposition of organic matter. The ultimate goals of this research project are to develop scientific understanding of the relationships among soil productivity, crop yield potential, input use efficiency, and C sequestration in corn-based cropping systems as follows:

- Identify the specific soil properties that contribute most to the ability of soil to support crop yields that approach yield potential levels for corn and soybean
- Identify the management practices and crop rotations required to consistently achieve yields that approach the yield potential ceiling while maximizing nutrient use efficiency and minimizing nutrient losses.
- Quantify and predict the potential for C sequestration in corn-based systems and identify cost-effective crop management practices to achieve it.

To address these broad-based scientific issues, we have brought together an interdisciplinary team of scientists that includes agronomists, soil scientists, crop physiologists, and plant geneticists.

To efficiently address these longer-term goals, however, requires an initial focus on quantifying crop growth rates and dry matter distribution among the various plant organs, nutrient uptake rates, and water requirements of corn and soybean crops when grown at yield potential levels. This information is required to allow accurate prediction of both yield potential and the resource requirements to achieve it in diverse soil and climatic environments of the north-central USA. In addition, some general information is needed about optimal plant population, fertilizer requirements, and the benefits (if any) of crop rotation for achieving yields that approach yield potential levels. To our knowledge, there are no previous studies that have reported such information in the scientific literature. Therefore, the short-term objectives of this project are to obtain these baseline data so that we can efficiently address the longer-term goals listed above.

Justification

Although there are a number of reports of record corn and soybean yields in the north-central corn belt, all of these reports are based on yield observations from farmers' fields. Published data in the scientific literature that document the nutrient requirements, soil properties, and management practices required to achieve yield levels of 300 bu/acre for corn and 100 bu/acre for soybeans in the north-central USA do not exist (Duvick and Cassman, 1999). Interviews with farmers who have achieved these record yields and visits to their farms suggest several common attributes and management practices. Prominent among these are a deep topsoil highly enriched with organic matter, recycling of tremendous quantities of crop residue, and higher plant density and greater fertilizer application rates than recommended by University guidelines. In the western portion of the corn belt, irrigation is needed to supplement rainfall. It also is surprising that record corn yields are typically achieved in fields that have been in continuous corn production, which is not consistent with present notions about rotational benefits and cropping system diversity. In summary, precise knowledge of soil properties, nutrient uptake requirements, and soil properties is needed in order to achieve optimal soil productivity at high yield levels (Cassman, 1999). Lack of this information severely limits our ability to develop improved management recommendations for farmers who wish to achieve higher yields and enhanced soil quality in a cost-effective manner.

Another justification for interest in optimal soil productivity is the interest in mitigating effects of atmospheric carbon dioxide enrichment, which results from increasing use of fossil fuels driven by population growth and higher standards of living worldwide. Because soil organic matter is a key component of soil quality and influences crop performance, it is likely that substantial increases in C sequestration will be required to achieve optimal soil productivity. Greater C sequestration requires the return of more crop biomass to the soil. High-yield systems can generate that biomass. For example, present corn and soybean yields in Nebraska and Iowa are less than 50% of the estimated yield potential of these crops (Cassman and Duvick, 1999; Specht et al., 1999). Therefore, we suspect that management practices to attain optimal soil productivity at high yield levels may also contribute to the mitigation of atmospheric carbon dioxide enrichment and global climate change by increasing C accumulation in soil.

Selected References

Cassman, K.G. 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proc. National Acad. Sci. (USA) 96:5952-5959.

Duvick, D.N. and K.G. Cassman. 1999. Post-green-revolution trends in yield potential of temperate maize in the north-central United States. Crop Sci. 39:1622-1629.

Specht, J.E., D.J. Hume, and S.V. Kumundi. 1999. Soybean yield potential: A genetic and physiological perspective. Crop Sci. 39:1560-1570.

Objectives

Quantify the yield potential of corn and soybean under irrigated conditions and understand the physiological processes determining it.

- What is the yield and biomass potential of soybean and corn under irrigated conditions?
- How do corn and soybean growth differ between average and near yield potential levels? Does the rate of leaf appearance increase at near yield potential levels? Do the dynamics of leaf area growth differ? Does the rate of leaf senescence decrease at near yield potential levels?
- Does the radiation use efficiency of corn differ between average and near yield potential levels? And if so, how is the difference related to dry matter and leaf area growth?
- What is the daily and seasonal course of light interception and how is this related to the concomitant increases in plant biomass? Do intensively managed systems utilize the light they intercept any more efficiently (for the production of biomass and grain yield) than conventional cropping systems?
- Does the nitrogen use efficiency of corn differ between average and near yield potential levels? And if so, how is the difference related to dry matter and leaf area growth? How do plant population and fertility management influence leaf canopy nitrogen distribution over the course of canopy development? Does corn leaf canopy nitrogen distribution under intensive management conform to current crop simulation model predictions?
- Where does the biomass that ends up in grain come from? Is it all produced post anthesis or is there a substantial redistribution of biomass from, for example, stems? Does this differ between average and near yield potential levels? How does management affect the relative carbon contribution from source leaves and stalk to the carbon in grain?
- How does rate of kernel and ear development differ from normal yield level sites?
- Can corn and soybean simulation models accurately predict the yield potential? Does corn leaf canopy nitrogen distribution under intensive management conform to current crop simulation model predictions?

Identify cost-effective crop management practices to achieve irrigated corn and soybean yields that approach potential levels. Compare conventional and intensive soil fertility management of corn-based cropping systems.

- How do fertility management and crop rotation influence corn yield components under elevated (non-conventional) plant populations?

- What are the nutrient requirements to achieve the genetic yield potential of modern corn and soybean varieties and how do they change depending on the yield level?

- How are input efficiencies impacted under intensive management?

- How is long- and short-term soil quality impacted by fertility management, crop rotation and residue levels? Do we need to increase soil quality to achieve optimal nutrient- and water-use efficiency in cropping systems that consistently produce corn and soybean yields that approach yield potential levels?

- Are the classical theories of plant nutrition and soil fertility management applicable to producing yields that approach the climatic yield potential? Do conventional soil tests accurately predict soil nutrient supply at elevated yield levels? Do we need to increase soil nutrient levels (P, K) beyond currently recommended sufficiency levels to sustain large soil nutrient supply rates during peak periods of crop nutrient demand?

- Does differential leaf area index influence our ability to diagnose optimum plant nitrogen status? Can the SPAD chlorophyll meter be used to diagnose plant N status without a "reference strip" and what are the management protocols for its use?

- Does the composition or activity of the microbial biomass differ among plant density or fertility treatments at corn silking? Do measured microbial parameters support observed differences in field respiration?

Quantify the energy use efficiency and soil C-sequestration potential of intensive corn and soybean management systems and validate current soil carbon sequestration models for intensively managed irrigated corn.

- What are the environmental consequences (nitrate loss, energy consumption, etc.) of elevated inputs required to reach yield potential levels?

- What is the C-sequestration potential of irrigated corn? Are current carbon sequestration models adequately structured to predict the C-sequestration potential of intensively managed corn systems?

- Does elevated nitrogen management needed to achieve yield potential levels result in soil C inputs with differential decomposition rates?

- Do the combination of elevated N inputs and greater residue C inputs under intensive management impact the emission of global warming gases?

- Does increased crop production lead to increased soil surface trace gas exchange? How does the intensity of crop management affect the daily and seasonal course of CO_2 flux in corn and the relationship between the flux of CO_2 and other important trace gases such as nitrous oxide and methane?

- Does an increase in external energy inputs under intensive management result in improved energy use efficiency?

Methodology

1999
2000

Three main factors were varied in this experiment: 1) crop rotation; 2) plant population; and 3) intensity of nutrient management. The initial soil conditions and experimental design are provided below. For specific methods used each year, click on the year of interest.

Average soil properties of the experiment site (data collected in Fall, 1998):

Texture:	sicl (silty clay loam)
pH:	5.0 - 5.7
Organic matter:	2.4 - 3.1 %
Bray P1:	55 - 78 ppm
Ammonium acetate K:	275 - 480 ppm

Experimental design:

Whole plot: Crop rotation

Levels:
- CC - Corn/corn
- CS - Corn/soybean
- SC - Soybean/corn

Subplot: Plant population

Levels:
- P1
  - corn: 30,000 plants/acre
  - soybean: 150,000 plants/acre
- P2
  - corn: 37,000 plants/acre
  - soybean: 185,000 plants/acre
- P3
  - corn: 44,000 plants/acre
  - soybean: 220,000 plants/acre

Irrigation:

Drip Irrigation

Potash & Phosphate Institute (PPI), 655 Engineering Drive, Suite 110, Norcross, Georgia 30092-2837 USA
Phone: 770-447-0335, Fax: 770-448-0439