Growing Energy: Comparing Bioenergy Crop Yields

Overview: Can perennial biomass crops compete with king corn? In this GLBRC *Data Dive*, students analyze and interpret data on the biomass production of different bioenergy crops grown on Great Lakes Bioenergy Research Center (GLBRC) experimental farms in Wisconsin and Michigan. Students read a brief summary of the GLBRC research questions and experimental design. They then are given the task of interpreting real GLBRC biomass data to answer the research questions about how perennial biomass crops, such as switchgrass and prairies, compare to corn.

Levels
High School (9-12)

Subjects
Environmental Science, Biology, Agriculture, Earth Science

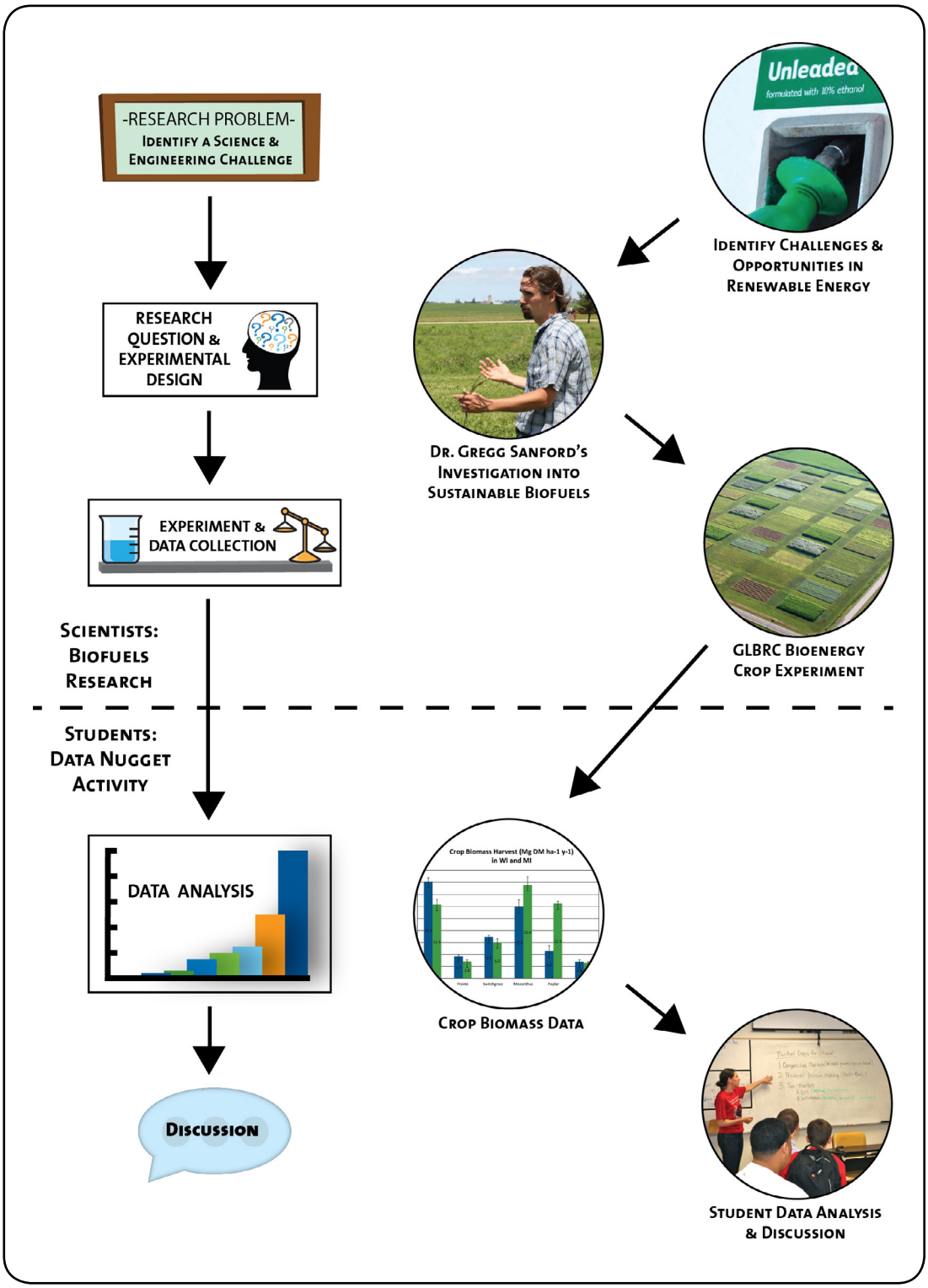
Objectives
- Identify the scientific questions and variables in GLBRC bioenergy crop farming experiment
- Interpret biomass units from the experiment (megagrams per hectare) and compare them to familiar mass and area units
- Analyze and interpret data on crop biomass production
- Propose an answer to the scientific question and support it with evidence from the data

Materials
Growing Energy Data Dive Package

Activity Time
One or two 50-minute class periods

Standards
Next Generation Science Standards (2013)
- Scientific Practices: analyzing and interpreting data; engaging in argument from evidence
- Disciplinary Core Ideas: ecosystems; earth and human activity
- Crosscutting Concepts: patterns; scale, proportion, and quantity; energy and matter
- Performance Expectations: See page 3 for details

NGSS Lead States. 2013. Next Generation Science Standards: For States by States. Washington DC: The National Academies Press



Growing Energy: Comparing Bioenergy Crop Biomass

Featured scientist: Dr. Gregg Sanford

Scientific Question:

1. What scientific question are the scientists trying to answer in this experiment?

   Answers will vary. The basic question: "In the upper Midwest, which perennial bioenergy crops, if any, can produce as much biomass as corn, the most productive annual crop?"

Scientific Data:

Part 1: Comparing Average Biomass Across Both Sites

To answer their question, the scientists started by calculating the average biomass for each crop across both sites. They organized the data in the following table:

Crop	Type	Average harvest biomass (Mg DM ha^{-1} yr^{-1})*	standard error**
corn	annual	14.2	0.6
prairie	perennial	3.3	0.2
switchgrass	perennial	6.5	0.3
miscanthus grass	perennial	14.0	0.9
poplar trees	perennial	8.5	1.4
weed field	perennial	2.7	0.2

**Harvest biomass is measured as the amount of dried biomass harvested from a certain area. In this study the units are "Megagrams of dried biomass per a hectare (Mg DM ha^{-1})."*
*** Standard error is a measure of how much variation there is in the biomass measurements.*

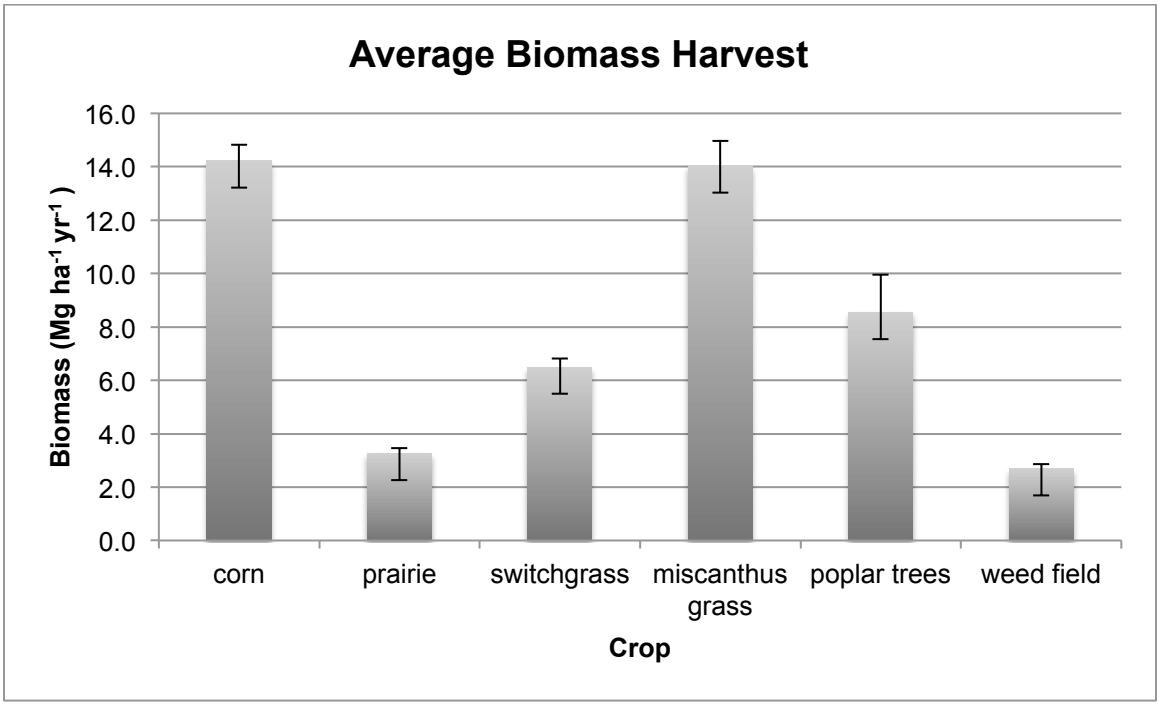
2. What data will you graph to answer your question?

   Independent variables: (a) *Crop*

   (b) *Crop type: annual or perennial*

   Dependent variable: *Dry harvested biomass (Mg DM ha-1)*

Graphing and interpreting data: *Below is a sample graph of the data.*



3. Based upon this evidence, write a statement that helps answer the scientific question. Justify your reasoning using data.

   Key take-away: Miscanthus, the highest yielding perennial crop, produces a similar yield to corn. The average yield for corn is 14.2 mg/ha and miscanthus is 14.0 mg/ha. Corn is slightly higher but the small difference is within the error bars as seen in the graph.

   Students may also observe that most of the perennial crops produced less biomass than corn. Four of the five perennial systems had lower yields than corn. Only miscanthus had had a biomass yield at the same level as corn. This result supports the hypothesis that most perennial crops will have lower yields than corn. Students might also compare the average biomass of all perennial crops (7 Mg/ha) to corn (14.2 Mg/ha).

4. *Your next step as a scientist*: Science is an ongoing process. Did this study fully answer your original question? What new questions do you think should be investigated? What future data should be collected to answer them?

Answers will vary. Some questions whether the same pattern would be observed at each site, at longer time scales, other regions, or different crop varieties. For example, data was aggregated and averaged across the two sites. Was the same pattern observed in both MI and WI? To answer this question the same data should be graphed and compared for each site separately. Similarly the data does not show trends in biomass over time. Would some crops increase in biomass production if data were collected over longer time scales?

Other questions might address why the pattern was observed? For example, why did miscanthus produce more biomass than the other perennial crops? Depending on the hypothesis, different studies could be proposed as compare possible causes such as water use efficiency, photosynthetic rate, pest pressure, etc. Lastly, students could pursue questions about other important variables that could be compared between crops, such as cost of production, fertilizer inputs, water use, harvest efficiency, biodiversity, etc. For any question, it is important for students to explain exactly what data would be collected and compared in future investigations.

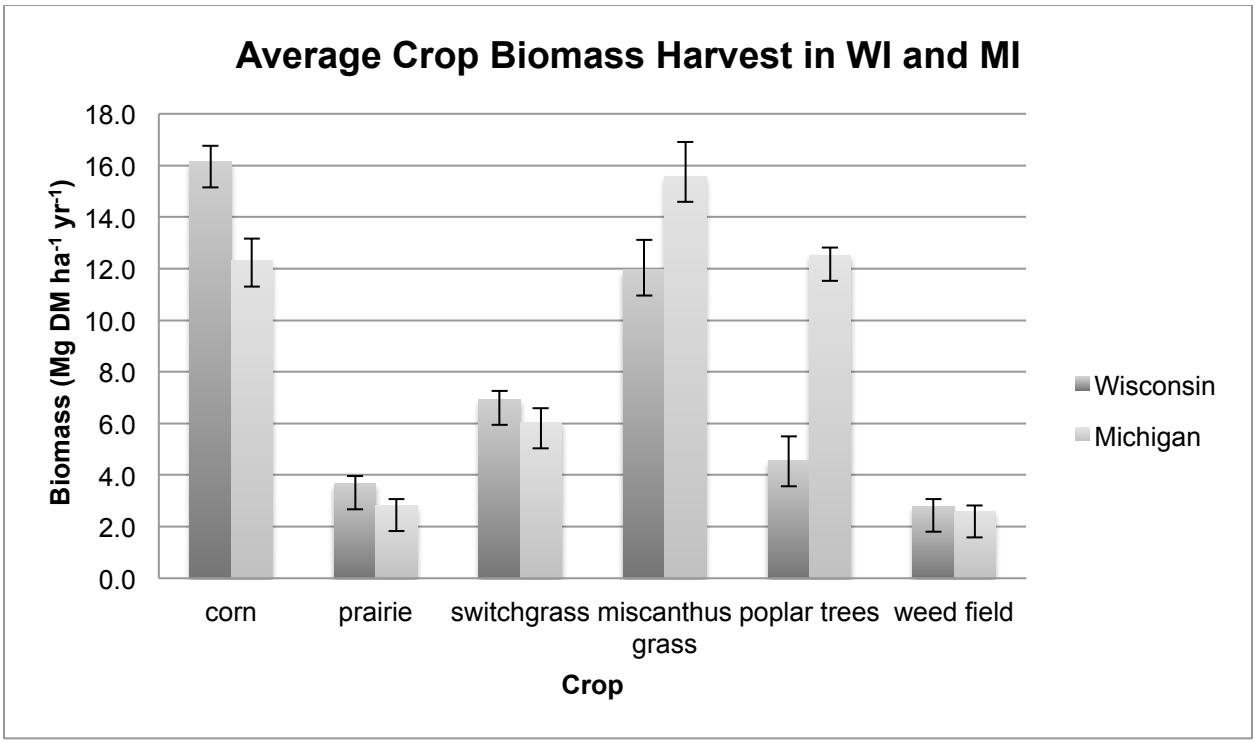
Part 2: Comparing Average Biomass between Sites (WI and MI)

Next, the scientists wondered if they would observe the same pattern in crop biomass if they compared the results from each site. As mentioned in the introduction, differences in climate and soils could affect the results. They organized the data in the following table:

Crop	Type	Wisconsin: Average biomass (Mg ha^{-1} yr^{-1})	standard error	Michigan: Average biomass (Mg ha^{-1} yr^{-1})*	standard error**
corn	annual	16.1	0.6	12.3	0.9
prairie	perennial	3.7	0.3	2.8	0.2
switchgrass	perennial	6.9	0.3	6.0	0.6
miscanthus grass	perennial	12.0	1.2	15.6	1.3
poplar trees	perennial	4.6	0.9	12.5	0.3
weed field	perennial	2.8	0.3	2.6	0.2

**Harvest biomass is measured as the amount of dried biomass harvested from a certain area. In this study the units are "Megagrams of dried biomass per a hectare (Mg DM ha^{-1})."*
*** Standard error is a measure of how much variation there is in the biomass measurements.*

Graphing and interpreting data: The graph below shows the average biomass production for each crop at both the Wisconsin and Michigan experimental farm.



1. Review the scientific question and your proposed answer for Part 1. How would you answer the question differently if you used only the data from Michigan or Wisconsin? Justify your reasoning using the data.

   Students should identify the different patterns in crop biomass production between the sites. If only the Wisconsin data were used, then one could conclude that no perennial crops produce as much biomass as corn. The highest producing perennial crop miscanthus averaged 12 Mg ha^{-1} yr^{-1} compared to 16.1 Mg ha^{-1} yr^{-1} for corn at the Wisconsin site. If only the Michigan data were used, then one would observe that miscanthus actually produced more biomass than corn (15.6 vs 12.3 Mg ha^{-1} yr^{-1}). At Michigan the poplar trees also produce equivalent biomass to corn (12.5 vs 12.3 Mg ha^{-1} yr^{-1}). Although the average for poplar is slightly higher than corn, the difference falls within the standard error so the difference is not statistically significant.

2. A. Explain what you learned from comparing the two sites.

   Students should observe that different patterns emerge when analyzing each site individually. This means that the location of the farm affects the results. And this could be related to numerous variables such as climate, soils, pest pressure, etc.

B. Based upon the new information you have gathered from comparing the sites, how would you revise your original answer to the research question from Part 1? Write an updated statement below. Justify your reasoning using the data.

In this revised statement, students should be more cautious about making generalizations about which perennial crop produces the most biomass. For example, when averaged across WI and MI sites, miscanthus, the most productive perennial crop, produced a similar yield to corn. The average yield for corn is 14.2 mg/ha and miscanthus is 14.0 mg/ha. However, there was significant variation in results between the two sites. In WI, miscanthus, the most productive perennial produced significantly less biomass than corn (16.1 vs 12 Mg ha^{-1} yr^{-1}). But in Michigan, miscanthus produced more biomass than corn (15.6 vs 12.3 Mg ha^{-1} yr^{-1}), and poplar produced equal biomass to corn (12.5 vs 12.3 Mg ha^{-1} yr^{-1}). In general, one can conclude that some perennial crops show potential to compete with corn biomass production but that results vary significantly based upon geographic region.

3. In large scale experiments like this one that include multiple sites across the country, what are some of the benefits and limitations in taking averages of all samples rather than looking at local patterns?

   Aggregating data across regions can be helpful for looking at large-scale trends and making large-scale projections. Scienstists might aggregate data to estimate how much total biomass could be produced over a large region. However, averaging across multiple site can mask different local patterns and variations. Analyzing data on smaller scales can help determine whether the patterns seen at large scale are universal. For examples, farmers would be more interested in analyzing local data to help decide which crops to plant. Local analysis can also produce clues as to what mechanisms or variables might be causing differences between sites. For example, scientists might observe the some crops produce more biomass at sites with more fertile soils, which other crops produce more in poor soils.

4. *Your next step as a scientist*: Science is an ongoing process. Did this study fully answer your original question? What new questions do you think should be investigated? What future data should be collected to answer them?

   Answers will vary. After comparing results between part 1 and 2, more questions arise about whether patterns seen in the data are universal. What patterns would you observe if more sites were compared across the

upper Midwest or other regions? Other questions might address why we are seeing differences in crop biomass production between sites. Students could ask questions about why one crop is more productive at one site than the other. Depending on their hypothesis, they might want to look for correlations between biomass production and variables such as average temperature, rainfall, soil fertility, or pest pressure. For example, in this study, the difference in poplar biomass between sites was caused by an outbreak of Marsonnina leaf blight at Wisconsin site that weakened or killed many of the trees. For any question, it is important for students to explain exactly what data would be collected and compared in future investigations.

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Learning Outcomes: Students will…

- Identify the scientific questions and variables in GLBRC bioenergy crop farming experiment
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This lesson assumes prior familiarity with the scientific method, hypothesis testing, graphing (if students are asked to create their own), graph interpretation, and basic statistics. For helpful resources on covering these concepts see:
http://datanuggets.org/concepts-to-cover-before-introducing-nuggets/

Standards

Next Generation Science Standards (2013)

Performance Expectations

High School:

- **HS-LS2-2.** Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
- **HS-ESS3-4.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and interpreting data Engaging in argument from evidence	**LS2**: Ecosystems: Interactions, energy, and dynamics **ESS3**: Earth and human activity	Patterns Scale, proportion, and quantity Energy and matter: Flows, cycles, and conservation

Activity Sequence:

Research Background:

1. OPTIONAL: Have students read and discuss a short Science of Farming research story for a more detailed background to the investigation.
2. Read and discuss the Research Background as a class. Have students identify science question driving the experiment.
3. Use accompanying PowerPoint slides to review key terms (biofuels, biomass, annual, perennial), review experimental design and to introduce the bioenergy crops with pictures.
4. Hand out worksheets with the appropriate graph level for your students as described below. Start by handing out only the Research Background section and Part 1 of the data analysis.
   a. Type A: data displayed on graph; axis labels and scale provided
   b. Type B: students graph data; axis labels and scale provided
   c. Type C: students graph data; axis labels and scale not provided
5. Review and discuss data table in Part 1. Have students identify independent and dependent variables.
6. Interpret the biomass measurement unit Mg DM ha^{-1} yr^{-1}. If time permits, have students complete the supplementary "Interpreting units" worksheet. Discuss and review answers using the accompanying PowerPoint presentation to help students visualize the scale of the units.

Data Analysis & Interpretation:

7. Part 1: Have students complete Part 1 of the data analysis and interpretation worksheet comparing average biomass across sites.
8. Share graphs and discuss answers as a class. In constructing a scientific argument, it is important for students to pinpoint specific numbers, trends and difference in the data to support their statements. Discussing next research steps should lead into questions about differences in results between the MI and WI sites (worksheet Part 2).
9. Part 2: Give students and have them complete Part 2 of the data analysis and interpretation worksheet comparing average biomass between sites.

10. Discuss answers and compare answers between Part 1 and Part 2. Guide students through comparing how the answers can vary depending on how data is aggregated and discuss benefits of analyzing at difference scales.
11. Sample grading rubric. See the sample grading rubric at DataNuggets.org.

Extensions & Variations:

- Advanced students can conduct their own data analysis of this experiment or other related research questions using the spreadsheet included in "Supplemental Materials."
- Before this activity, have students read and discuss the short Science of Farming research story for an in-depth look at the scientists working on this experiment.
- Use this activity as an introduction to students' own investigations and related hands-on activities. See for example, Field Investigation: Biomass Yield and Root Growth in Crops, Root Depth Model, The Bioenergy Farm Game, and Fields of Fuel computer game.

Additional Resources:

- The **GLBRC Education and Outreach site** has a collection of many other high-quality instructional materials to explore dimensions of producing and using biofuels appropriate for a range of K-12 STEM subjects and content areas. See: https://www.glbrc.org/education/classroom-materials.
- The **MSU Data Nuggets site** has many helpful resources for teachers, including materials for introducing students to the scientific method, scientific argumentation and basic statistics. See: http://datanuggets.org/
- **Reference Article:** See how the researchers analyzed, explained and discussed this data in the following publication:

  Gregg R. Sanford, Lawrence G. Oates, Poonam Jasrotia, Kurt D. Thelen, G. Philip Robertson, Randall D. Jackson, Comparative productivity of alternative cellulosic bioenergy cropping systems in the North Central USA, Agriculture, Ecosystems & Environment, Volume 216, 15 January 2016, Pages 344-355, ISSN 0167-8809, http://dx.doi.org/10.1016/j.agee.2015.10.018.

DOE Bioenergy Research Centers

WWW.GLBRC.ORG/EDUCATION
EDUCATION@GLBRC.WISC.EDU

U.S. DEPARTMENT OF ENERGY