

TEACHER ANSWER KEY



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)*	Variation (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 around the average.*

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

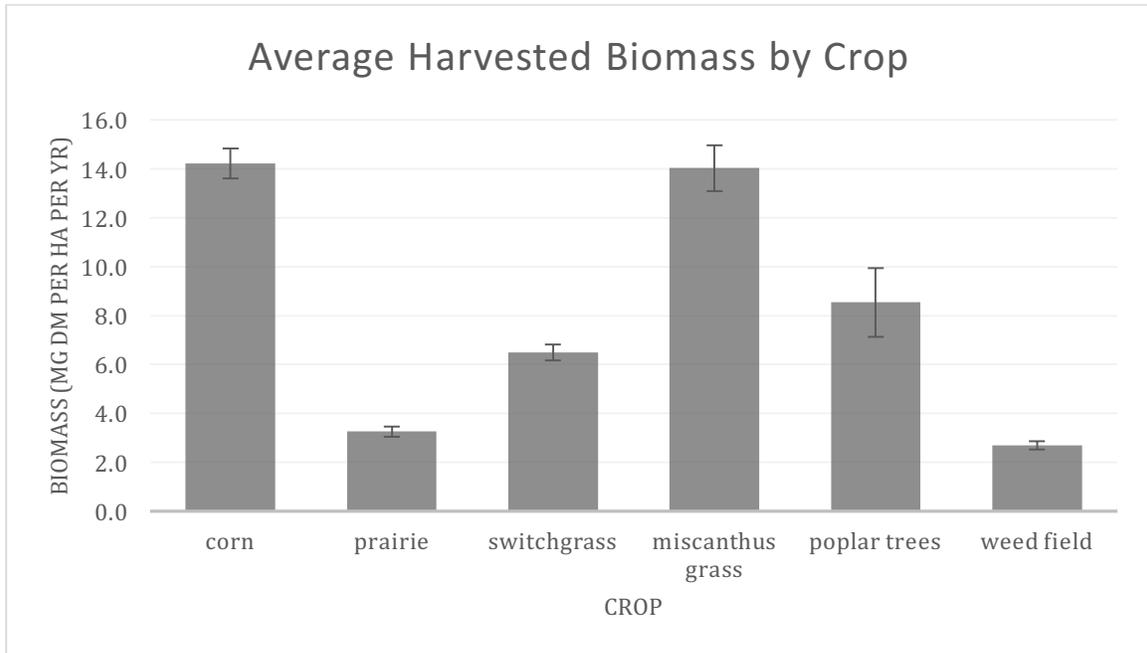
Independent variables: (a) Crop

(b) Crop type: annual or perennial

Dependent variable: Dry harvested biomass (Mg DM ha⁻¹ year⁻¹)

TEACHER ANSWER KEY

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?

TEACHER ANSWER KEY

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:

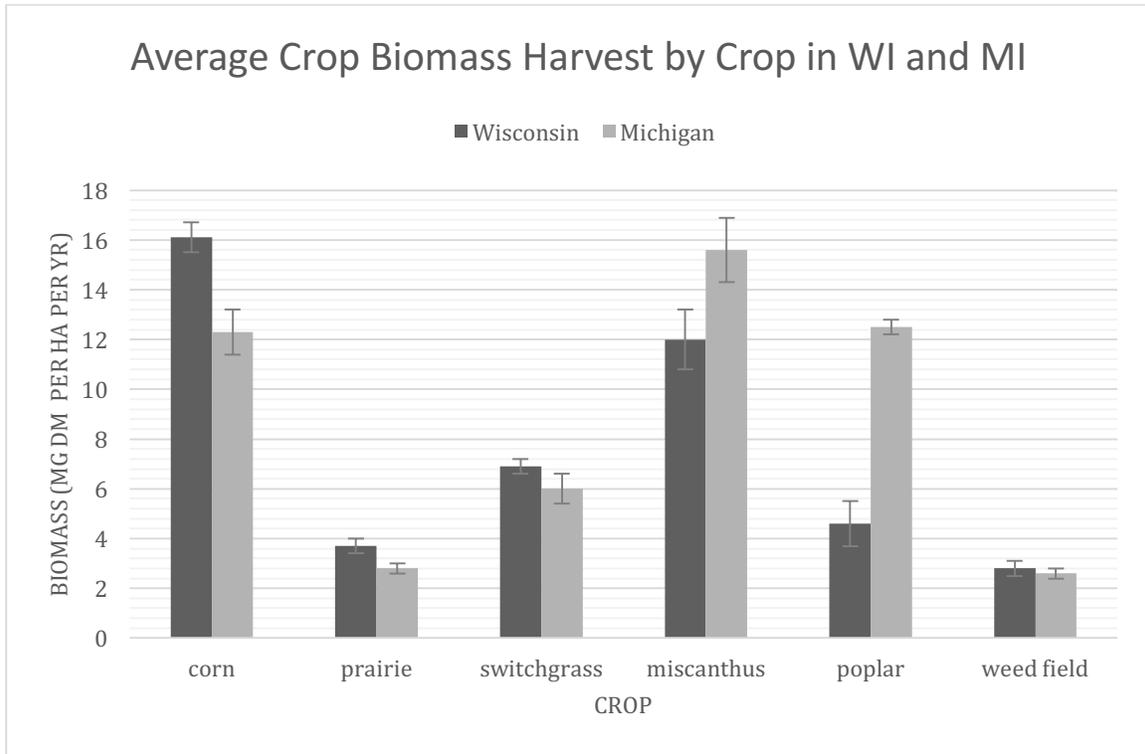
Crop	Type	Wisconsin: Average biomass (Mg ha ⁻¹ yr ⁻¹)	Variation**	Michigan: Average biomass (Mg ha ⁻¹ yr ⁻¹)*	Variation**
corn	annual	16.1	0.6	12.3	0.9
prairie	perennial	3.7	0.3	2.8	0.2
switchgrass	perennial	6.9	0.3	6.0	0.6
miscanthus grass	perennial	12.0	1.2	15.6	1.3
poplar trees	perennial	4.6	0.9	12.5	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 around the average.*

TEACHER ANSWER KEY

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 $12 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ compared to $16.1 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ 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 ($15.6 \text{ vs } 12.3 \text{ Mg ha}^{-1} \text{ yr}^{-1}$). At Michigan the poplar trees also produce equivalent biomass to corn ($12.5 \text{ vs } 12.3 \text{ Mg ha}^{-1} \text{ yr}^{-1}$). Although the average for poplar is slightly higher than corn, the difference falls within the standard error so the difference is not statistically significant.

TEACHER ANSWER KEY

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. Scientists 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.

TEACHER ANSWER KEY

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.