

# Can Winter Rye be a Carbon Sink Energy Source?

## A Biophysically Modeled Case Study

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### Introduction and Objective

- Harvesting winter cover crops as energy double crops may be one option for a food-neutral source of plant biomass for cellulosic biofuel production.
- We investigated the environmental trade-offs associated with adding winter rye to corn-soybean rotations in three locations in the northeast United States. We are interested in the question: Can winter rye limit nitrogen losses and produce a low carbon emission cellulosic biofuel without hurting corn and soybean yields?

### Study Method

We used the agroecosystem model CYCLES to simulate 29 years of crop growth and carbon and nitrogen cycling in a corn-soybean rotation (with no nitrogen stress) at each location. Figure 1 describes the modeling scenarios.

The following metrics were used to frame the response to our question:

- Net Energy Yield, MJ/ha.
- Near term & long term CO<sub>2</sub> equivalent emissions per unit of energy output, g CO<sub>2</sub> eq emissions/MJ.

$$\text{Near Term CO}_2 \text{ eq. emissions / MJ} = \frac{[\text{CO}_2]_{\text{Ag}} + [\text{CO}_2]_{\Delta\text{soil c}} + [\text{CO}_2]_{\Delta\text{N}_2\text{O}}}{\text{MJ produced in system}}$$

$$\text{Long Term CO}_2 \text{ emissions / MJ} = \frac{[\text{CO}_2]_{\text{Ag}} + [\text{CO}_2]_{\Delta\text{N}_2\text{O}}}{\text{MJ produced in system}}$$

where:

$[\text{CO}_2]_{\text{Ag}}$  = CO<sub>2</sub> eq. emissions for machinery and fertilizer

$[\text{CO}_2]_{\Delta\text{soil c}}$  = CO<sub>2</sub> eq. emissions for change in soil organic carbon compared to winter fallow

$[\text{CO}_2]_{\Delta\text{N}_2\text{O}}$  = CO<sub>2</sub> eq. emissions in change in nitrous oxide emissions compared to winter fallow

N losses:

$$\text{Annual N loss (kg N/ha)} = \text{NH}_3 \text{ volatilized} + \text{N}_2\text{O volatilized} + \text{NO}_3 \text{ leached}$$

$$\text{N loss / DM (kg N / Mg)} = \frac{\text{Annual N loss (kg N/ha)}}{\text{Grain and Biofuel DM output (Mg/ha)}}$$

$$\Delta \text{N loss / MJ} = \frac{(\text{Annual N loss})_{\text{winter fallow}} - (\text{Annual N loss})_{\text{system}}}{\text{MJ produced in system}}$$

Table 1. Averaged Annual N losses (N volatilized as NH<sub>3</sub> and N<sub>2</sub>O and N leached), annual N losses per unit dry matter (DM) output (Grain and Biofuel DM), and annual N losses per unit MJ biofuel for all management scenarios in all locations.

Fertilizer	Management Scenario	Annual N Loss		N Loss per unit DM output		Δ N Loss per unit MJ output	
		kg N/ha		kg N/ Mg		kg N/ MJ x 10 <sup>-3</sup>	
		Low Organic Matter	High Organic Matter	Low Organic Matter	High Organic Matter	Low Organic Matter	High Organic Matter
Manure 252 kg N/ha	Winter Fallow	25	28	4.1	4.6		
	Cover Crop Spring Till	25	26	4.0	4.1		
	Rye-Rye Biofuel Harvest	22	22	2.7	2.6	-0.5	-0.6
	Rye-Stover Biofuel Harvest	22	23	2.4	2.3	-0.2	-0.3
	Rye-Rye +UAN Biofuel Harvest	35	33	3.4	3.2	0.7	0.4
	Rye-Stover +UAN Biofuel Harvest	36	35	3.5	3.4	0.8	0.5
UAN 186 kg N/ha	Winter Fallow	24	26	3.9	4.3		
	Cover Crop Spring Till	23	24	3.8	3.9		
	Rye-Rye Biofuel Harvest	21	21	2.7	2.6	-0.6	-0.7
	Rye-Stover Biofuel Harvest	21	21	2.2	2.2	-0.2	-0.3
	Rye-Rye +UAN Biofuel Harvest	32	31	3.2	3.1	0.7	0.4
	Rye-Stover +UAN Biofuel Harvest	34	33	3.3	3.2	0.8	0.5

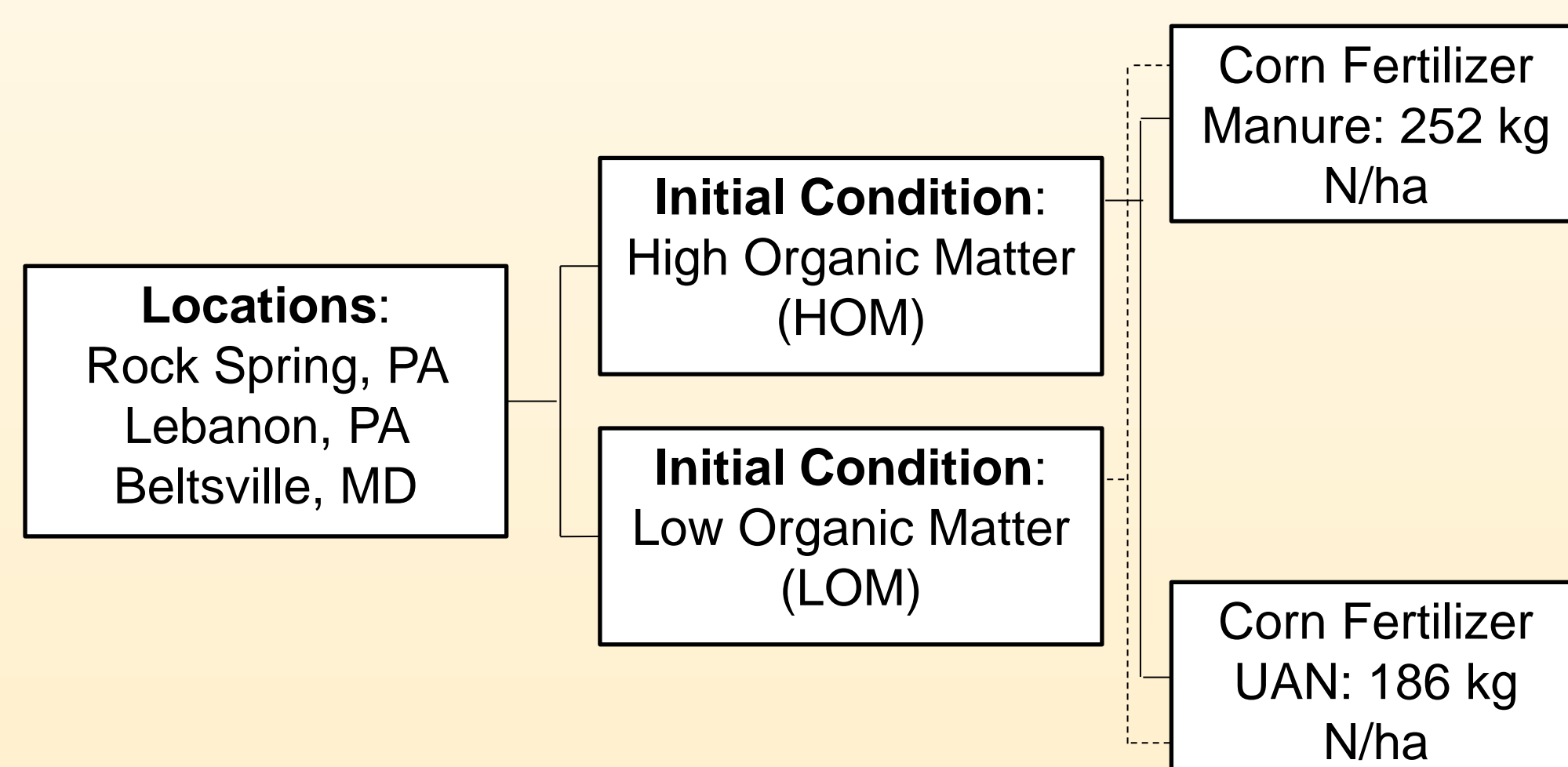


Figure 1. Modeled scenarios. Each location was modeled with two initial soil organic matter conditions and two fertilizer sources of N (organic and inorganic) at rates that prevented corn N stress. Six cropping and harvest scenarios were then simulated for each of the four soil x fertilizer scenarios to capture a range of responses to cellulosic bioenergy management decisions.

Management Scenarios		Crop Rotation			
		Corn	Winter Rye	Soybean	Winter Rye
Winter Fallow	Cellulosic Biofuel				
Cover Crop Spring Till	Cellulosic Biofuel				
Fertilizer N applied to corn only					
Rye-Rye Biofuel Harvest	Cellulosic Biofuel		Rye		Rye
Cellulosic Biofuel	Cellulosic Biofuel	67% Corn Stover removal			Rye
Fertilizer N applied to corn & UAN applied to rye at planting to achieve 75% potential yield					
Rye-Rye +UAN Biofuel Harvest	Cellulosic Biofuel		Rye		Rye
Rye-Stover +UAN Biofuel Harvest	Cellulosic Biofuel	67% Corn Stover removal			Rye

### Results

- Net energy yield for high organic matter soils were slightly greater than low organic matter soils (for both fertilizer treatments, only one shown) (Figure 3). Unfertilized biofuel harvest of winter rye and corn stover (Rye-Stover Biofuel Harvest) produced the highest energy yielding systems.
- CO<sub>2</sub> equivalent greenhouse gas emissions were comparable in near-term and long term scenarios for all biofuel harvest scenarios (only one soil x fertilizer scenario shown). Rye-Stover Biofuel Harvest was the only scenario that decreased CO<sub>2</sub> equivalent emissions in the long term. This was due to the stabilization of the largest soil carbon losses out of all systems. Unfertilized biofuel harvest of winter rye or stover were net nitrous oxide sinks compared to Winter Fallow and Cover Crop Spring Till.
- When comparing unfertilized bioenergy scenarios (Rye-Rye Biofuel Harvest, Rye-Stover Biofuel Harvest) to conventional practices (Winter Fallow and cover Crop Spring Till) averaged over three locations, annual N losses decreased by 14% and N losses per Mg output (harvest) decreased by 40% (Table 1). When comparing fertilized bioenergy scenarios to conventional practices, annual N losses increased by 33% but N losses per Mg output from the field decreased by 19%.
- When corn yields were low due to weather variability, winter rye yields increased due to an increase in residual N in the field (Figure 4). Thus, the major benefit of the cover crop was expressed in years where cash crop production level was below average.

### Conclusions

- Corn-soybean rotations can accommodate cellulosic biofuel production based on winter rye or a combination of winter rye and stover harvest without creating N-stressed crops.
- Cellulosic biofuel with the lowest near and long term CO<sub>2</sub> equivalent emissions is obtained from systems that have no synthetic N fertilizer applied to winter rye.
- A combination of unfertilized winter rye and stover harvest in corn-soybean rotation produced a small decrease in N losses per MJ but synthetic N fertilized rye did not significantly increase N losses per MJ. This creates an incentive to fertilize winter crops for increased yield but does not improve Net Energy Yield or CO<sub>2</sub> equivalent emissions of the system.

Legend for Figures 2 and 3: Rye-Rye Biofuel Harvest (Green), Rye-Stover Biofuel Harvest (Red), Rye-Rye + UAN Biofuel Harvest (Orange), Rye-Stover + UAN Biofuel Harvest (Blue).

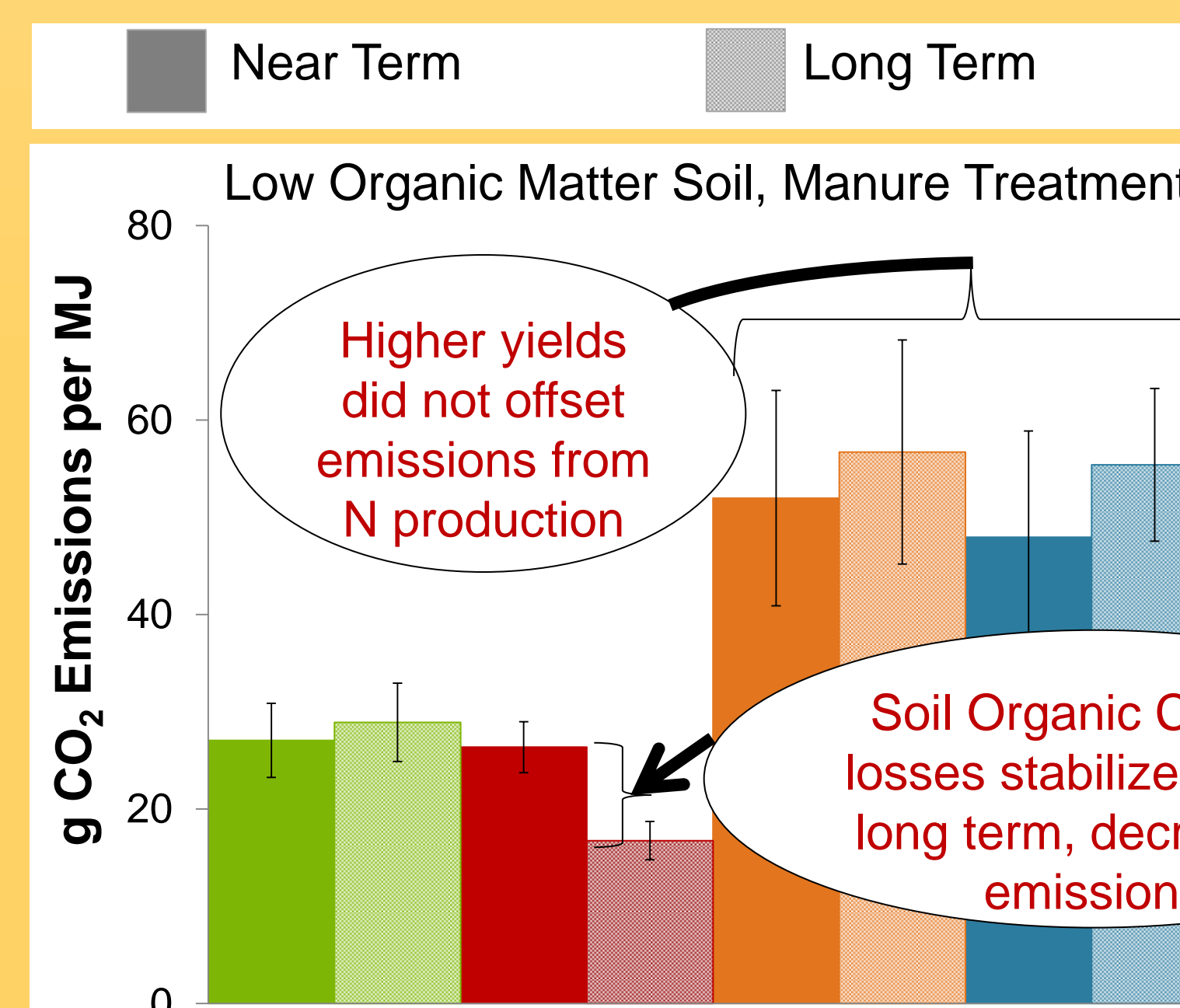


Figure 2. Annual near term and long term g CO<sub>2</sub> emissions per MJ for bioenergy cropping systems averaged over all locations.

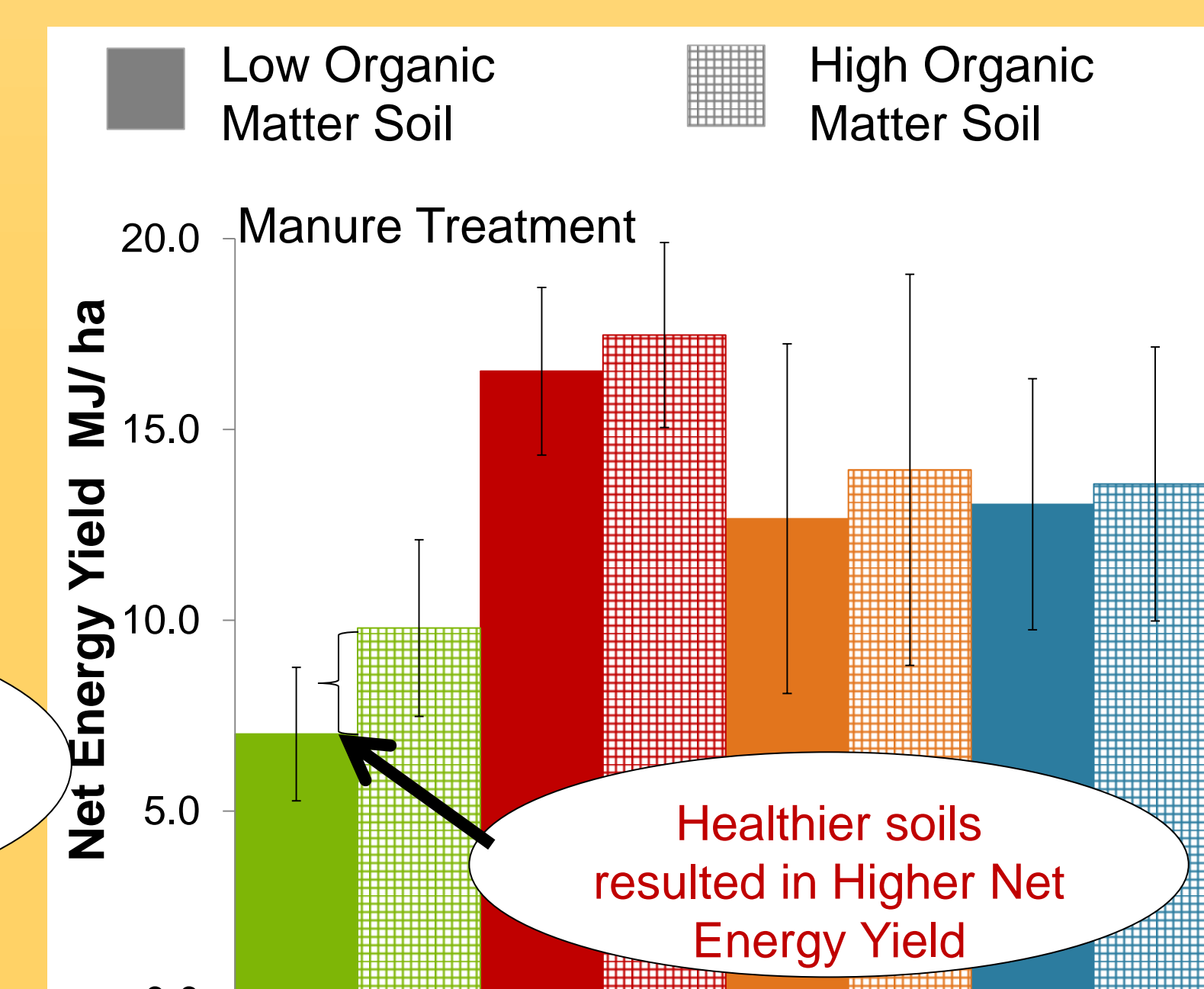


Figure 3. Annual Net Energy Yield per ha for bioenergy cropping systems averaged over all locations.

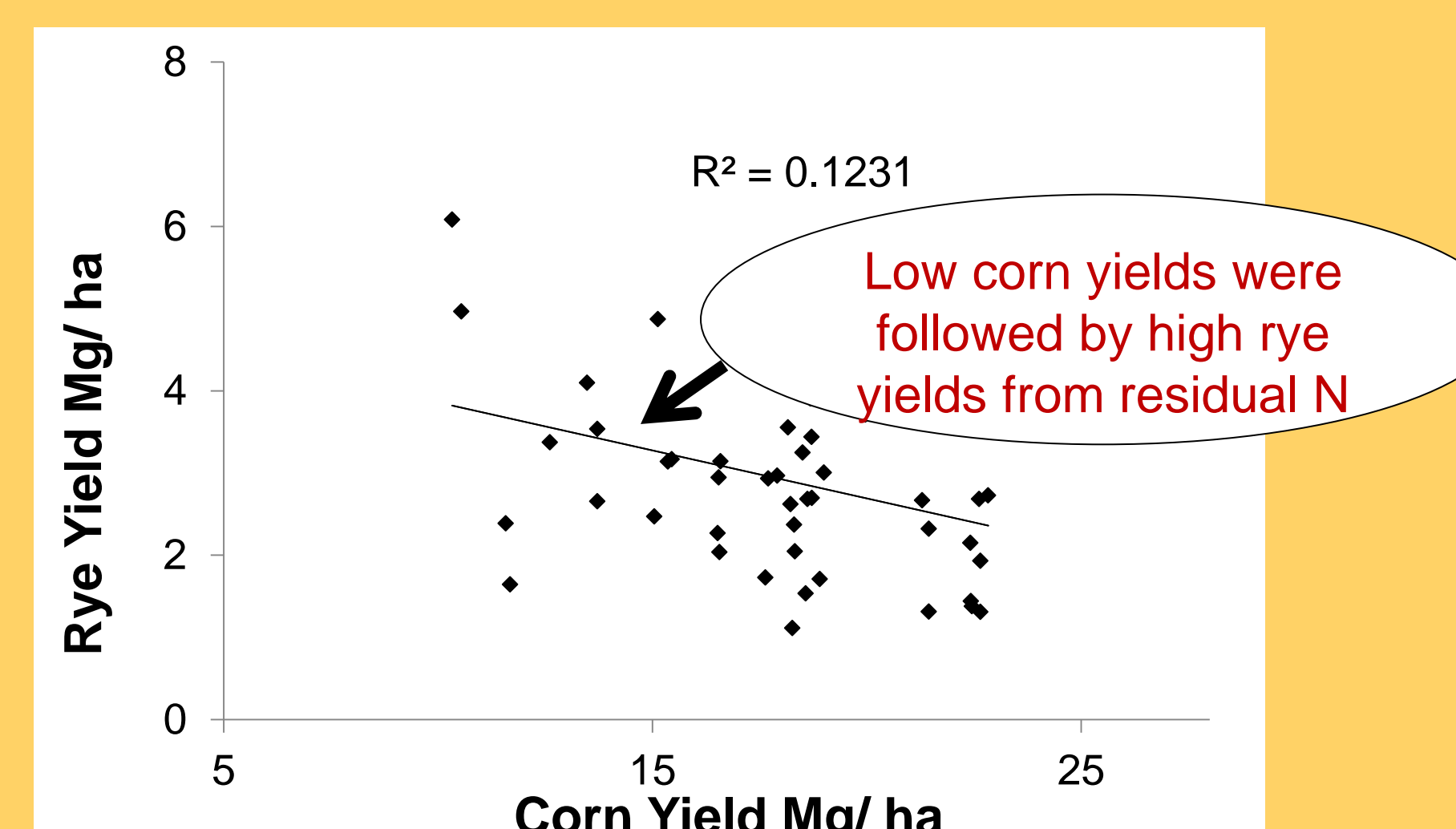


Figure 4. Rye grown after corn vs corn for all locations.

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