An Emergy Comparison of Annual and Perennial Small Grain Cropping Systems

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Background

Perennial small grain crops are a promising option for the sustainable intensification of agriculture. They require fewer material and labor inputs while simultaneously providing ecosystem services, such as erosion control, water quality protection, and soil health improvement, that are not possible with annual crops[1]. For several decades breeding programs have developed perennial grain varieties with several nearing commercial viability[2,3]. Recent investments into research and development of these crops by major food industry firms that hope to increase the sustainability of their supply chain by incorporating perennial grains into commercial food products has created substantial interest from both growers and consumers[4].

Emergy evaluation is a method of sustainability analysis that quantifies all material, energy, and human capital inputs to a production system (Figure 1), converts those inputs to a common unit that accounts for differences in quality, and then compares the sustainability of systems based on the proportions of renewable and nonrenewable resources used in production[5]. In this study we use emergy evaluation to compare production of two novel perennial grain cultivars to two typical annual small grain crops grown in the Fingerlakes region of New York, with the objective to better understand how differences in inputs over the life of each system influence indicators of sustainability.

Methodology

Data were collected from an ongoing field experiment at Musgrave Research Farm, Aurora, NY comparing production of annual and perennial grain cropping systems over three years using the following crop cultivars:

- 'Kernza' intermediate wheatgrass (*Thinopyrum intermedium*; P)
- 'ACE-1' perennial cereal rye (*Secale cereale*; P)
- 'Warthog' hard red winter wheat (*Triticum aestivum*; A)
- 'Endeavour' and 'Scala' winter malting barleys (*Hordeum vulgare*; A)

All grain crops were grown using organic management practices, and split plots were interseeded with medium red clover (*Trifolium pratense*) to evaluate intercrop complementarity .

Emergy inputs were accounted from the following sources:

- Climate data from an on-farm weather station
- Soil erosion estimates based on literature values
- Seed and fertilizer quantities used in production
- Fuel, machinery, and labor values recorded during field operations

Unit emergy values of inputs were found in the literature and were adjusted to an emergy baseline of 12.1E+24 seJ yr^{-1} where appropriate[6].

Figure and Tables

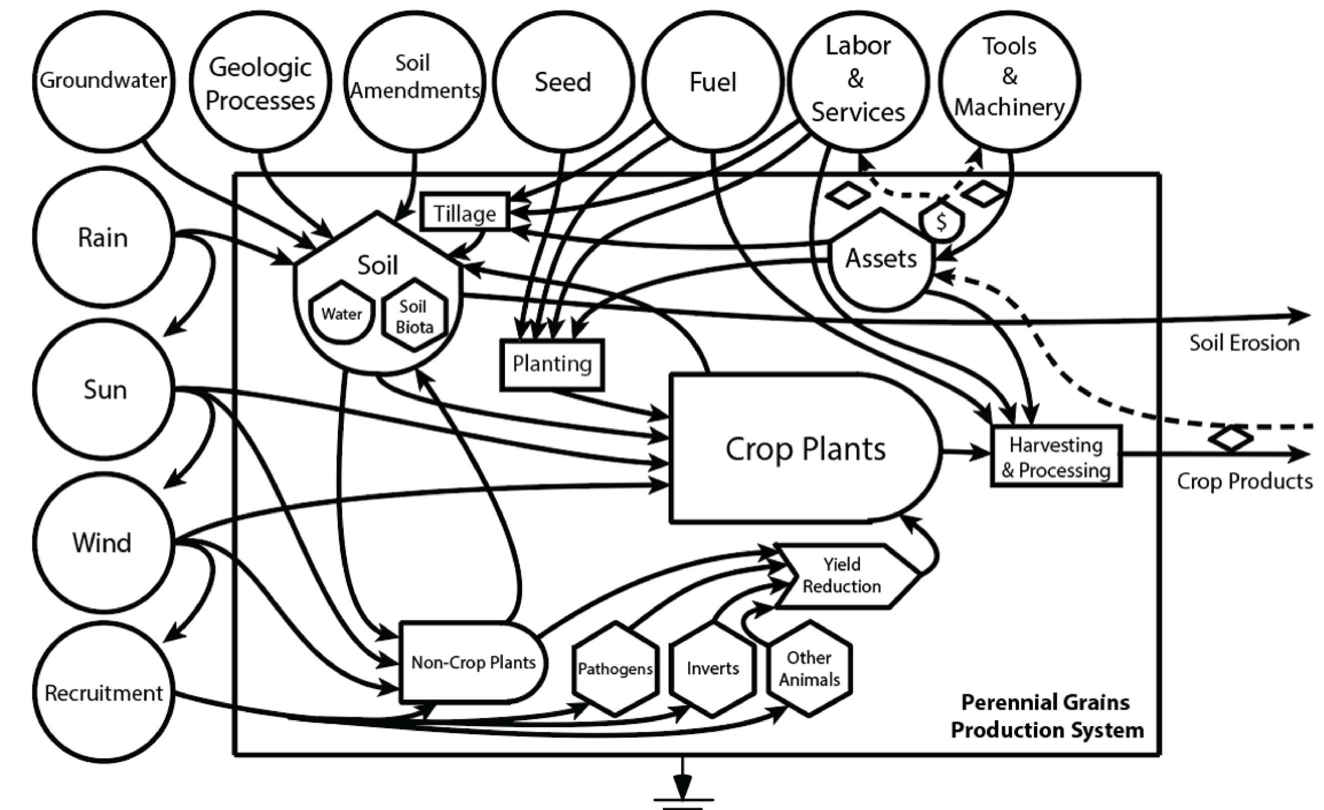

Figure 1: Diagram of emergy flows, storages, and interactions driving a generic grain production system.

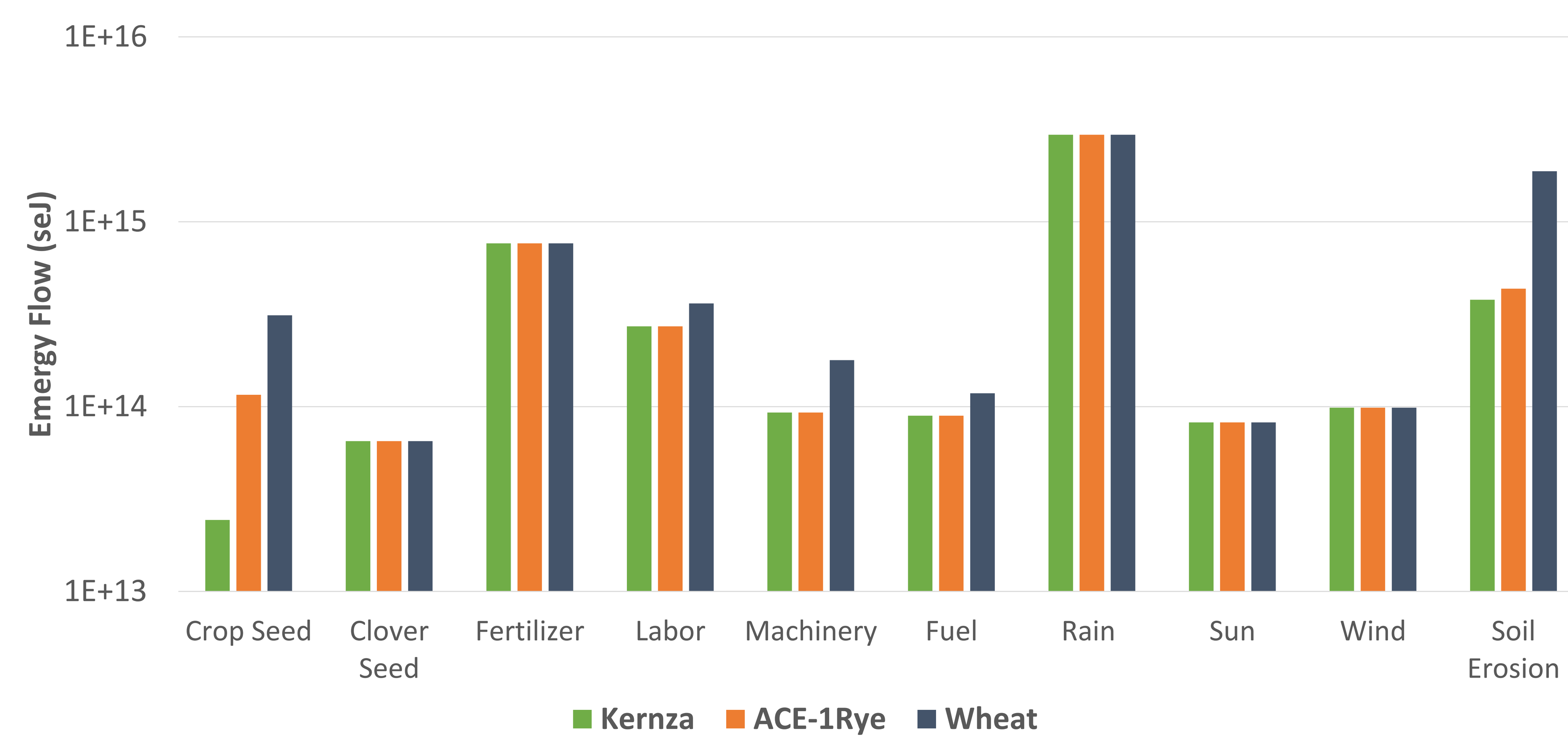

Figure 2: Emergy flows calculated for major forcing functions in the production of grain and forage from 'Kernza' intermediate wheatgrass, 'ACE-1' perennials cereal rye, and 'Warthog' winter wheat, each intercropped with medium red clover. Emergy flows for barley production were similar to wheat and are not shown here.

Table 1: Sustainability indicators calculated for perennial and annual grain production systems.

Sustainability Indicator	Kernza	ACE-1 Rye	Wheat	Barley
Unit Emergy Value - Grain	8.06E+09	4.87E+09	1.18E+09	1.27E+09
Unit Emergy Value - Forage	1.11E+09	1.18E+09	8.16E+08	1.46E+09
Emergy Yield (Y)	4.81E+15	4.96E+15	6.77E+15	6.77E+15
Renewable Fraction (R)	3.14E+15	3.14E+15	3.14E+15	3.14E+15
Nonrenewable Local Fraction (N)	3.78E+14	4.34E+14	1.88E+15	1.88E+15
Purchased Fraction (F)	1.30E+15	1.39E+15	1.75E+15	1.75E+15
Emergy Yield Ratio (Y/F)	3.71	3.57	3.86	3.86
Environmental Loading Ratio (N+F/R)	0.53	0.58	1.16	1.16
Emergy Sustainability Index (EYR/ELR)	6.96	6.16	3.33	3.33

Results

The top three inputs for both perennial and annual grain and forage production systems were rain, organic fertilizers, and soil erosion (Figure 2). Soil erosion was the second highest input for annuals but ranked third for perennials due to reduced tillage operations and increased ground cover throughout the year. Labor, machinery, and fuel inputs were higher for annual crops due to the field operations needed to till and replant in the second year but these differences were not large. Crop seed inputs varied between systems due to replanting and different seeding rates for the four crops.

Sustainability indicators varied between crops (Table 1) due to the differences in inputs noted above, but all indicated that organic small grain production is relatively sustainable (i.e., EYR > 1, ELR =< 1, ESI > 1). These indicators were all more favorable for perennial crops than annual crops. Unit emergy values, which indicate the amount of emergy required to produce one unit (in this case gram) of a given product, were higher for perennials than annuals for grain and were higher for perennials than wheat for forage.

Discussion and Future Work

Our main observation from these preliminary results is that the two perennial grain crops had higher Unit Emergy Values calculated for grain (and wheat forage) outputs but better performance for EYR, ELR, and ESI indicators than the two annuals. This indicates that current perennial grain cultivars are less efficient at converting available emergy into useful products than their annual counterparts due to lower grain and biomass productivity, but that they also utilize a higher proportion of locally available, renewable resources in producing those products. In other words, fewer purchased material inputs required to produce perennial grain crops coupled with reduced soil erosion makes them more sustainable (from an emergy perspective) than annuals despite lower yields. These calculations also omit the value of additional ecosystem services provided by perennials that would increase this disparity.

We will be collecting a third year of data from the field experiment in 2019 and expect that sustainability indicators for perennial grains will improve due to the reduced field operations and seed inputs in post-establishment years, while those for annual grains will stay relatively constant on a year-to-year basis. We hope to improve the estimates of soil erosion used in calculations by directly measuring erosion rates with rainfall simulators. This work will also be complemented with estimation of total energy use and greenhouse gas emissions from these systems using the Farm Energy Analysis Tool[7].

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Acknowledgements

This research was supported by NESARE Grants LNE16-351 and GNE17- 156, and a SUNY Diversity Fellowship awarded through Cornell University.
We would like to acknowledge the stewardship of the Cayuga Nation, a member of the Haudenosaunee Confederacy, on whose traditional homelands this research was conducted.