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COMMENTARY FROM THE U.S. AGROECOLOGY SUMMIT 2023

Finding synergies between agroecology and industrial ecology toward sustainable agricultural systems

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The question of how humans will co-create better food and agricultural systems is extremely complex, and responses vary significantly due to experiences, worldviews, and values. Those of us working on this question typically agree that the goal is to realize systems that are equitable, just, minimize harm to, and ultimately support healthy ecosystems for current and future generations. I will refer to this goal as sustainability. My training is in industrial ecology and civil and environmental engineering, and my professional research focuses on questions of the climate and nutrient impacts associated with agriculture and food products as they are in our time, i.e., dominated by commodity crops. I was introduced to agroecology about 15 years ago while looking into ways to reduce nutrient runoff and improve soil and ecosystems, such as alternative cropping systems, integrated farming practices, permaculture, and more. Eventually, I learned of agroecology as a science, movement, and practice, which increased my interest to learn more. Both industrial ecology and agroecology, and the many branches within them, earnestly pursue facets of sustainability in agriculture, food, and other bio-based systems, and collaboration could lead to synergistic efforts.

Industrial ecology is a relatively new field with no singular definition, initially stemming from engi-

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neering and economics. One succinct definition is a "systems-based, multidisciplinary discourse that seeks to understand emergent behavior of complex integrated human/natural systems" (Allenby, 2006, p. 33). Industrial ecology's beginning is associated with the hypothesis that ecosystems serve as the best models for how human-made systems can be made more sustainable. One example is the observation that in ecosystems, materials and energy are cycled among multiple species at intertwined scales, enabling waste from one community to be used by another (Gallopoulos & Frosch, 1989). Thus, one major focus in industrial ecology research is on how materials flow from the earth (e.g., minerals, water), through human systems (e.g., manufacturing operations, cities), and ultimately back to earth systems, with the goals of minimizing waste and supporting human well-being. Industrial ecology methods associate material and energy flows to goods and services produced and consumed by humans and the resulting environmental impacts. There is a recognition in industrial ecology that humans and our cultures and values and resulting institutions, policies, and markets, drive the use and management of materials and energy, as well as what is produced, consumed, or wasted (Clift & Druckman, 2016). Understanding and mathematically relating production, consumption, and impact enables the analysis of how an intervention may contribute to an overall goal, such as reducing the risk of hypoxia in a waterbody. Reactive nitrogen applied to soil used for agriculture is the leading cause of hypoxia in coastal waterbodies. Industrial ecologists relate the reactive nitrogen applied to land to the harvested crop, resulting in a metric, e.g., grams of nitrogen per kilogram of crop. The creation of these per-unit metrics is the core idea of life cycle assessment (LCA).

LCA is a method that aims to account for the risk of impacts introduced across the entire supply chain of a good or service—that is from mining or harvesting of materials, manufacturing, use, and disposal—in order to avoid moving burdens from one area to another. LCA has long promoted the representation of multiple facets of sustainability when considering options among alternatives. There has been active work on developing methods to include social metrics within LCA for many years (United Nations Environment Programme [UNEP], 2009, 2020). However, environmental metrics are the most actively researched. In all cases, the goal is to use science-driven metrics to account for materials and energy use and relate them to impact, with a preference for quantitative metrics; for example, relating greenhouse gas (GHG) emissions to the risk of climate change as a function of the relative warming potential of each GHG. LCA methodology has gained attention due to being specified in regulations, policy, and market incentives to calculate carbon intensity scores (Califonia Air Resources Board [CARB], 2023; Energy Independence and Secuirty Act [EISA], 2007).

There are four steps in an LCA. The first is the "goal and scope," a critical step that ideally involves clarifying perspectives on what it would mean to achieve sustainability in a specified system and what metrics will be used to assess movement toward or away from the goal. The system's functional unit is also defined in this step, which captures the function(s) of the product, process, service, or system and serves as the quantitative unit of reference for analysis, e.g., one ton of dry switchgrass. The inclusion of agroecology perspectives during this stage is critical for the best representation of novel management options, as well as to aid in addressing questions related to food sovereignty, shifts in socio-political relations, or variations on economic systems. Historically and currently, there has been a lack of full inclusion of all relevant voices in LCA research and the formalized metrics used in incentive programs, although there are examples of efforts to develop participatory approaches in LCA (Rouault et al., 2019) and much to be learned from social scientists and agroecologists.

The second step in LCA methodology is to create a life cycle inventory of materials and energy flows within the system to be analyzed. This is time-consuming and involves site-specific data collection, informed estimation, and the use of databases that capture upstream common processes like mining or power generation. There is great need to better understand the nuanced changes in biogeochemistry that, for example, result in nutrient pollution and GHG emissions from agricultural management options recommended by agroecological research. The GHG emissions from agricultural soils, livestock, and manure management are often estimated using country-specific multipliers from the Intergovernmental Panel on Climate Change, which do not capture geographic nor practice-specific variability.

The third step is life cycle impact assessment. This step uses established methods for approximating the relative risk of substances identified in the inventory in relation to a particular impact category, e.g., climate change or eutrophication potential (Bare et al., 2002). Impact assessment values are updated given new science and analytical methods. There is great need to improve impact assessment methods for application in agricultural and food systems, particularly for nondominant practices. A few important areas currently under scrutiny are the estimation of location-specific GHGs, notably nitrous oxide (Basche et al., 2014; Gaillard et al., 2018), nutrient pollution due to agricultural systems (Henderson et al., 2021), and how to represent the potential benefits of regenerative practices (Schulte et al., 2022). The final step is the interpretation of results in relation to the goal and scope. Typically, there is not a single option that performs best across all impacts. Thus, LCA makes explicit the tradeoffs among choices and provides a framework within which to deliberate and negotiate toward improvements in as many areas as possible.

While LCA, and derivatives like carbon accounting, can be very useful, there are risks of oversimplification and valuation of efficiency, particularly in agricultural systems (Berardy et al., 2020; International Panel of Experts on Sustainable Food Systems [IPES-Food], 2022). Oversimplification can arise from the lack of sufficient perspectives on what makes a system sustainable or the lack of a mechanism to value those perspectives in markets. On the quantitative side, oversimplification can occur due to assumptions embedded in LCA methods, e.g., simple representations of emissions. There is also a danger of focusing on the efficiency of an individual operation rather than systemwide impacts (Algren et al., 2021; Hill, 2022) or singularly focusing on carbon accounting (IDS & IPES-Food, 2022).

As industrial ecologists turn their attention and methods to agricultural and food systems, there is a need to integrate knowledge from agroecology. There are many frameworks for defining agroecology; most include a robust consideration of biophysical, social, and relational principles central to defining a sustainable food system (Wezel et al., 2009). Industrial ecology could improve the capacity to provide analysis that communicates systemwide benefits, given agroecologists' knowledge of the details of diverse and integrated cropping and livestock systems, and of the social and economic arrangements required to support these systems. To realize the promise of truly sustainable systems requires understanding them from the atomic and microbial level to field, watershed, and even global scales.

Envisioning future food systems is for all people to participate in along with farmers, growers, herders, and others who tend to plants and animals. Agroecologists and industrial ecologists can engage with these stakeholders to envision and evaluate options for realizing ever-improving and sustainable agriculture and food systems. However, working with communities and researchers outside of one's own field of expertise is challenging and sometimes contentious. My observation from working in multidisciplinary teams and communities is that these areas of contention are where the effort toward shared understanding is most needed while being the most difficult aspect of a research project. The Agroecology Summit was a rare moment in my professional experience where I felt that tangible efforts were made to address contention across people with different foundations and a shared vision. I look forward to crossing paths more frequently.

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