Terrestrial Ecosystem Ecology and the Application of Scale in Agro-ecological systems

As the population of the earth continues to grow, and the amount of arable land to produce food continues to decrease, it is becoming increasingly valuable to critically examine agricultural practices at a fundamental level. Terrestrial Ecosystem Ecology (TEE) is a science that addresses the associations between organisms and their environments in integrated ecosystems (Chapin III et al. 2011). By assessing agriculture as one of these integrated systems, we might gain valuable insights into their management; in particular, this might be done by the application of the underlying concept of *scale* in TEE. By recognizing and applying levels of complexity at different spatial, temporal, and biological scales than traditional agricultural practices, it may be possible to manage our agricultural systems in a more holistic and sustainable fashion.

One underlying theme in TEE is the idea of significant spatial heterogeneity within ecosystems. The massive level of complexity in earth's natural systems means that ecosystems are inherently variable; every square foot of forest is slightly different than those next to it. This applies to agriculture as well— at one study site in Iowa, the majority of soil properties related to production (soil moisture, structure, soluble nutrient levels, and various other factors that affect crop yield) were either moderately or highly spatially dependent (Cambardella et al. 1993). Most conventional agriculture treats each field as a uniform individual, with single crop, fertilizer, and irrigation regimes applied equally across entire fields. Potential yield is therefore lost from each square foot where that regime is not perfectly ideal. While it would not be logistically feasible to treat each square foot in a field as a true "individual", there are nonetheless options available to farmers to integrate finer levels of spatial variation into agricultural systems. Options include computer-based fertilizer application that measures output and soil conditions across fields, and applies fertilizers accordingly, as well as drip-irrigation regimes which apply water based on the drainage patterns and water-retention qualities across fields, and seeding systems which alter sowing density across fields depending on conditions. Where such systems are economical and feasible to introduce, they maximize productivity by taking into account the variability within of natural systems at finer spatial scales, and can therefore improve the efficiency and output of many agricultural systems.

Another common theme in TEE is the idea of temporal scale. Few biological systems are constant; ecosystems are often in various states of change. Flows of matter within ecosystems, for instance, occurs over long periods of time, and involves gradual fluxes of elements between various physical or biological pools, with net change in the system representing the sum of these individual fluxes. Conventional agriculture is largely based on production at the seasonal or annual scale, however, a longer-term view that takes into account these element fluxes may help maximize outputs and minimize inputs in the long run. For instance, a farmer might choose to reduce tillage in a field to help preserve soil fungal networks, which can help improve soil aggregation (Bethlenfalvay and Barea 1994)— over time, this may increase soil retention and minimize the loss of water and nutrients by leaching. Other farmers, meanwhile, might focus on improving yields in degraded soils by maintaining inputs of soil surface residue (ex. from high-residue-producing crops or mulch) which can result in increases of organic carbon and nitrogen — and soil fertility— over time (Havlin et al. 1990). Even a change in the way production is viewed and communicated— for instance, referring to mean decadal yields, as opposed to annual yields— may help reinforce the paradigm of maximizing longer-term production. This shift in viewpoint may be particularly relevant for intensive, high-input conventional farms, which have the potential to reduce soil organic matter and degrade soils over time (losing water retention, soil fertility, etc.), and may therefore be made more sustainably productive by a more holistic, longer-term view. This focus on inputs and outputs from a system can therefore help improve the productivity and sustainability of agricultural systems by shifting the focus onto system-wide trends over longer timescales.

Lastly, TEE emphasizes the importance and complexity of the interactions between organisms within biological communities. Management regimes that take advantage of these biological interactions, instead of focusing solely on a few crop or pest species, may result in agricultural systems that are much more productive and sustainable. For instance, it is an underlying concept in TEE that greater biodiversity within ecological systems enhances their productivity (Tilman et al. 1996), as well as their resilience and functioning. Practices that aim to promote biodiversity within cropping systems may experience greater productivity and resilience to pests, diseases, and environmental disturbance; similarly, practices which aim to promote biodiversity in surrounding ecological communities may also reap the benefits, such as the consumption of pest insects by birds, or by surrounding vegetation reducing erosion in years of drought. The consideration of larger systems of biological interaction may therefore help agricultural systems become more productive and resilient.

In summary, it is the application of different concepts of scale within TEE, either spatial (variability of soil conditions within plots), temporal (long-term net fluxes of nutrients) or biological (the effects of biodiversity within and around plots), which offers unique and meaningful advances in agricultural management and thinking. All of these practices, of course, depend on the feasibility of application and whether or not the technology exists to implement them in a cost-effective way. However, one of the main values of TEE in agriculture is a more general “widening of perspective” with regards to the spatial, temporal, and biological considerations of agricultural management. As humanity continues to grow and struggle to feed itself, it may be necessary to examine our agricultural practices from these broader ecological perspectives in order to come up with the solutions to feasibly and sustainably feed humanity.

Sources

Bethlenfalvay, G. J., & Barea, J. M. (1994). Mycorrhizae in sustainable agriculture. I. Effects on seed yield and soil aggregation. *American Journal of Alternative Agriculture*, 9(04), 157-161.

Cambardella, C. A., Moorman, T. B., Parkin, T. B., Karlen, D. L., Novak, J. M., Turco, R. F., & Konopka, A. E. (1994). Field-scale variability of soil properties in central Iowa soils. *Soil science society of America journal*, 58(5), 1501-1511.

Chapin III, F. S., Matson, P. A., & Vitousek, P. (2011). *Principles of terrestrial ecosystem ecology*. Springer Science & Business Media.

Havlin, J. L., Kissel, D. E., Maddux, L. D., Claassen, M. M., & Long, J. H. (1990). Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Science Society of America Journal*, 54(2), 448-452.

Tilman, D., Wedin, D., & Knops, J. (1996). Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature*, 379(6567), 718-720.