SCIENCE WITHOUT SHINY LABS

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The tangle of vegetation may look like an abandoned field. Or an overgrown vacant lot (Figure 1). But it is a farm. And a shining example of indigenous scientific knowledge. Indeed, this image can help us reassess the widespread expectation (this month's Sacred Bovine) that science – or the best *modern* science – owes its effectiveness to lab experiments and the latest shiny technology. First, we might appreciate how this field can reflect good science, then ask more about science itself in an indigenous context. That might inform us more deeply about how science works.

○ Hidden Ecological Knowledge

The farm here is a *milpa*. It embodies methods developed millennia ago in Mesoamerica. This agricultural strategy helped build and sustain the cities of the Maya and other early civilizations. While the field may appear chaotic, it is mindfully organized. The key feature is *intercropping*. Three crops are grown simultaneously on the same land: corn (maize), squash, and beans. (I recently witnessed the same approach in Amazonia, where manioc replaces corn.)

To a "modern" eye, managing these multiple crops may seem problematic. How does one apply fertilizers, pesticides, and herbicides or sow and harvest efficiently? But the milpa solves these problems in its own way (González, 2001; Penniman, 2015; Jenkins, 2017; Perroni, 2017). First, the mosaic of different species makes it harder for voracious insects or fungal diseases to spread from plant to plant. Also, the squash release small amounts of cucurbitacins, which inhibit herbivores. The beans, too, produce a substance that deters the corn earworm. Thus, no need for chemical pesticides. Second, the large leaves of the squash help shade out unwanted weeds. No need for chemical herbicides. Third, the beans contain nitrogen-fixing bacteria that help enrich the soil. Less need for chemical fertilizers. That makes the milpa effective even where the soils are less fertile. Fourth, the maize benefits from the direct sun, while protecting the beans and squash from the intense heat. Shade from the squash further helps preserve soil moisture. Three healthy crops instead of just one. Increased overall productivity. Forty to fifty percent more than a one-crop field. Fifth, the whole system is typically practiced on a smaller scale. No expensive machines. And no expensive fuels that only add to global warming anyway. Less costly. Less environmental impact. All things considered, what may appear to be a primitive, chaotic (and perhaps unscientific) garden embodies significant ecological knowledge about how to grow crops.

Multiple crops also produce root systems at multiple depths, which reduces soil erosion. And when the growing season is over – if there is not another crop to grow – the plant stubble is left and turned into the soil, helping to conserve soil nutrients and moisture. The mulching also yields better soil structure, which also means less erosion. In addition, the milpa methods work on slopes, so the farmers can capitalize on land that would be inaccessible to someone relying on heavy machinery. In Amazonia, some fields are not much more than beaches of loose soil, exposed when the wet season's floodwaters recede (Figure 2). The farmers there do not need long straight rows of plowed ground to cultivate productive crops. Overall, better land use and better soil conservation.

Figure 1. A milpa (indigenous farm) in Central America, showing intercropping of maize, beans, and squash. (Photo courtesy of Leah Penniman)

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Figure 2. The Amazon's annual floodwaters have receded, and farmers have planted in the new beach of loose soil. Soon this will be a lush farm of manioc and squash.

Figure 3. Monoculture, the core assumption of modern farming, reflecting ideal research conditions. (Photo: Pixabay)

Appreciating those insights only leads to the deeper and more important question: How did indigenous cultures, without all the shiny tools of modern science, develop such sophisticated knowledge of nature? What is their science like?

○ The Assumptions of Modern Science

The milpa system contrasts sharply with the image of growing only a single crop in any given field. Vast "amber waves of grain," as the song says (Figure 3). Why? Note that "modern" agricultural practices neatly align with typical "modern" research methods. One limits the number of variables. Ideally to just one. Mixed crops only seem able to confuse the process. This approach to doing science thus implicitly promotes single-crop farming (DeWalt, 1994). Perhaps even without a recognition that an assumption is at work.

Second, in seeking to control variables and test each, one by one, modern science favors a stable and consistent background. Visualize a greenhouse with carefully regulated growing conditions and a standardized genetic strain. There is no theoretical reason why such conditions should foster better farming. But they do facilitate experimental manipulations and comparisons. Coincidentally, such relatively uniform conditions were found historically in the temperate United States: in the large expanses of flat, fertile land, especially across the prairies of the Midwest and the Atlantic coastal plains. The ultimate outcome has been large-scale farms where one can easily manage uniformity. Large scale, in turn, promotes mechanization (at least where fuel is available cheaply). The economics of capital-intensive agriculture, in turn, shift power from individual farmers to large industries. Major consequences from a "simple" assumption. At the same time, genetic homogeneity becomes another crop management ideal. Controlled sameness. However, this raises vulnerability to disease and insect herbivores. More problems. Indigenous alternatives help highlight the often unnoticed assumptions about what some may see as just "ordinary" farming, here related to the research goal of controlling variables.

A third assumption involves soil and environmental contexts. Again, "modern" research seeks to reduce variables. So, an agronomist will tend to regard a bare field, isolated from its surroundings, devoid of vegetation – an agricultural "tabula rasa" – as an appropriate baseline. Thus, scientists will focus on controlling and measuring each soil nutrient individually. They thereby promote the corresponding notion of artificial fertilizers to manage soil. Tillage practice will target leaving bare ground. But this will accelerate soil erosion. Long-term soil conservation becomes an afterthought. Meanwhile, when one focuses on crop yield alone, one can easily overlook the runoff of excess fertilizers. That's not part of the system under study. When eutrophic marine dead zones appeared worldwide, where major rivers dump fertilizer runoff into the ocean, many scientists were surprised. But in retrospect it seems wholly predictable. Again, simple assumptions about science can have unexpected but profound consequences.

Of course, farming using this set of "modern" research assumptions has been remarkably successful. By one measure, at least. Output per acre has increased dramatically. Yields are up. Labor costs are down. U.S. agricultural productivity more than doubled in the second half of the twentieth century. Impressive, indeed! But this goal as a standard of "effective" farming is itself a feature of context. It ranks productivity, or volume of yield, above all other values. As scientists have learned in the past few decades, those high returns depend, sadly, on immense energy inputs. In fact, modern "scientific" farming is not very efficient at all when one compares food energy (output) with the agricultural labor and energy inputs. Today, more energy is used in producing industrially farmed food than is available nutritionally in the food itself. For similar reasons, Jared Diamond (1987) famously called farming "the worst mistake in the history of the human race." Now, we also see other consequences: global warming from the use of carbon fuels and environmental degradation from excess chemical pesticides and fertilizers. Modern agriculture's achievements come at an often unacknowledged cost. Attitudes about sustainability are surely evolving, but the key question may be: Why did the science lead us here and seem to justify it?

Indigenous practices begin with different assumptions, based on their cultural and economic contexts. Productivity is rarely the primary aim. In Oaxaca, Mexico, for example, the goal is described as *mantenimiento*, or maintenance. Maximal harvests are not as important as a predictable food source. That includes accommodating droughts, hurricanes, or spikes in pest populations. Sustaining the land for farming in future generations also matters. Namely, both short- and long-term effects are considered (González, 2001). Self-sufficiency and sustainability, not annual profit, guide the observations and reasoning about milpa farming (Pulido & Bocco, 2003). The indigenous communities collect evidence and reason scientifically about agriculture, just as other scientists do, but the result may seem unfamiliar to "modern" eyes because they work from their own set of assumptions.

○ Alternative Styles of Doing Science

Indigenous agriculture employs a different style of science than is common in "modern" contexts, but it is equally science. Farming research is addressed in situ, with all its "messy" complexity, its multiple variables and myriad interactions. In such cases, science works most effectively through studying individual cases in depth. One analyzes details and compares them to similar cases. More and more, philosophers of science are coming to appreciate this mode of science and articulating its distinctive epistemic strategies (Creager et al., 2007). That is, indigenous farmers do not try to reduce the problem into separate, partial problems and subject each to the regime of a controlled experiment (DeWalt, 1994; González, 2001). There are no high-tech labs. No digital pH meters. No genetic sequencers. None of that shiny equipment. For these indigenous scientists, broad-based experience and analogical comparisons are more valuable than narrowly focused, decontextualized experiments. That may be why, in part, it does not *look* like science to some.

Absence of a reductionist approach does not mean, however, that indigenous farmers forsake experimentation. When they encounter or imagine new methods, they test them. For example, they try new seeds. They try new cultivation methods or tool designs from neighboring communities. They repurpose familiar methods for killing snakes to controlling an invasive insect. They imagine new composting methods to treat sodic soil, ruined by poorly managed irrigation (Prakash, 2002). They observe and collect data – but informally, not on huge computer spreadsheets. In the 1960s, the Mexican government introduced and promoted chemical fertilizers. Farmers in the Rincón in Oaxaca tried it. Yet they quickly discovered that the recommended amounts of fertilizer "burned" their crops. No sophisticated equipment was needed to see the damage. These campesinos now use fertilizer, but in a way shaped by local experience. They use (a) quite small amounts, (b) applied directly in deep pits, and (c) on the uphill side of each cluster of maize plants (González, 2001). Elsewhere, in Niger in the 1980s, crops were threatened with striga (witchweed), which parasitizes roots. Farmers there used simple selection to breed strains with shorter growing seasons. The new millet matured before the striga attacked (Warren, 1991). Indigenous science is not just traditional lore from some remote past, frozen in time. It is dynamic and innovative. Natural knowledge evolves and grows, guided by exploration and material evidence.

Certainly, there are limits to indigenous science. While the farmers know their local crops and weed plants very well, they tend to know less about insects and their life cycles. Even less about plant diseases. Their observations are limited without "shiny" microscopes (Bentley, 1989). For example, a region in Honduras was beset with waves of devastating insects, which the locals simply called "locusts." In the 1980s, visiting international scientists were able to identify them as four different moth species. By investigating their life histories, they deciphered why they were so hard to control, providing hints toward an eventual set of solutions (DeWalt, 1994).

Skeptics of indigenous science may also find fault with some of the ways the knowledge is expressed. For example, the Zapotec farmers in Mexico explain plant growth through the metaphorical concepts of "hot" and "cold." Chilies, garlic, dark panela sugar, low-altitude fields, and fertilizer are "hot," for example. Avocados, refined white sugar, humid soil, shade, and crowding between coffee trees, by contrast, are "cold." These attributes are used to explain why things thrive (from balanced heat) or languish (too little heat). Too much heat can also be detrimental – as in the case of excess fertilizer "burning" the crops (González, 2001). Of course, such concepts have no place in modern science. No one can measure this "heat" objectively. Yet one can equally overstate the epistemic role of these notions. They are simple local models that help classify properties that promote or inhibit growth, and that prove useful for organizing thoughts and discussing experience. Accordingly, "hot" and "cold" designations seem quite flexible, often shifting to fit what has been observed. Ultimately the farmers' knowledge is embedded in and measured by their practice, not their conceptual schemes. One might easily discount indigenous science based on such concepts, but this may reflect yet another "modern" bias: privileging abstract theory over concrete results and instrumental models. Here, the actual effectiveness of indigenous farming speaks more fully than the informal explanations farmers use to account for it.

Indigenous knowledge is also limited by tending to be inherently local. While it is usually rich in details, it is also deeply contextualized. Transferring results from one locale to another can occur only with caution and appropriate further work. Agricultural knowledge adapted to one particular soil type, terrain, or microclimate may not travel well. As a result, there is little motivational context to generalize or form abstract theories. Again, analogical reasoning (or thinking laterally from one case to a similar one) tends to dominate over hierarchical, theory-based, or deductive thinking. Science always faces a trade-off between generality and specificity. Indigenous science tends to focus on the specifics. Local observations and evidence matter more than theoretical explanations. Indigenous practices highlight the contrast between "local" and "cosmopolitan" science (González, 2001).

So, indigenous science is different, but no less science. It is less theory-oriented and more case-based. It is experimental, but not reductionistic. It tends to be local and specific, not general or abstract. Still, the milpa, as historical proof, shows that it works.

○ Does Science Rely on Shiny Labs?

To assess the relative status of indigenous science, one might ask whether its practices (such as intercropping) have any relevance in "modern" agricultural contexts. Examples beyond the milpa certainly help underscore how insights from one local indigenous science can indeed apply elsewhere. For example, insecticidal properties of the neem plant, recorded in ancient Sanskrit writings in India, have proven useful in Niger and Togo in Africa, where neem trees are also abundant. The leaves, and especially extracts from the seeds, have contributed to preserving stored grain there and to protecting standing crops (Warren, 1991). In the United States, many scientists are inspired by indigenous examples. For example, an American version of intercropping – mixing peanuts (legume), watermelon (shade cover), and okra (insecticidal deterrence) – was studied recently at Texas A&M University (2017), with positive results. Of course, their selection of species was just informed guesswork, and further results underscored that combining other species was less effective. The study also highlighted the problems of scale. The method may be limited to moderate-size garden-type farms. Other research on intercropping continues at numerous institutions (Wright, 2015; Bybee-Finley et al., 2016). At the Columbia Basin Agricultural Research Center in Oregon, researchers echo the optimism, while emphasizing the need for adaptation. Intercropping farmers in the United States might alternate crops in the familiar long straight rows, so as to facilitate mechanization (Machado, 2009). It may be ironic that even when indigenous farming methods are adopted, scientists still need substantial additional research, but now the local context is a "modern" one.

Ultimately, indigenous farming practices, despite being developed in and adapted to local contexts, can provide models even for "modern" scientists. The indigenous approaches exemplify how science may work effectively even without "shiny" labs.

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