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Paradigms of Smart Farming: Chemical, Ecological, Algorithmic †

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Abstract: This paper briefly sketches the ontological, epistemic, and ethical implications of three farming paradigms: 20th Century Chemico-mechanical agronomy, Microbiomic-ecological cultivation, and Algorithmic "Smart" farming. The position ultimately taken, though not fully defended, is that Smart farming algorithms will predictably fail, likely catastrophically, if doesn't become the dominant paradigm in practice as we integrate and connect and scale up.

Keywords: AI; ethics; agriculture; ecology

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1. Introduction: The Chemical Paradigm for Farming

Background assumptions, ideology, metaphors, analogs, and paradigms all inform our thought processes, judgments, and decisions. As they say, when you're a hammer, everything looks like a nail. Applying this to disciplinary paradigms, when you're a chemist, everything looks like a chemistry problem. For example, Monsanto was a chemical company, so it approached agriculture chemically. The chemical paradigm leads us to think in terms of atoms, ions, and molecules; bond structure, geometrical structure, chimerity and conformation changes. In particular, the chemical paradigm leads us to think in terms of localized reactions between few chemical kinds in isolation, in laboratory conditions, or in closed systems.

The chemical approach to agriculture has been widely criticized since at least the 1980s, particularly in conjunction with industrialized agriculture. As Callicot explained in 1990, the classical "chemico-mechanical conception of growing food" regards soil as "nothing but a physical substratum in which plants sit" [1] (p. 39). But we know that farms are not properly reducible to their chemistry:

> "[L]et me hasten to say that I am not for a moment suggesting that such elements as carbon, nitrogen, phosphorus, and potassium are discredited theoretical entities-like phlogiston ... What I am suggesting, rather, is that, prior to the twentieth-century, modern science thought that reality was *exclusively* mechanical and chemical and ... twentieth century agronomists proceeded on the assumption that soil was *nothing but* a mechanical medium and that plants were *nothing but* complex assemblages of a few simple elements and that agricultural goals-increasing yields, controlling weeds, pests, and pathogens, maintaining fertility, and so on- could be achieved Cartesian-style, by finding a separate solution for each and summing the results". [1] (p. 41)

What else is there to soil and plants and growing food? What we need is a paradigm that better reflects the complexity of an open systemic whole, e.g., an ecological paradigm. Again appealing to Callicott's view, ecologic *systems* have four features.

1. A genuinely systemic whole exhibits **emergent** properties that are neither reducible to nor predictable from the properties of the parts.
2. A genuinely systemic whole exerts **downward causation** on its parts, e.g., individual organism phenotypes are shaped in part by the environment.

3. The parts of a genuinely systemic whole are **systemically related.** The components of societies, organisms, and ecosystems involved multiple and interacting positive and negative feed-back loops with indirect, synergistic, and nonlinear causation.
4. The parts of a genuinely systemic whole are **internally** related, e.g., grass and grazer, predator and prey, host and parasite co-evolve as mutually constitutive pairs.

Now it might be argued that the chemical paradigm can accommodate all four criteria. Emergence is certainly common in chemistry. Molecular conformation can be affected by environmental factors like acidity. The chemistry of cell signaling demonstrates the systematic relations of complex chemical reaction cascades and feedback modulation. (The idea that a cell is *alive* need not have explanatory power here) And it is common to conceive of certain chemicals as internally related, e.g., "catalyst" is relational in the requisite sense and a protease is relationally understood to be a "cleaver" of proteins. What is it that's really missing according to the critics of the chemical paradigm for farming? Well, in a word, *life*.

2. Adding Life to Farming

Let us follow the corporate trail then, to Monsanto's purchase by Bayer in 2016. Bayer is ideologically a pharmaceutical company at heart. Its pharma paradigm leads us to think in terms of chemistry, but also in terms of health and disease, toxicity, prophylaxis and cure-and most importantly-individual living organisms with life cycles. This is a step in the right direction. It doesn't bring us all the way to ecological systems, but at least the pharma paradigm includes the conceptual framework of life.

Taking another step in the direction of life, the microbiomic revolution in the 21st Century has recently led to a fundamental shift in both medicine, where I take this to include the pharmaceutical paradigm, and in ecology. We now know that individual organisms aren't 'uni-genetic'. From humans to wheat, every individual organism is actually an ecosystem. For example soil, air, and water are also ecosystems, full of microorganisms. We also know that a healthy microbiomic ecosystem is necessary for individual organism health. Like the classic ecological paradigm, the neo-ecological paradigm leads us to think in terms of multi-organism interactions like communication, cooperation, and competition; niches, co-evolution, co-adaptation, symbioses and parasitisms; homeostatic balance, stability, and replenishment. The difference is that the microbiomic ecological paradigm has more levels than the 1980s paradigm.

Metaphysically, the ontology of neo-ecology and its causal mechanisms are distinct from those central to the chemical or medical paradigm. Neo-ecology includes a broader range of entities that are more heterogeneous, as well as more layers from microscopic to macroscopic. It's ontologically open [2] (p. 99), and it comprehends both chemistry and medicine.

It may seem then that the neo-ecological model is unproblematically the best available paradigm for agriculture, but its very complexity is itself a problem:

> "[E]cology is captivating due to the **sheer comprehensiveness** of its scope and complexity of its subject matter; ecology addresses everything from genetics, physiology, and ethology of animals (including humans) to watersheds, the atmosphere, geological processes and influences of solar radiation and meteor impacts–in short, the totality of nature". [3] (p. 1)

> "Beyond expected and unresolved terminological vagueness, we argue that 'assessments and comparisons' of 'taxonomic and functional' profiles in **microecology** suffer from **theoretically unresolvable arbitrariness and ambiguities**. We divide these into problems of 'scale, individuation', and 'commensurability'". [4] (p. 1225)

Epistemically, the complexity of the neo-ecological paradigm yields an unfulfilled promise to grandly unify everything: The requisite theoretical integration across levels is just as bad as it is for chemico-physics, perhaps worse since we must add life. Since we're still experimenting with what to idealize, which parameters we can exclude, etc., the modeling problems may be insurmountable for the foreseeable future-you have to know a lot about a system to model it usefully. Consequently, neo-ecology's false promise of comprehension and completeness may be no better than the false promise of certainty for the chemical and pharmaco-medical paradigms.

These complexity-derived problems threaten to make the neo-ecological paradigm for agriculture a non-starter because agriculture presumes human **monitoring** and **intervention**–the creation and maintenance of an artificial system. This entails that we must determine what to monitor and how to intervene. The chemical paradigm led to RoundUp, antibiotic resistance, soil exhaustion, waste, and pollution. We weren't properly monitoring the system of life, and the interventions ultimately weren't sustainably healthy. The neo-ecological paradigm offers a different set of targets for monitoring and approaches to intervention. For example, neo-ecology can accommodate phenomena of 'wound-healing' and immunological self-reinforcing systems at the ecosystem level that penetrate to the microbiomic level, which means that neo-ecology tends to recommend much greater biodiversity and far less intervention in agriculture. Bayer's current public relations rhetoric carries an obvious strain of neo-ecology, which is commendable if operative, but it also carries a worrisome strain of techno-solutionism, which brings us to consider the algorithmic paradigm in Smart farming.

3. Smart Farming, i.e., Parameters for AI in Agriculture

Smart farming is nominally the new paradigm for agriculture. It includes remote monitoring technologies, e.g., satellite, drone, and networked local sensors, with the aim of widespread connectivity within and across farms; as well as remote interventions like automated delivery of irrigation control, pesticides, and fertilizer. Predictive integrations, for example, integrating meteorological data into smart irrigation systems, are becoming more common. We're also seeing an explosion of interest in biomodification technologies like CRISPr as well as smart tracking and distribution systems.

The algorithmic paradigm that underlies these agrotech developments leads us to think in terms of datasets, correlations and proxies, inductive continuity and stability over time, large scale implementation and deep connectivity, and full automation of complex monitoring and intervention systems. We've seen Smart technologies fail, sometimes spectacularly, in a variety of domains. To give just a few examples of well-known problems, many public-facing exposees have been written about:

- Racially biased facial recognition software, search engines [5], etc. (bias in, bias out)
- Self-confirming predictive software (e.g., Allegheny Family Screening Tool [6])
- Unstable proxies (e.g., tracking clouds instead of German tanks on cloudy days [7])
- Stable proxies with incorrect intervention recommendations
- Black box opacity (sometimes unnecessary; thwarts verification and correction of algorithm)
- Real-world discontinuities that derail inductive reliability (e.g., pandemic disrupts market & supply beyond what Bayesian updating can handle)
- Misapplication (using software designed for X to do Y instead, without full understanding of the difference)
- Unrepresented entities and mechanisms (what we need might not be in the data at all)

What lessons should we learn from these failures of the algorithmic paradigm in other "smart" domains? Pragmatically, as we develop Smart algorithms for farming we need to keep in mind that: (1) Mechanisms matter. Intervening on proxies is a disaster waiting to happen. Ecological systems are causally extraordinarily complex with scale boundaries like those between physics and chemistry. (2) Not everything scales up (or down), especially in biology and ecology, thus also in farming. (3) Problems of induction in our climate-changing Anthropocene are enormous, and we don't know what we don't know. (4) Techno-solutionism threatens to recapitulate the over-interventionist practices of 20th century farming.

There are also several very basic ethical considerations that should be parameters for decision-making in Smart farming (and I contend that these are in fact the responsibility of programmers and developers). **Consequentially,** the stakes couldn't be higher. If we fail at scale, millions or billions of people die. Possibly the whole biosphere collapses, given its current precarity. This is ethically a strict liability context-good intentions mitigate nothing. **Deontologically**, everyone participating in agritech has a public fiduciary duty (to the world, nature, biosphere). Few individuals have obvious large-scale decision-making power, but responsibility without control is actually the human norm (however uncomfortable that is). Thus the exercise of responsibility in agritech is non-trivial. These are not highly controversial positions. Since they have proved inadequate thus far, however, we need to broaden the ethical perspective to draw some conclusions that may be more challenging to the status quo. From a **virtue** perspective, a distinct kind of courage is required to organize and speak truth to power, especially against the current of market forces and our own techie "family". Moreover, from a **care** perspective, I submit that our public fiduciary duty in Smart agriculture should be internalized as care for our home–a *family* farm ideal-in which we are fully invested, as opposed to a Kantian-disinterested or utilitarian-contractual unwanted burden. And Finally, from a **social justice** perspective, many of our institutions and educational programs, locally and globally, need to be (further) reconceived in order to responsibly pursue Smart farming. For example, indigenous experts, subsistence farmers, and environmental ethicists who have historically been excluded with prejudice should have seats at the table; and rights of environmental *as-if persons* like Denali and the Ganges must be protected.

4. Conclusions (Well, Suggestions)

Though I have only sketched considerations here, I think it is clear that Smart farming algorithms will predictably fail, likely catastrophically, if neo-ecology doesn't become the dominant paradigm in practice as we integrate and connect and scale up. "Move fast and break things" can't be our motto. We need to tread very carefully despite terrific social and market pressures, and this (to my surprise) may ultimately require an ideological shift from the scientific-disinterested approach to agriculture to a "spiritual" [8] approach to agro-ecology in which we are all dwellers in a system full of *as-if persons* for which we must *care*.

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