Justus von Liebig Makes the World

Soil Properties and Social Change in the Nineteenth Century

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Abstract Just as capitalism's exchange of commodities between disparate locations requires a singular referent of value, so does the movement of ideas and practices necessitate consolidations of meaning through complex fields of people, landscapes, and things. Introducing key innovations in agricultural and chemical science, Justus von Liebig's chemical model of soil fertility involved a profound reenvisioning of organic development, distilling complex processes to a series of chemical relationships easily recognized in any geographic context. Drawing on Henri Lefebvre's (1984) arguments about the production of abstract space, this article argues that Liebig's assessment of nutrient extraction was essential to a broader mid-century reconsideration and reorganization of capitalist agricultural production, an example of what world ecologist Jason Moore calls an "organizational revolution," allowing global capitalism to overcome past limits and thus move through systemic crises.

Keywords chemical science, agriculture, history of science, soil fertility, capitalist agriculture

In his best-selling 2006 book *The Omnivore's Dilemma*, journalist Michael Pollan derides contemporary conventional farming's idea that soil vitality can be effectively managed by the targeted addition of nitrogen (N), phosphorus (P), and potassium (K), what he calls the "N-P-K mentality" (146). Pollan draws both the term and its critique from an earlier popular treatise on agriculture, Albert Howard's *An Agricultural Testament* (1943). A foundational figure in what would become the organic farming movement, Howard advocated for a new attention to soil biology in the face of widespread decreases in soil fertility associated with industrialized farming in the early twentieth century. It is no small irony that the figure against whom both of these authors inveighed was himself a best-selling writer, the German chemist Baron Justus von Liebig, whose nineteenth-century publications, teaching, and penchant for self-promotion helped embed the so-called NPK mentality in the industrial agrarian consciousness. Then, as now, debates over environmental best practices reflected not just divergent technical opinions but also conflicting investments in the nature of human societies. Such

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positions value and cultivate particular manifestations of life in place, including but not limited to human life. While they write from different moments of crisis, *The Omnivore's Dilemma*, *An Agricultural Testament*, and Liebig's *Familiar Letters on Chemistry and Its Relation to Commerce, Physiology, and Agriculture* (1848) all advocate transformations in soil management in relation to the linked social and environmental crises of modern global market capitalism within agriculture.

Liebig's interventions were both practical and epistemological. Liebig's own commercial formulas for soil amendment were widely dismissed as ineffective. However, the *idea* that plant growth was reducible to measurable chemical interactions was revolutionary. As transformative was the practical implication that farmers could reliably overcome the local limits of fertility via capital investment in off-site resources, thus amplifying the overall space of production. Moreover, the chemical theory of organic growth enacted a powerful parallel conceptual transformation, framing a commensurability between the world's diverse soils that could accommodate a singular management strategy across diverse landscapes.

Though Liebig's technical recommendations have long been eclipsed by new insights, his model of soil as a chemical repository has had a stubborn appeal, as evidenced by critics' inevitable return to his work. This article interrogates the sustained utility of Liebig's innovations as they relate to the re-alignment of liberal capitalism in the second half of the nineteenth century. Why has his chemical model of soil fertility persisted in agriculture despite an established body of scientific research asserting the importance of soil biology and ecology in plant growth? If chemical-based soil management is not the most effective route to soil vitality, what other functions does it effectively fulfill within industrialized production?

Just as capitalism's exchange of commodities between disparate locations requires a singular referent of value, so does the movement of ideas and practices necessitate consolidations of meaning through complex fields of people, landscapes, and things. As key innovations in agricultural and chemical science, Justus von Liebig's contributions involved a profound reenvisioning of organic development, distilling complex processes to a series of chemical relationships easily recognized in any geographic context. Drawing on Henri Lefebvre's arguments about the production of abstract space,[1] I suggest here that Liebig's assessment of nutrient extraction was essential to a broader midcentury reconsideration and reorganization of capitalist agricultural production, an example of what world ecologist Jason Moore calls an organizational revolution, allowing global capitalism to overcome past limits and thus move through systemic crises. Alongside revolutions in railroad and steamship technology, Liebig's innovation created a foundation for the expansion and acceleration of global capitalist production based on cheap food, expanded distribution, and readily available investment capital in the late nineteenth and early twentieth centuries (Arrighi 2007: 100–101). The chemical model of soil fertility was a key product of this crucible of creative destruction (Schumpeter 1942: 83).

1. Lefebvre, *The Production of Space*.

Moreover, it is essential to consider Liebig's technical contributions as a manifestation of his broader social and political commitments. I turn to Antonio Gramsci's (1977) explorations of the intellectual in society to investigate Liebig's writings on political community and the social function of knowledge—a body of work that has been heretofore overlooked by historians of science and agriculture. I argue that Liebig's theories were directly and self-consciously shaped by commitments to an ascendant bourgeoisie as the German state of Hesse-Darmstadt transitioned from feudalism to liberal democracy. Liebig's political writings argue for the primacy of professional authority over lay knowledge in modern society at the same time that his practical model of soil fertility shifted the power of soil assessment from the farmer to the laboratory. By investigating not only Liebig's scientific findings but also the methods by which he, his students, and his supporters legitimized and reproduced that knowledge, we can begin to understand how nineteenth-century descriptions of plants exerted an international influence on the economic and political structures of social life.

The ongoing relevance of Liebig to contemporary debates speaks to how deeply his conceptual insights have shaped modern farming, with lasting social and environmental implications. Chemical-based farming allowed farms to become both larger and more productive, which in turn supported more workers laboring in city centers, driving an era of unprecedented technical and industrial innovation. In addition, chemical-based soil management allowed commercial farmers to expand production even in unfamiliar landscapes with very different soil profiles, supporting the growth of colonial and settler-colonial agriculture in places such as North America, Africa, and Asia. I show how Liebig's ideas circulated to embed a particular set of political commitments in an expanding landscape. Farmers read books and magazine articles written by Liebig and employed his methods to convert forest and grasslands to farming and maintain productivity on existing fields. Experts in the newly formed United States Department of Agriculture, for example, traveled to Germany to study in Liebig's laboratory, returning to train farmers and a new generation of agronomists (Brock 1997, 2003).

Liebig's farming methods also created new global markets for key agricultural chemicals. During the nineteenth and early twentieth centuries, millions of tons of organic nitrogen fertilizer extracted from plant and animal bodies were circulated on the global market to fertilize the world's commercial farms. These novel products and markets drove new political contests over who would control territory as well as new international labor relationships (see Melillo 2012). After the Second World War, factories built to produce chemical weapons were converted to produce a more affordable synthetic nitrogen for an even larger number of farmers worldwide, harnessing the infrastructure of military power to shape a new industrialized global food production system.

World Ecology, Soil, and the Production of Abstract Space

As Jason Moore writes in his investigations of what he calls the Capitalocene—the contemporary era of human-induced geologic change—"capitalism does not *have* an ecological regime; it *is* an ecological regime" (Moore 2011, 34). Taken as a whole, the human and nonhuman worlds form what Moore calls the *oikeios*. However, a constitutive feature of the Capitalocene is the epistemological separation pitting nature and society in an artificial Cartesian binary, what he terms the *epistemic rift* underwriting Karl Marx's metabolic rift between production and reproduction in capitalist regimes (Moore 2015). The conceptual separation of the two lays the foundation for the ontological extraction and social/spatial alienation required for processes of commodification. While such constructions may temporarily mask the practical impossibility of extricating society from the physical material of human existence, that impossibility continually reveals itself in ongoing social and physical crises generated by capitalist production, including crises of soil vitality as well as crises of climate, water systems, and human health.

As capitalism and modes of accumulation develop over time, they do so through transformations in the nonhuman as well as the human world. Perceived ecological crises such as erosion and diminished soil fertility are both produced by particular regimes of accumulation and generative of novel modes of production. While the central relation of the *oikeios* is consistent across historical stages, its expressions shift to reflect changing stages of development. Following Arrighi, Moore writes that

> ascendant world powers have risen to global preeminence (hegemony) through varied "organizational revolutions" in the structures of capitalist and territorial power. Such revolutions achieve their qualitative shifts in response to—and on the basis of—the accumulating (quantitative) contradictions of the previous era. The systemic crises that are the occasion of such qualitative shifts are internally constituted- the limits of capitalist development in any era are registered by the exhaustion of an older organizational revolution and its regime structures, and the emergence of new ways of knitting together the capitalist *oikeios* (36–37).

As such, moments of ecological crisis are also moments of deep social contest as to the nature of the emergent regime; scientific, technical, and political innovations are all part of this process. Liebig's insights into and advocacy of chemical-based soil management were one such innovation.

Accepting the category of epistemic rift as a general feature of globally scaled capitalism is merely a first step toward understanding the role of conceptual practices in capitalist development. Just as quotidian practices of capitalist production vary across time and space, so do its epistemologies. Henri Lefebvre's investigations of global capitalism are useful here in that he directs his attention away from the products of capitalist exchange and toward the processes of their production. Production in this sense extends beyond farm or waged labor's transformation of materials to encompass all the social activity, repressive and expressive, generative and destructive, required to sustain the market society. What capitalism produces, then, is not merely goods for sale, or their end objective—profit—but rather social space as a whole.

While the production of space is not limited to capitalist societies, Lefebvre's work is primarily concerned with what he terms the "abstract space" produced via modern industrial capitalism, initiated in (but engaged beyond) Western Europe. Abstract space is the mode of social production according to which the elements of social life are practically and conceptually transformed into equivalent objects for market commerce. Abstract space is, in the first place, a "medium of *exchange* (with the necessary implication of interchangeability) tending to absorb *use*," with use in this case referring to the lived, dynamic engagement of people with the organic material of social practice (Lefebvre 1984, 7).

Expounding on the trinity formula of land, labor, and capital laid out in the last, incomplete volume of Karl Marx's *Capital*, Lefebvre writes against the conceptual excision of nature from society in economic analysis, pushing toward a model that accounts for rather than excludes ecological forces. He cites:

> three, not two, elements in the capitalist mode of production and in bourgeois society. These three aspects or 'factors' were the Earth (Madame la Terre), capital (Monsieur le Capital), and labour (the Workers). . . . And *three*, I repeat, rather than two: the earlier binary opposition (wages *versus* capital, bourgeoisie *versus* working class), had been abandoned [by Marx]. In speaking of the earth, Marx did not simply mean agriculture. Underground resources were also part of the picture. So too was the nation-state, confined within a specific territory. And hence ultimately, in the most absolute sense, politics and political strategy (325).

In this formulation, society must be understood as composed not just of humans in their various classes but also of the living and nonliving material with which humans engage—Moore's *oikeios*.

However, in the liberal capitalist production of abstract space, the so-called natural world emerges in social life as property—its metabolic forces and cultural valences rendered conceptually inert in the process of objectification for exchange by market subjects. Abstract space engages abstracted subjects alongside abstracted objects, with subjects politicized as citizens and objects as property. These conceptual distinctions underwrite the necessary exploitations of capitalist development. *How* these objects are abstracted, however, is in no way given. Which qualities will be marked from matter's vast particularities and foregrounded to represent a universalized category? How will abstracted forms shape real world socioecological outcomes?

Acknowledging the rich diversity of human understandings of the world's soils, this article is concerned particularly with the soil abstractions that have underwritten modern capitalist development. In particular, I argue that Liebig's model of chemical-based soil fertility was a fundamental aspect of the hegemonic transition between modes of capitalist development in the mid-nineteenth century. The first half of this transition (c. 1763–1848) saw a reorganization from peasant production to capitalist family farmers facilitated by the emergence of the liberal state. Agricultural production in this period embedded itself more deeply within capitalist systems via debt, capital inputs, and commodity markets as part of an emergent world-historical era of global British hegemony.

Noting these transformations in nineteenth-century England, Karl Marx observed that the industrialization of farm production coupled with the spatial separation of food production and consumption had caused soil nutrients to be extracted from British farmland at a rate that exceeded nutrient replacement. This dissonance between the rate of ecological extraction and renewal he termed the "metabolic rift" of capitalist production, a concept that also implied the spatial disconnect between sites of extraction and sites of use. Moore contends that the effects of the metabolic rift manifest cyclically alongside development cycles:

> Over time . . . these new ways of producing nature—through political regulation, built environments, industrial organization, agricultural innovation, not to mention class struggles—begin to generate contradictions through the corrosive effects of plunder and productivity. The widening and deepening movements of accumulation by appropriation undermine the extant capacities of human and biophysical natures to reproduce themselves independently (or relatively so) from the circuit of capital. Sooner or later, but typically in the ballpark of a half-century, the *rules of reproduction* change in the direction of capital dependency (37).

In the case of soil depletion, we can see the interjection of off-farm nutrients as an example of such an emergent capital dependency.

Marx's analysis drew on Liebig's published writing as well as his own observations of commodity circulation and waste deposition to identify soil nutrient exploitation as a key crisis of capitalist agriculture (Marx 1999: 588; Saito 2017). Following Marx, contemporary scholars reflecting on industrial capitalism's metabolic rift have returned to Liebig's concepts of soil metabolism and dwindling soil nutrients to pose more ecologically sensitive theories of capitalist development (Foster 1999; Foster 2000; Foster and Magdoff 2000; Swyngedouw 2004, 2006). While these scholars have invoked Liebig's work to support important arguments for the unsustainability of capitalist production, those invocations have neglected to simultaneously consider the centrality of Liebig's intellectual contributions to subsequent developments of industrialized capitalist agriculture.

In fact, Liebig's chemical model of soil emerged as a constitutive aspect of the nascent late-nineteenth-century capitalist *oikeios*, temporarily resolving the problem of nutrient depletion and establishing a straightforward equivalence between all of the world's soils. It is critical to consider how these emerging modes of production transformed not only ecological processes but also the subjective experience of producers.

Conceiving Agricultural Science

The professional life of Justus von Liebig, like many iconic figures, is distinguished by both the magnitude of his achievements and the extent to which those achievements have been overestimated. The son of a dry salt and dye merchant, Justus Liebig was born in 1803 in the German state of Hesse-Darmstadt just as the state was being incorporated into the Napoleonic empire. A failed teenaged apprenticeship to an apothecary was followed by several years of university study in Germany and finally doctoral research in two private French laboratories, where Liebig sought to compensate for the lack of direct laboratory experience offered to students at German universities. Sponsored by Duke Ludwig of Hessen-Darmstadt, Liebig's international study was funded in part with the hope that the young chemist would bring the techniques of new French industries, including the processing of sugar beets and production of pharmaceuticals, back to aid an emerging cohort of German capitalists (Brock 1997: 116).

In 1824, Justus Liebig was installed in a professorship in chemistry in the Hessen-Darmstadt University of Giessen, a position he was to retain for almost thirty years as a servant of the state. In the period when it solicited Liebig's services, Liebig's patron state of Hessen-Darmstadt was embroiled in a profound transformation. The 1824 edition of *Encyclopedia Britannica* offered the following description:

> The sole government is, at present, the Grand Duke, but he has pledged himself to convene the states this year (1820) and to form a free constitution. The revenues amount to about 500,000 pounds sterling, but are insufficient to meet the expenditure. The taxes are higher than in any other part of Germany, and the debt very heavy. The military forces, though reduced, still reach to nearly 7000 men, and a militia of the whole population. . . . More corn is grown than is generally consumed, but that arises from the lower classes being subsisted principally on potatoes. Some of the best wines are made in this state. It supplies other countries with fruit, nuts, madder, clover-seed, potash, honey, and wax, and with manufactures of yarn and linen. . . . There are more nobles with extensive estates than in the other parts of Germany, and the peasants were in a state of slavery until they were liberated in the year 1813.

Moving at breakneck speed from feudal fiefdom to republican territory, Hessen-Darmstadt sustained sharp inequalities between rich and poor. Student and popular mobilization for liberal reforms put additional pressure on the state government, which frequently mobilized its military to settle unrest among demonstrators. Liebig's state-sponsored work was part of a larger government developmental program designed to seed and support a nascent bourgeoisie as part of a liberal transition, an undertaking conceived to neutralize local popular uprisings while defending against British incursions into domestic markets. William Brock links these priorities simultaneously to new fiscal and education policies, noting that Hessen-Darmstadt was one of the first small German states to dispense with traditional border tariffs and join the *Zollverein* in 1828. The Prussian-devised customs union supported free trade across state borders while protecting central European producers with high tariffs on imported goods. New trade policy would be one important front on which to compete with the growing power of British industry; technical education and expertise would be another (Brock 2003: 35–6).

Under this reform program, the university town of Giessen soon nearly doubled in size, expanding on a modern urban grid plan from a pastoral market town to a busy trading hub focused on a newly installed railway system (33). The career Liebig began in Giessen was marked by two major transitions that would have international implications. First, Liebig successfully petitioned the municipal government of Darmstadt to provide funds for a new teaching laboratory. Not coincidentally, this lab would be built in old military barracks vacated by the upgrade and expansion of state forces in 1820. Prior to the construction of Liebig's lab, scientific instruction had been most commonly conducted through lecture and demonstration; students would observe the experiments of professors, note their explanations, and craft an understanding of the physical world accordingly. Liebig's students were called on to conduct experiments themselves in his laboratory and report their results to Liebig, a model that attracted students from around the world and led the University of Giessen to unparalleled prominence in the field of chemistry (Browne 1942: 7). Though Liebig was not, as is often assumed, the originator of this pedagogical model—historians B. H. Gustin and J. B. Morrell have shown that university-level instruction in lab techniques in Europe predated Liebig's efforts at Giessen—the scale and efficiency of Liebig's lab set an entirely new standard for training in chemistry and transformed popular ideas about effective scientific education (Fruton 1988: 5).

The second development foundational to Liebig's career was his shift in 1838 from pure organic chemistry to agricultural chemistry. While his contributions to the first, including the investigation and analysis of different chemical compounds, were significant, it was his work in the latter that earned him a place among the most influential intellectual figures of the nineteenth century. Indeed, it was through his work in the applied field of agricultural chemistry that Liebig effectively pursued the position of gatekeeper between the industrializing world and the field of chemistry, a discipline he believed to be foundational to all of modern social, political, and economic life. While much of Liebig's success in this role should be attributed to the breadth of his professional activities, which I will explore later in this paper, the latter period of his career was marked by several key conceptual positions through which those activities and his influence more generally should be understood.

First, Liebig began both his scientific inquiries and his industrial interventions with the assumption that there was no meaningful difference between the constitutions of living and nonliving matter. All material bodies could be productively reduced to a series of relationships between discrete chemical agents and interventions performed at the level of those chemicals. Furthermore, these agents could translate uniformly between dramatically different contexts, building blocks in a world of circulating equivalents in which all matter was nominally equal to the sum of its parts (Lipman 1967: 177). While dominant thinking in this period retained a commitment to a fundamentally spiritual aspect of living organic processes—Romantic natural philosophy's so-called *vis vitalis* or vital force—Liebig's analysis aligned him with the materialists of the day in arguing that such forces were themselves the product of practically identifiable origins (Kirschke 2003). Liebig saw chemistry as an analytic lingua franca for connecting organic processes, concluding "the only known ultimate cause of vital force, either in animals or in plants, is a chemical process" (99). A chemical model of metabolism resolved the troubling distinction between living and nonliving things. Moreover, once mechanisms of growth were identified as interactions between a limited number of chemical molecules, the possibility arose for systematic, informed interventions into that process.

Liebig's first public foray into the world of agricultural chemistry in 1840 brought those insights to bear on crop production in particular, weighing in against the prevailing "humus theory" of soil productivity with a new "minerality" model of plant sustenance. Laid out most explicitly by Albrecht Thaer in *Principles of Rational Agriculture* (1809), the humus theory held that plants fed on organic material in the form of decaying plant and animal material, which transmitted fertility via the *vis vitalis*. While Thaer and others understood that plants could and did obtain carbon through atmospheric CO_2, they argued that, the source being unlimited, it was the presence of humus and its "nutritive juices" that was the limiting factor in plant growth. Thaer and his followers advocated for a program of soil management based on regulation of the humic balance through fallowing, manuring, and successive plantings of forage and cash crops. Rather than the universal applicability of minerals, they saw humus' connection to place-based growth and decay as the primary source of its utility.

In contrast, Liebig saw soil fertility as a function of the presence or absence of the minerals required for plant growth, the source of which was irrelevant. Liebig used chemical analyses to determine the mineral content of dry plant matter. Drawing on these experiments and, to an often under-appreciated extent, the previous assays of Thaer's student Carl Sprengel (Jungk 2009), he arrived at a formula of elements necessary for growth. Dismissing humus as mold, Liebig proposed a "mineralist" model of fertility management in which agriculturalists would focus on the addition of minerals according to the needs of particular plants. Soil, he argued, was best conceived as a "magazine of inorganic matters, which are prepared by the plant to suit the purposes for which they are destined in its nutrition" (Liebig 1843: 29–30). Plant metabolism in Liebig's model was resonant of the factory floor, with organic machines assembling a set number of standardized inputs on the steady march to harvest. While Liebig's limited understanding of phosphorus and potassium and misunderstanding of the actions of nitrogen and ammonia nullified many of the specifics of his theory (Manlay et al. 2007: 222–23), its general outlines had a deep and lasting effect on conceptions of soil fertility.

These conclusions are directly related to the other concept for which Liebig is most commonly credited, the Law of the Minimum, which holds that the mineral available in the most limited quantity is the determining factor in plant growth, curtailing the capacity of a plant to make use of elements present in greater quantities and rendering those elements effectively inactive. Indeed, Liebig saw this principle as underlying the whole of his work in agricultural chemistry. Using mineral amendments beginning at the level of this minimum soil component, soil managers could effectively take control of fertility at a given site. While organic chemists Sprengel and Nicolas de Saussure had each articulated this general idea in earlier publications (Sprengel publicly posited a "Law of the Minimum" as early as 1828) (Junk 2009), it was Liebig's more explicit and simplified formulation of the concept in 1855 that brought it into common scientific parlance.

Notably, in distilling plant growth to the mineral components of soil, Liebig's law of the minimum excluded conditions such as temperature, moisture, oxidation, soil density and texture, and qualities of the plant beyond its consumptive capacities. This was a departure from the earlier work of Sprengel, who emphasized soil nutrients in the context of conditioning environmental factors and who cautioned against the potential toxicity of excessive chemical fertilizers. The result of Liebig's simplified formulation was a model of land management based on the addition of what Liebig termed "chemical fertilizers" (Browne, 1942," 71–72). By identifying the specific chemical elements needed to bring a soil to maximum fertility and adding them accordingly, Liebig held, farmers could dispense with the inefficiencies of traditional crop-and-fallow systems and instead collect consecutive, maximized harvests from the same fields. While Liebig's supporters and contemporaries such as Adolf Mayer and Ewald Wollny sought to amplify the Law of the Minimum in a way that accounted for other ecological factors, culminating in G. Liebischer's 1895 "Law of the Optimum," which explicitly broadened the category of growth factors to all conditions external and internal to the life processes of a plant, it was Liebig's articulation of the Law of the Minimum toward which practical and epistemological responses were pitched well into the twentieth century (Brock 1997; Browne 1942; Thomas 1929).

These two assertions, simultaneously elegant and portable in their simplicity, served as the conceptual vehicles by which Liebig sought to extend the science of chemistry to the practice of modern life. Indeed, if laboratory scientists were embroiled in debate during the period Liebig was working, the character of German and European society was even more so. By 1848, violent insurrections and political revolutions were sweeping Europe, with Germany, Ireland, and parts of Italy following France in demanding deep political and economic reorganization. The decades that followed saw ongoing struggles to secure territorial authority in the context of widespread demands for liberal reform, while unevenly burgeoning industrial capitalism ignited new desires, demands, and alliances. Birthed in this foment, Liebig's work sought to also intervene in it. While Liebig was known to the world as a chemist, his true genius lay in his capacity to imagine and broadly interpret chemistry as a tool for social transformation. Indeed, as is clear in his writings on politics, Liebig himself was deeply engaged with the power of material inquiry to support political change.

Gramsci, Liebig, and the Politics of Agricultural Thought

In a critical examination of Marx's claims about the influence of industrialization on rural soil fertility, Schneider and McMichael (2010) contend that the theory of metabolic rift presented in *Capital* relies on a flawed evidence about rural soil management practices in nineteenth-century Britain. Rather, they argue, Marx and more contemporary theorists of the metabolic rift have focused on the *division* of labor without a concurrent attention to the concrete *practices* of labor, a myopia that has left the ecological aspect of capitalist development both undertheorized and overly abstracted. In particular, Marx's claims about the deleterious effects of diminished supplies of "humanore," or night soil, following the mass migration of workers to the city from the countryside, they contend, is not supported by more recent historical studies of English farming practices at the time, which show that humanore was only a minor part of complex land management strategies (see Duncan 1996; Friedmann 2000). Schneider and McMichael, in contrast, posit an alternative explanation for the significance of urbanized labor to rural soil fertility. Citing the epistemological break that followed the spatial reorganization of labor in industrializing Europe, they contend that the central loss to rural land management systems was not humanore but rather place-based peasant knowledge that retreated from the countryside alongside employment-seeking workers.

This article concurs with Schneider and McMichael's conclusion that the epistemic aspect of changing spatial relationships is key to understanding nineteenth-century capitalism's widening metabolic rift. However, as important to that transition was the particularly situated knowledge that *replaced* peasant knowledge, specifically the modern theories of chemical soil fertility propagated by Justus von Liebig, theories that were themselves a product of changing relations between town and countryside. In the case of Liebig's ideas about soil fertility, the organic knowledge that had previously guided farmers' place-based land management was replaced over time by a body of professionalized knowledge embedded in the interests of the emerging liberal capitalist state. This replacement was achieved by private and state-sponsored agricultural education as land around the world fell increasingly into the hands of investors seeking market-based returns on capital investments.

Historians and sociologists of science have, over the past quarter century, done much to explicate the complex structures and practices through which scientific expertise is constructed and disseminated. A key feature of much of this work is its concern with the exceptional position of science and scientists in society, symbolically sustained through ritual purification from both politics and profit. Agricultural science is in many ways an uncomfortable fit with this body of work. Indeed, much of the work of agricultural science has been openly directed at mediating the relationship between labor and capital, with the production of the agricultural commodity at the center of its disciplinary inquiry. Furthermore, the ongoing translation of agricultural expertise across the institutional structures of land-grant universities and experiment stations, state-sponsored extension offices, state and county fairs, and high school 4-H clubs unsettles conventional understandings of a prescribed community of expert investigators, troubling the scientific category itself. In light of the resistance that agricultural science represents to a straightforward analysis according to the conventional tools of either science studies or political economy, I would suggest that this cultural site might in fact be productively plumbed through a methodological frame that makes its own deliberate reach across analytical categories, specifically Antonio Gramsci's writings on the state, society, and the intellectual.

Gramsci himself does not substantively differentiate in his writings between scientific ideology and other kinds of ideological production and reproduction, all of which he understands as the historical manifestation of particular modes of social relations. For Gramsci, because social organization is constituted through (though not confined to) material organization, all knowledge production is simultaneously occupied with both of these fields. He includes scientists with administrators, scholars, theorists, and nonecclesiastical philosophers in the category of *noblesse de robe* that emerged in alliance with feudal monarchies as they struggled with the church and ecclesiastic intellectuals for control over land and the social privileges that control conferred in the Enlightenment era (Gramsci 1977: 7). What characterized these emerging groups was less that they applied abstract analysis to the world than the concrete and particular organizational channels of the general system of social relations through which their analysis was applied.

Significantly, Gramsci takes pains to emphasize the ways that intellectual labor is intrinsically bound up in all forms of activity. Even the degraded mechanical labor of Frederick Taylor's so-called trained gorillas occurs under specific conditions that necessarily shape human consciousness. However, while every class position represents the raw material of a system of ideological understanding, not every class is positioned to systematically reproduce that understanding throughout society. What is at stake, then, is not the existence of ideas in society but the ways in which certain conceptions of the world come to be held in common within heterogeneous social contexts. The work of so-called traditional intellectuals, ostensibly severed from material production and supported by the institutions of state and civil society, should be seen as part of an ongoing, active process of generating consent across all classes to a particular structure of social relations. Indeed, a central consequence of the professed autonomy of traditional intellectuals is their capacity to intervene in society on behalf of the interests of dominant classes while claiming a fundamental independence from those interests.

The process of ideological extension as a means to secure social consent is, for Gramsci, amplified by the marriage of the state and the bourgeois class under capitalism. He writes,

> The revolution which the bourgeois class has brought into the conception of law, and hence into the function of the State, consists especially in the will to conform (hence the ethicity of the law and of the State). The previous ruling classes were essentially

> conservative in the sense that they did not tend to construct an organic passage from the other classes into their own, i.e. to enlarge their class sphere "technically" and ideologically: their conception was that of a closed caste. The bourgeois class poses itself as an organism in continuous movement, capable of absorbing the entire society, assimilating it to its own cultural and economic level. The entire function of the State has been transformed; the State has become an "educator." (260)

The continuous and concurrent material and ideological assimilation of society by the dominant bourgeois class can be seen to follow the movement of capitalism, the existence of which is premised on ongoing expansion through the appropriation of resources and the transformation of social relations in the interests of the same class. At the same time, this process of assimilation must also at all times account for the multiplicity of life experiences that generate context-specific consciousness distinguished by those factors of class, race, gender, and professional specialization through which power is organized in society. The slippage, then, between knowledge emanating from traditional sites of intellectual production and that which emerges organically from life experience becomes the ground on which struggles for political enrollment are most actively staged.

Liebig's own writings on society reveal a strikingly complex notion of the relationship between material experience, politics, and the production of ideas. In an essay titled "The Development of Ideas in Physical Science," delivered in 1866 to the Royal Academy of Sciences in Munich and included the next year in an edited volume titled *The Culture Demanded by Modern Life: A Series of Addresses and Arguments on the Claims of Scientific Education*, Liebig posited a theory of physical inquiry in which the physical experiences of labor itself served as evidence from which humans might generate hypotheses about the nature of the world and model technical innovations to replace the force of man with the force of nature, the harnessing of which is the beginning of capitalist industry (361). Not unlike Gramsci's notion of the organic intellectual, Liebig's model of physical inquiry saw the conditions of material production, and specifically the relational moment between the human and nonhuman world, as the engine driving human intellectual activity. Furthermore, this intellectual production was directly linked to the political economy of a nation.

For Liebig, the emergence of liberal capitalism represented the highest end of that activity. As much as the physical inquiry of organic intellectuals may have underwritten the technical innovations that enabled social and scientific progress (he uses the example of the invention of optical glass as the prerequisite for modern astronomy; the steam engine for theories of heat; and photography for theories of light), it is only a dedicated intellectual class that can transform material innovation into socially available scientific truths, and such a class requires certain economic conditions. Tracing the development of scientific thought from ancient Greece through the nineteenth century, Liebig's analysis follows the relationship between social and political structures and the progress of intellectual and industrial innovations. Indeed, the narrative Liebig draws here posits industrial capitalism as the natural partner of intellectual productivity beginning in the earliest centuries of Western civilization. He equates the manufacturing output of Corinth with the wares of Sheffield and Birmingham and that of Athens with the woolens, tweeds, earthenware, and shipbuilding of Leeds, Staffordshire, and London, and describes the "counting-houses" along the Black Sea. The men of science were "burgher's sons and initiated in industrial pursuits." Socrates was a stone cutter, and Aristotle an apothecary. It was exactly the intimacy of the scientific thinkers with the processes of manufacturing that enabled their intellectual output (360–61).

In the medieval period, the institution of Latin among the scholastic and ecumenical classes, what Liebig terms "warfare against physical inquiry," cut them off from productive laborers and caused an overall paralysis of scientific progress (369). At the same time, Liebig likens the spatial and social restraints imposed by feudalism to "the old slave-condition, in which the pith and marrow of the people is poor and without susceptibility for intellectual and moral culture." Excluded from the processes of formal intellectual production, the burghers in this period started the first popular schools, promoting literacy and oral communication among the manufacturing classes. Civilization, for Liebig, rests in the innovative material production of societies.

Moreover, it was the present moment in Europe, with the rise of the manufacturing classes and their intimate connection to the intellectual classes, that bore the most promise for the development of civilizations. This promise would be best realized in the context of modern states such as Canada and the United States, poised, he says, to achieve the highest point of culture and civilization attainable by men that could most freely apply its laws and institutions to support the development of industrial capitalist enterprise. He explains,

> The effect of riches on the spirit of the productive classes is visible in the commercial states whose trade rests on industry. The sons of the opulent manufacturers and merchants abandon their father's business, which was the source of their wealth; being rich to superfluity, they transfer their ambition to the pursuit of rank and reputation, devoting themselves to science, to politics, to the army, or church, and in this wise the intellectual class grows out of the productive (363).

Furthermore, this class and scientific knowledge will be constantly revitalized by the circulation of individuals across class, a process which he links indirectly to a social shift from hereditary to commercial wealth.

In modern Europe, a manufacturer is not transmitted to the third generation; so, too, most commercial houses pass to other hands in the second. Hence, in a free country, the renewal of the producing class with each generation, and the constant resuscitation of industry. The industrials, grown rich, give place to energetic, inventive poor men, and thus a circulation is established in the state, through which its power and wealth increase continually (364).

Modern industrial capitalism, then, promises not only to facilitate the highest degree of civilization of which mankind is capable but also will do so by breaking down divisions between classes. As an emergent lingua franca of organic and inorganic mechanical processes, chemistry will further enable those transformations.

It would be a mistake, however, to mistake Liebig's interest in class mobility and emphasis on the value of laborers' "productive inquiry" for a wholesale commitment to the empowerment of the working classes. Rather, Liebig takes pains in his writing to distinguish between experience—the raw material of scientific labor—and truth, which is that labor's product. As such, if laborers provide the raw material for the intellectual development of nations, it is the exclusive provenance of scientists (and chemists, in particular) to transform that material into the refined matter of material progress.

Letters on Modern Agriculture (1859), presumably directed to an audience that included agriculturalists, is full of examples of well-meaning, practical, and professional agriculturalists whose zealous blundering in trade journals, popular publications, and general professional congress posed a grave threat to civilization itself. Though such unschooled experimentation bore the appearance of science, with documented trials and reports and confident conclusions about manure, irrigation, and the like, Liebig declared that it was in fact "*all sham: without a single law or a single truth* . . . 'dressed in the livery of science like a monkey in regimentals, and understanding and appreciating the language they talk at second-hand, as much as the organ-grinder does the opera tune that his winch works threadabare'" (11–12). The problem, Liebig suggested, lay in practical agriculturalists' failure to discern the difference between the practical and the scientific:

> Agriculturalists had not yet acquired the faculty of distinguishing between mere opinions and correct facts. Every fact was acceptable; every opinion was received by them. *If science doubted the truth of one of their explanations, they imagined that she was disputing their facts*. If she asserted that a great progress would be made for substituting for stable manure its active constituents, they believed that in doing so she denied the efficacy of the former. About misunderstandings of this kind disputes then arose. The practical man did not yet understand the deductions of science. His dispute was with the bug-bear of his own false conceptions, not with science. He did not know that science also has a moral of her own, the foundation of which lies in the precepts of the school and their practice in education. (17–18)

Though they might observe phenomena in their fields, these observations could in no way stand in for the perceptions of a trained scientist working in the regulated conditions of the laboratory. While agriculturalists were distracted by their emotions and the myriad of conflicting opinions reflected in their popular journals, scientists were educated to distinguish and understand different *categories* of knowledge. Thus, "Each day brings its own progress without strife; for each cultivator of these sciences knows what constitutes a fact, conclusion, rule, law, opinion, and explanation." Science, Liebig wrote, had "prepared a house" for modern agriculture using its unique capacities to organize experience into knowledge (1–2). Agriculturalists had only to acknowledge those capacities to step inside. The power of ideas, rather than mere utility, would precede and enable the political and financial power of a modern, progressive society.

Liebig's conclusions on these points mirrored those of another British philosopher, one with whom Liebig had cultivated a relationship of reciprocal public acknowledgement. Nearly two decades earlier, the renowned British Liberal John Stuart Mill (1806–73) had cited Liebig's research in his volume *Logic* to support his call for a radical utilitarian social transformation based on the scientific method. Opposed to the notion of universal suffrage, Mill advocated for democratic rule by an intellectual elite, and Liebig's writings provided the conceptual justification for the stratified political structure Mill envisioned. Describing the key conditions requisite to good government, Mill wrote:

That it be government by a select body, not by the people collectively: That political questions be not decided by an appeal, either direct or indirect, to the judgment or will of an uninstructed mass, whether of gentlemen or clowns; but by the deliberately formed opinions of a comparatively few, specially educated for the task.

Furthermore, this class would be drawn from the middle class, the very class Liebig saw as the engine for productive progress:

> No practical and judicious statesman could . . . take his stand anywhere but on the middle class . . . it does not follow, that he is obliged to take their policy; it follows only, that he must be able to make them take his. . . . He cannot, therefore, attempt Universal Suffrage. To extend the suffrage to the whole middle class, to equalize its distribution among that class, to enable that class to exercise it freely, all this can be and ought to aim at. (Munday 1988: 404)

Using the logical processes of science, this educated elite would craft a progressive revolution in business, politics, and social life.

Alerted to Mill's work (and his own citation in it), Liebig familiarized himself with the English edition and set about facilitating its translation for a German public. An 1847 letter to his friend, the German publisher Eduard Vieweg, reveals both Liebig's enthusiasm about Mill and his frustration with the contributions of German philosophy in this period:

> I have read and studied Mill's *System of Logic* with increasing satisfaction, and am of the view that this man knows more about chemistry, physics, medicine, political science, etc. than most German chemists, physicists, or physicians. . . . Mill has done me the honor of taking up my method of research (on agricultural and animal chemistry) as a model in his book and, if you read what he says about it, you will not be able to resist publishing this book. (Munday 1988: 413)

Clearly, the empirical bent of British philosophy that birthed Mill's utilitarianism was simultaneously a source of inspiration and frustration for Liebig. However, in Mill, he found an intellectual ally who both saw the political as appropriately structured through the material and understood the material as best organized by the mental labor of specially trained intellectual workers.

Liebig's own students, many of whom were involved in the March 1848 uprising that led to the formation of the German Parliament, translated and championed Mill's *Logic* for a German-speaking public. Jacob Schiel, who fled Germany under accusation of organizing a student democratic organization, wrote to his mentor Liebig,

> For heaven's sakes I ask you to be careful with your progress in agricultural chemistry! If bad luck wills it, and your ideas on soil cultivation and production gain a real foothold, then all the socio-political questions which the state deals with will draw the attention of the police to chemistry. I still do not understand why they are not keeping a vigilant eye on you and your wholly communist scientific direction. Oh! If I were the police chief! You would be the first among the demagogues. (Munday 1988: 417)

Clearly, the political implications of Liebig's recommendations for agricultural and industrial practice were not so subtle as to escape the notice of the young chemists he was turning out into European society. For Schiel, and presumably many of his peers trained in Liebig's laboratory, science and politics were one and the same.

Innovation, Circulation, and the N-P-K Mentality

As many historians of science have noted, the genius of Justus Liebig as an intellectual force lay less in the innovation than in the dissemination of knowledge. This circulation was achieved both through his own writings and associations and through the work of students like Schiel and hundreds of other young chemists working in Europe, North America, and the colonized world. The concepts for which he is most renowned—notably the mineralist model of soil fertility and plant metabolism; the law of the minimum; practical laboratory training; and even the technology for the laboratory condenser that bears his name—were already publicly circulating well before he introduced them to the world. In a 1940 paper commemorating the centennial of the publication of Liebig's *Organic Chemistry in its Applications to Agriculture and Physiology*, Rutgers soil scientist Selman Waksman argued that Liebig's influence was a function of exceptional rhetorical gifts:

> Liebig's place in agricultural science is not that of a great experimenter and discoverer, but of a brilliant coordinator and popularizer, who clearly summarized the existing knowledge, and who pointed the way to new discoveries. His fine style of presentation, his logic, and his biting sarcasm enabled him to reach a far wider circle of readers than those scientists who merely discovered the various links in the chain of scientific elucidation of soil processes and plant nutrition (63).

Like Gramsci's traditional intellectual, Liebig situated himself at the institutional intersection of the state, civil society, and the general public in his efforts to apply epistemological pressure to processes of production.

Waksman rightly points to the role of Liebig's many students in spreading his influence and ideas. Indeed, a large number of his students at Giessen's chemical laboratories, the first and most prestigious mid-nineteenth century training grounds for practical laboratory work, were preparing for professional careers in pharmacy and manufacturing. Having taken on the task of educating more chemists than had every been trained in laboratory techniques in a university setting, Liebig devised a system of instruction that enabled a high volume of potentially under-prepared students to produce and publish scientifically credible work. Furthermore, the labor of the students at Giessen, assigned to execute the laborious extracting and measuring required to provide data for Liebig's own writing as well as to test the conclusions of his adversaries, afforded Liebig a rate of productivity that furthered his own reputation and that of the lab. Executed on a large scale, the result was a kind of international "knowledge factory" characterized by the "steady and systematic production of reliable experimental results by ordinary students whose scientific mediocrity had been converted into scientific competence by the acquisition and use of these very techniques" (Fruton 1988: 5). While not all research at Giessen can be characterized as mechanical repetition, this knowledge factory conveniently mirrored new industrial methods of systematized production and training, producing a model for the expansion of chemical investigation both within the academy and beyond.

Students who left the lab to take positions in universities and in government, often at Liebig's recommendation, benefited from and enhanced the range of Liebig's influence while replicating many of his core theories and methods. These trade chemists carried Liebig's ideas with them into the factories, boardrooms, and laboratories of industry, including his emphasis on methodical replication and systematic quality control and his belief in the capacity of chemistry to address all problems of material production.[2] Historian Marika Blondel-Mégrelis explains, "In fact, Liebig wanted everybody to believe that chemistry commanded every phenomenon in living nature. Alles ist Chemie [Everything is chemistry]" (2007: 48).

In addition to using professional training as a way to embed his own thinking in the relatively new discipline of chemistry, Liebig also trafficked his work through academic journals such as the *Annalen der Chemie and Pharmacie* (later *Liebig's Annalen*), published, at Liebig's suggestion, in French, German, and English (Blondel-Megrelis 2007: 46). Liebig instructed his publisher to reserve two thousand to three thousand copies of his key publications to be sent "to all the kingdoms of the world." At home, he also worked to place his work major newspapers to "make more noise about it, if possible"

2. One of Liebig's more famously successful students was Georg Merck (1825–73), son of a Darmstadt apothecary who transformed his family business into one of the world's largest pharmaceutical companies (Brock, *Justus Von* Liebig, 120).

(48). As his intended fields of intervention extended from the laboratory toward the factory and the farm, he sought out an even broader audience for his work, adjusting his language and strategy accordingly for popular American and British magazines such as *The Cultivator* and *Cornhill*. With the international publication of *Agricultural Chemistry* (1840) (originally *Organic Chemistry and Its Application to Agriculture and Physiology*), Liebig was in active pursuit of an audience that extended well beyond chemistry's scholarly community, and he took pains with typesetting, graphics, and high-quality paper stock to appeal to the taste and sensibilities of a well-bred popular audience. His *Agricultural Chemistry* dispensed with chemical formulas and tables in favor of accessible language and familiar images to lessen popular distrust or fear of chemical analysis.

As Liebig's professional influence grew, the chemical model of soil fertility achieved increasing dominance on an international scale. Moreover, for agriculturalists seeking a reliable return on investment, chemically based agriculture promised to tame the vagaries of agricultural life. This was particularly the case in frontier environments, where growers were investing increasing amounts of capital in relatively unfamiliar landscapes. In the United States, Liebig's students went on to populate the bureaucratic desks of the nascent Department of Agriculture and its public and private laboratories. Charles Wetherill received his training in Liebig's laboratory before he was appointed the first USDA scientist in 1862 (Browne 1942: 8). Yale chemistry professor S. W. Johnson was Liebig's student in Munich and was deeply instrumental in formulating the policies of the Land Grant College movement. Johnson was a champion of the agricultural experiment station based on similar stations in Germany and authored two books on agricultural science—*How Crops Grow* and *How Crops Feed*— that were widely read and highly influential throughout the United States (Bradfield 1942:55).

As an essential site of both national production and reproduction, agriculture for Liebig represented the foundation of modern society. He wrote, "There is no profession which can be compared in importance with that of agriculture, for to it belongs the production of food for man and for animals; on it depends the welfare and development of the whole human species, the riches of states, and all industry, manufacturing and commercial" (Howe 1942: 46). At the same time, Liebig saw chemistry as important not just as a form of industrial innovation but as a structure of understanding that would revolutionize and optimize society itself. In the preface to his *Familiar Letters on Chemistry*, he explains that the book contains sketches that were

> Written for the especial purpose of exciting the attention of governments, and an enlightened public, to the necessity of establishing Schools of Chemistry, and of promoting, by every means, the study of a science so intimately connected with the arts, pursuits, and social well-being of modern civilized nations. For my own part, I do not scruple to avow the conviction, that ere long, a knowledge of the principal truths of Chemistry will be expected in every educated man, and that it will be as necessary to the Statesman and Political Economist, and the Practical Agriculturist, as it is already indispensable to the Physician and the Manufacturer. (5)

Here, as elsewhere, Liebig saw the education of the public in the truths and techniques of chemistry as essential to the productive development of the developing capitalist nation-state.

Conclusion

It is difficult to find an aspect of contemporary life in the developed world that has not been in some way influenced by Justus Liebig's early insistence on the capacity of chemistry wedded to capitalism to transform the world. Industrial agriculture, the mass production of pharmaceuticals, the pedagogical and practical centrality of laboratory training to the reproduction of scientific knowledge—all of these have had direct and indirect influences on the lives and livelihoods of human beings around the world. By embedding a particular formulation of social power within a scientific model of agricultural practice, Liebig promised a concert of human/nonhuman interactions timed to the engine of nineteenth century industrialism. Enabled by the state and reproduced by the educating institutions of civil society, the productive possibilities Liebig envisioned brought the disciplinary tools of the laboratory—efficiency, standardization, and the conceptual disassembly of systems—to the land and those who labored on it. These linked practical and epistemological transitions helped generate the distinct social-ecological footprint of modern industrial capitalism. In the world of soils, farmers have reached the limits of chemical-based fertility management to sustain productivity. Moreover, it has become clear that the cost of productivity within the N-P-K mentality may well be life itself, in its myriad diverse and interconnected forms. As the importance of living soil systems becomes impossible to ignore, capital investment is already concentrating around efforts of commodifying the organisms and processes that undergird land's vitality (see the introduction to this special section). These ruptures are just one aspect of the profound instabilities facing the contemporary *oikeios*; it remains to be seen whether the innovations emerging from the present crisis will be sufficient to shore up industrial capitalism in the contemporary moment.

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