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Chemical fertilizer in transformations in world agriculture and the state system, 1870 to interwar period

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Abstract

The role of fertilizer in spreading commercial agriculture during the first food regime (ca 1870 to the First World War) is well established. What is less understood is the role of fertilizer in industry at this time. This paper details superphosphate fertilizer, part of a class of chemical fertilizers that emerged in the metropoles from the 1870s, and its role in the transformations in world agriculture as well as in industry. Superphosphate fertilizer was not just for the soil. The manufacture of superphosphates also provided a base for the growth of chemical industries. This growth was constitutive of industrial transformations in imperial states—the second industrial revolution—in which mass production units became integrated through a handful of chemicals. One of these chemicals is sulphuric acid, of which superphosphates require large amounts in their manufacture. As the main market for sulphuric acid through the interwar period, superphosphate manufacturing created synergies with other industries and thus made sulphuric acid cheaper. By connecting the manufacturing centres of fertilizer to the multiple farming regions undergoing accelerated commodity production, this study shows that the first food regime and the second industrial revolution were mutually constitutive moments to explain transformations in agriculture and the state system in the long 19th century.

KEYWORDS

agricultural industrialization, chemical fertilizer, first food regime, long 19th century, second industrial revolution

La France, grâce à l'Afrique du Nord, est la seconde puissance du monde vient immédiatement pour ses richesses en phosphates de chaux; elle après les États-Unis, dont les gisements sont généralement de teneur plus riche.

[Thanks to North Africa, France is the second world power after the United States at the level of phosphate riches. The phosphate of the United States is generally of better quality.]

(Levainville, 1924, p. 161)

1 | INTRODUCTION

In the wake of the First World War, proclamations were made within imperial France of the great wealth lying beneath the soil of North Africa (Geopfert, 1925; Levainville, 1924; Moret, 1930). After annexing Morocco and beginning phosphate rock mining—and after more than three decades of phosphate rock production in Algeria and Tunisia—France took a lead in the world market of phosphate rock (Geopfert, 1925), producing half of the world supply in 1929 and 1930 (de Bailliencourt-Courcol, 1933). The export of phosphate rock from the colonies to the manufacturing centres of France helped transform industrial capacity in France: at the end of the 1870s, France had only three superphosphate factories (Daviet, 1988, p. 293), and in two decades France became the largest superphosphate producer in Europe (Haber, 1971, p. 18). The phosphate (and iron) industries were being trumpeted for precipitating the rapid creation and wealth generation of France's "North African Empire" (*empire d'Afrique du Nord de France*; Geopfert, 1925, p. 25), and yet, it was the French imperial state—not France's colonies[1]—that gained wealth and industrial power through the control over, trade in, and manufacture of North African phosphate rock into superphosphate fertilizer.

Phosphate rock is a general term referring to sedimentary rock "containing abundant phosphate" (Cook & Shergold, 1986, p. 5). Unlike the other essential elements to life, phosphorus does not circulate freely as part of the atmosphere. The element circulates through an inorganic cycle that regularly leaves parts of phosphorus from the Earth's crust in the soil and in the water bodies and deposited as sediment; and through organic cycles, through living land-based and water-based organisms, which are constitutive of the biogeochemical cycle and govern the biosphere (Ashley, Cordell, & Mavinic, 2011; Emsley, 2002). Plants can only absorb the soluble inorganic form of phosphorus, which is attained by combining the rock with large amount of sulphuric acid to make fertilizer. From roughly the 1870s to the First World War, all the imperial states were securing access to phosphate rock deposits, either domestically or abroad, and superphosphate fertilizer became the main fertilizer in a new class of chemical fertilizers (Gray, 1944; Haber, 1971; Nelson, 1990). By the interwar period, the imperial states were manufacturing phosphate rock into superphosphate fertilizer on a commercial scale, either for national agriculture or for regional trade. And many other states (independent, nominally so, or colonized) attempted to follow the metropoles and build national industries by developing superphosphate manufacturing capabilities (Lamer, 1957).

Signalling the importance of phosphate rock as a strategic natural resource, in the 1930s, following the proclamations of the wealth of France's colonial territories, the United States (US) Tariff Commission issued antidumping proceedings against phosphate rock imports from French Morocco (Lamer, 1957, p. 147). Then, in 1938, in a message to the US Congress, President Roosevelt stated that "the question of continuous and adequate supplies of phosphate rock directly concerns the national welfare", and then went on to identify and quantify all the known domestic deposits (Gray, 1944, p. 78). In short, on the eve of the Second World War, phosphate rock was securely positioned as a vital resource in the national interest of industrialized states.

Superphosphates played a role in the commercialization of agriculture in the metropoles. However, superphosphates were not just for the soil. The manufacture of superphosphates provided a base for the growth and expansion of chemical industries domestically (Haber, 1971; Lamer, 1957; Nelson, 1990). The growth of chemical industries was part of industrial transformations in imperial states—the second industrial revolution (ca 1870–1914)—in which mass production technologies (and production units) became highly integrated through a handful of chemicals. One of these chemicals was sulphuric acid, which remains a main chemical of industrial production. Because superphosphate manufacturers required large amounts of sulphuric acid, diversifying into and from superphosphate manufacturing enabled capitalists to exploit economies of scale—to expand sulphuric acid units of production—and of scope—to widen the kinds of commodities produced from sulphuric acid.

In this paper, these new processes by which the imperial states gained industrial strength—what I term "chemification"—played a crucial role in cementing the relationship between superphosphate manufacturing and

[1]Said (1993, p. 11) addresses the distinction between what I am referring to as an imperial state, following Wilder (2015), and a state having an empire: "For the enterprise of empire depends upon the *idea of having an empire*."

the first food (wage foods) regime. Through a reconfigured international division of labour, the imperial states controlled the international trade in phosphate rock and established the hub of superphosphate manufacturing in the metropolitan centres. From the manufacturing centres, they orchestrated a regional trade in superphosphate fertilizer that spread fertilizer markets and thus commercial agriculture for the production of wage foods (especially colonial substitutes such as sugar beet) for the metropoles. These links between superphosphate manufacturing and wage foods production demonstrate how the first food regime (Friedmann & McMichael, 1989; McMichael, 2013) and the second industrial revolution (Chandler, 1990; Landes, 1965) (ca 1870 to the First World War) reproduced one another.

Processes of chemification cemented the role of the state and empire in bringing together superphosphate manufacturing, commercial agriculture, and the chemical industry. States were gaining (industrial) power in international relations through the coupling of the energy revolution in fossil fuels with the multiplication, recovery, diversion of materials transformed into new forms of energy (e.g. steam power, soil enhancers such as phosphates) and into commodities (e.g. fertilizers), in effect accelerating capital accumulation in domestic industries and agricultures. These materials were attained and transformed through combinations of appropriation (of unpaid work/energy brought into the commodity system) and exploitation (of labour power) (Moore, 2015). A focus of this paper is on appropriation and how processes of chemification created multiplier effects of appropriation: one form of unpaid work/energy being brought into capital circuits multiplying other forms being brought in. Sulphuric acid in different combinations with other materials can turn into other acids, which then become the basis for producing a wide range of intermediary commodities (e.g. steel, glass, and bleaches) as well as end user commodities (e.g. soaps, fertilizer, and weaponry).

The intricate connection between fertilizer and industry is missed in studies on fertilizer largely because the focus has been on Peruvian guano and Chilean nitrates, the primary nitrogenous fertilizers during the latter half of the 19th century, which were not manufactured on a large scale. These commercial fertilizers did not constitute the new class of chemical fertilizers that emerged as a driver in the growth and diversification of the chemical industry. This study, in contrast, will first detail the interconnectedness of fertilizer manufacturing (of superphosphates, in particular) and chemical industries in the metropolitan centres.[2] These manufacturing centres will be connected briefly to the main commodity frontiers (Moore, 2015) of phosphate rock—in the American Southeast, French North Africa, and the South Pacific—in order to trace the minimally processed phosphate rock to the metropolitan centres, where it was traded regionally and helped spread commercial agriculture. This partial commodity chain captures analytically and theoretically a piece of the puzzle of the twin transformations in agriculture and industry in the imperial states during the latter part of the long 19th century.

2 | FERTILIZER, COMMERCIAL AGRICULTURE AND URBAN–INDUSTRIAL COMPLEXES

The growing commercial trade in, and consumption of, fertilizer in the long 19th century has been placed in transformations in agriculture toward input-intensive farming—what is referred to variously as, the second agricultural revolution (Foster, 1999; Mazoyer & Roudart, 2006; Thompson, 1968) or the first Green Revolution (Melillo, 2012). Studies of fertilizer have sought to illuminate transformations in farming in the industrializing world, especially in the US and the United Kingdom (UK). In these studies, high farmers in the UK and entrepreneurial farmers in the US heralded an ecological shift in farming that replaced a waste-recycling feedback system with a throughput system of inputs and outputs (Blakey, 1973; Clark & Foster, 2009; Cushman, 2013; Foster, 1999; Foster & Magdoff, 2000; Leigh, 2004; Melillo, 2012; Smil, 2001; Wines, 1985).

[2]It should be noted that this paper focuses on the metropolitan centres of Britain, France, Germany, and the US. But other significant and less significant centres of industry are also addressed—Australia, New Zealand, and Japan, as well as in greater Europe (such as Italy, Spain, Belgium, and the Netherlands).

In this fertilizer study, the perspective on agricultural industrialization extends far beyond trans-Atlantic capitalist farming. The growing trade in commercial fertilizer was significant to different types of farming systems undergoing accelerated commodity production—multiple agrarian capitalism*s* (Bernstein, 2010)—capitalist farming "from above" (the UK variety), capitalist farming "from below" (the French and US varieties), plantation slavery of the American South, landed estate farming of the Junkers in Germany, and so on. This expanded perspective of the use and importance of commercial fertilizers is significant in that agricultural industrialization was constitutive of processes of modern state building. As the critical agrarian studies literature highlights, agricultural industrialization within the metropoles and beyond was consequential for modern state building for a host of reasons; the most important of which, for the purposes of this study, is that the industrialization of agriculture helped expand the production of wage foods—that is, cheap food commodities for the labouring classes—and industrial crops for the manufacturers in the metropolitan centres.[3] The food regime concept, as McMichael (2013) reminds us, was intended to capture the new role of commercial agriculture in the process of state building. In the first food regime (ca 1870 to the First World War) (as well as the second food regime, from about the Second World War to the 1970s), commercial agriculture supplied "rising urban–industrial complexes (whether domestic or overseas) with raw materials and food, thereby strengthening national industry" (McMichael, 2013, p. 4).

This study of superphosphate fertilizer demonstrates that chemical fertilizer did not just play a role in supplying raw materials and food to the urban–industrial complexes (indirectly, via agricultural commercialization). The manufacture of superphosphates was also a node in these complexes. Of the vast trade in commercial fertilizers in the long 19th century, there was one class of chemical fertilizers; that is, fertilizers processed via large-scale manufacturing. And superphosphate was the most significant fertilizer in this class of chemical fertilizers. Studies of fertilizer have generally missed the intricate relationship between fertilizer manufacturing and the urban–industrial complexes, because the nitrogenous fertilizers of the long 19th century (Peruvian guano, Chilean nitrates), the focus of most studies, were not significant to fertilizer manufacturing.[4] What is the relationship between fertilizer manufacturing and the urban–industrial complexes, then? The complexes were highly integrated through a handful of chemicals—and the mass production of these chemicals multiplied the types of industrial commodities produced.[5] One of these chemicals, sulphuric acid, connected superphosphate manufacturing to the growing, diversifying chemical industry of the second industrial revolution. Drawing on Mitchell (2011), in the section that follows I make this connection through an analysis of the materiality of superphosphates. By connecting superphosphate manufacturing to (chemical) fertilizer manufacturing to the chemical industry—through sulphuric acid—this material analysis demonstrates how the first food regime and the second industrial revolution reproduced one another. By doing so, this study adds to the wage foods thesis to explain how national agricultures and national industries were brought together in a tight web in the metropoles.

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[3]For examples of how this thesis is used, see the food regime literature (Araghi, 2003; Friedmann & McMichael, 1989; McMichael, 2013), critical political economy of agriculture and food (Bernstein, 2010; Mintz, 1985), and food studies (Guthman, 2011).

[4]Nitrogenous fertilizers became integrated into the growing military–industrial complexes from the turn of the 20th century (and especially during the world wars and in the interwar period). For example, during the First World War, the production of synthetic nitrogen began on a commercial scale, and after the war synthetic nitrogen became a key input in the manufacture of explosives (Leigh, 2004; Smil, 2001). Even before this, at the turn of the century, a main nitrogen product, sodium nitrate, was a significant market for the manufacture of explosives (Melillo, 2012). In short, a rather narrow direct role of fertilizer in these urban–industrial complexes is established in the literature. Nitrogenous fertilizers assumed a more expansive role in these complexes with the commercial production of synthetic nitrogen in the interwar period. However, the production of synthetic nitrogen was concentrated in Germany until after the Second World War.

[5]The literature on the technological transformations of the second industrial revolution does not highlight this interconnectedness (Chandler, 1990; Hobsbawm, 1968; Landes, 1965). However, Landes (1965) does remark how the chemical industry has not received as much attention as it deserves. This interconnectedness is rather demonstrated in the literature on the chemical industry broadly defined. On the chemical industry of the metropoles, see League of Nations (1927), Haber (1958, 1971), and Hohenberg (1967). On national chemical industries, see Reader (1970) on the UK and Molony (1990) on Japan. On sulphuric acid and its place within the chemical industry and industrial production more generally, see Lunge (1891, 1903), Wells and Fogg (1920), Duecker and West (1959), and Haynes (1959).

In Thompson's (1968, p. 71) words, this study elaborates on the "highly specific" ways in which agriculture, mining, and manufacturing became intertwined. In his study of commercial fertilizers in the UK, from 1815 to 1880, Thompson (1968, pp. 71–72) hints at, but does not detail, how "entire industries like oil-crushing and heavy chemicals were only able to develop as they did because there was an agricultural demand for their oil-cakes and their sulphuric acid, as well as an industrial demand for their oils and their alkalis". This paper confirms that the intertwining of agriculture, mining, and manufacturing did not happen in a commercially significant way until the industrial transformations from 1870 onwards. What Thompson is referring to, as the second agricultural revolution, can therefore be considered the beginnings or the initial phase of this interconnectedness. A lens on *chemical* fertilizers has the advantage of making these connections between agriculture, mining, and manufacturing.

Furthermore, these agriculture-industry transformations from roughly 1870 are situated within a reconfigured international division of labour. According to the food regime literature, this reconfiguration was born out of imperial policy changes from the 1870s, which responded to the onset of the Great Depression and competition from imported settler grains (Friedmann & McMichael, 1989, p. 100; McMichael, 2013, p. 8). The first was the creation of new colonies—and the administration of them from the metropoles. The second was an institutionalization of a domestic agricultural policy within (select) imperial states designed to displace colonial crops—a process of converting agricultural areas for the production of sugar beet (to replace sugar cane), vegetables and animals (from which fats could be produced to replace tropical oils), and other colonial crop substitutes (Friedmann & McMichael, 1989, p. 99). By substituting one cheap (minerals) for another cheap (labour), the new class of chemical fertilizers helped producers in the metropoles compete with colonial producers.

By placing chemical fertilizer within the international division of labour, this paper further qualifies explanations in studies of fertilizer of commercialization being a response to rapid urbanization during the 19th century. According to this town–country divide thesis, capitalist farmers were responding to the fast pace of urbanization by relying increasingly on commercial inputs in the face of soil degradation or the lack of nutrient recycling (from intensified production) (Clark & Foster, 2009, p. 318; Cushman, 2013, pp. 39–40; Wines, 1985, p. 4). In theoretical terms, the growing divide between town and country forged a "metabolic rift"—a rift in the metabolism of human society (Foster, 1999; Foster & Magdoff, 2000).[6] As the second section of this paper demonstrates, there were many types of farming regions consuming chemical fertilizer—and these regions were not necessarily responding to a growing urban market. For example, the plantation South was responding to ecological destruction from centuries of slavery and monoculture cropping (for distant markets) as well as growing competition from new producing regions (largely in the colonized world). Some farming regions in Europe that converted to the colonial crop substitute, sugar beet, such as the Junkers of Germany, were responding to policies that were in effect blocking international competition. In essence, farming regions throughout the metropoles were consuming chemical fertilizer in response to an increasingly competitive "world-price-governed" market for agricultural commodities (McMichael, 2013, p. 8), an outcome of the reconfigured international division of labour.

In world-ecological terms, this historical moment was the beginnings of a long wave of accumulation—of a great expansion in the scope, scale, and speed of appropriation of unpaid work/energy (Moore, 2015, p. 135). Appropriation involves bringing nature (with a lower-case "n") into the circuits of capital, in effect turning unpaid work/energy into a commodity form, producing Nature (with a capital "N") (Moore, 2015, pp. 2–3). The ecological surplus of this long wave—that is, the system-wide appropriation of unpaid work/energy exceeding the system-wide mass of capital—depended on Four Cheaps (food, labour power, energy, and raw material) (Moore, 2015, p. 95). Chemical fertilizer played a double role in contributing to the ecological surplus of this long wave (of the 20th century): Chemical fertilizer increased agricultural productivity and made food cheaper, and created synergies with other industries and thus made sulphuric acid (and industrial processes) cheaper. And it was processes of chemification that turned chemical fertilizer into cheap energy, which turned into cheap food, cheap labour power, and other forms of cheap energy. These multiple avenues for appropriating unpaid work/energy in processes of chemification, in turn, provided

[6]See also Moore's (2011) critique of the concept of metabolic rift - of the town-country divide creating the rift rather than constituting the rift - and long before the 19th century industrial revolution.

a basis for imperial states' industrial strength—and help explain the unprecedented scope, scale, and speed of appropriation that began circa 1870.

3 | CHEMIFICATION: THE CHEMICAL INDUSTRY AND FERTILIZER MANUFACTURING

An account of the connection between phosphates and fertilizer manufacturing and the chemical industry should begin with sulphuric acid, an acid that is manufactured from sulphur-bearing materials. At the end of the 19th century, the manufacture of acids and alkalis remained "the foundation upon which the whole chemical industry" of the time was built (Lunge, 1891, p. 1). Sulphuric acid was (and remains) the main acid that interconnects the many branches of industrial production. Fertilizer manufacturers were among the largest consumers of the chemical during the rapid growth and diversification of the chemical industry or domestic chemical industries that were developing throughout the metropoles. And superphosphate fertilizer was the main fertilizer in this new class of chemical fertilizers (known at the time as "artificial manures").

The central role of sulphuric acid in the growing and diversifying chemical industry, in particular, reflects what Chandler (1990, p. 21) refers to as the industrial transformations of the second industrial revolution—of "unprecedented cost advantages" of maintaining a long-term rate of return on investment by increasing the size of the unit of production *and* diversifying each unit (to produce more than one commodity). Alonzo White, Chief of the Sulfuric Acid Unit of the US War Production Board during the Second World War, described the multifunctional qualities of sulphuric acid as such (Eddy & Frank, 1959, p. 1):

Like a returnable steel drum, after initial use in some phases of the explosives, petroleum, and dye industries, the sulfuric acid is recovered in a form often unsuitable for use in the same process but of a strength and grade entirely suitable for use in other process industries. Sulfuric acid is not a one-process product.

The chemical's versatility created many opportunities to increase the scope and scale of production, and helps explain why in the initial era of the chemical industry's development, from the mid-18th century to the mid-19th century, sulphuric acid transformed from a negligible material to "a yardstick of industrial activity" (Haber, 1958, p. 1; Landes, 1965, p. 501, quoted in Thompson, 1968, p. 72).

By the end of the 18th century, sulphuric acid was being manufactured on a commercial scale in Western Europe (Haber, 1958, p. 3; Lunge, 1891, p. 8).[7] It was the establishment of the Leblanc process that cemented the role of sulphuric acid in the alkali industry: the Leblanc process combined sulphuric acid with sodium chloride in order to produce "soda ash" (sodium carbonate), which produced glass, paper, soaps/detergents, a common alkali (used in chemical factories), and other products of the alkali industry. During this initial phase of the chemical industry, sulphuric acid also became central to the commercial manufacture of bleaching materials (Haber, 1958, pp. 8–9).[8]

[7]Chemical manufacturing existed as a cottage industry—labour-intensive and skilled—in Western Europe (and far beyond) in various forms long before the Middle Ages (Haber, 1958). The change toward commercialization in the mid-to-late 18th century was partially a response to the lifting of protections for the alkali industry (on imports from the colonies, in particular), which was consistent with the shift in British hegemonic policy at the time of increasingly offshoring production (Haber, 1958, p. 1). Concomitant with changes in trade policy were technical developments in manufacturing; significant among them was the development of lead chambers in the UK for the commercial manufacture of sulphuric acid.

[8]The commercial scale of chemical manufacturing depended, of course, on the expanding commodity frontiers of the natural resources upon which this manufacturing depended—for example, salt, lime, pyrites, and wood ashes. Sulphuric acid production, in particular, grew exponentially in the metropolitan centres with the expanding commodity frontier of sulphur-bearing mined minerals. When domestic supplies of sulphur-bearing materials began to dwindle in Europe in the 18th century, Sicily was literally occupied (Haynes, 1959). All sulphur rock from Sicily was exported to other European countries (Buonanno, Durante, Prarolo, & Vanin, 2012). In the US in the initial years of the sulphuric acid industry, Sicilian sulphur rock (or brimstone) was the primary sulphur-bearing raw material used (Wells & Fogg, 1920). Rather quickly, sulphur rock substitutes were developed and began to be exploited—the most important substitute being pyrites, or iron sulphide minerals, which contain sulphur and iron (Jones, 1959). Among the largest of the pyrites mines were the pyrites in Andalusia, Spain, which were being exported to Northern Europe by the middle of the 19th century (Harvey & Taylor, 1987).

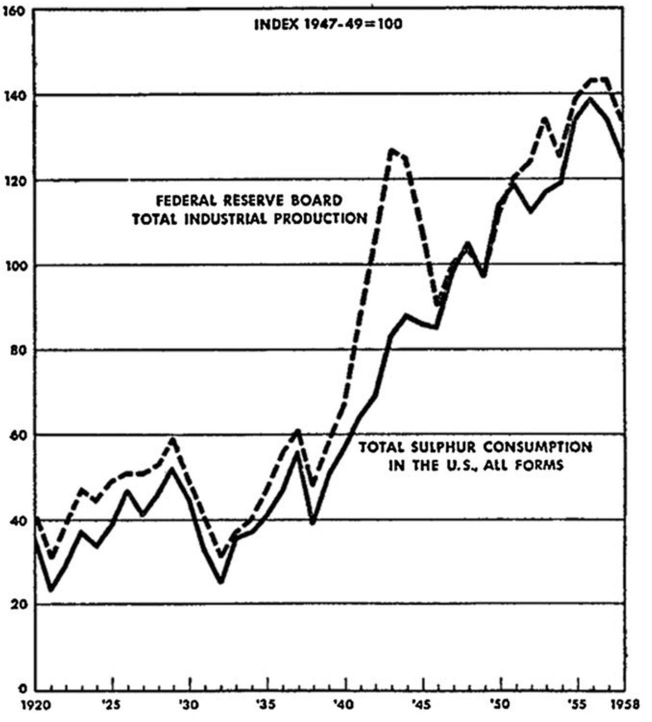

FIGURE 1 The correlation between US consumption of sulphur and US industrial production, 1920–1958
Source: Haynes (1959, p. 238)

Even though the Leblanc process was phased out and replaced by more efficient technologies by the end of the 19th century, sulphuric acid continued to be the grease of the second industrial revolution. Sulphuric acid became the basis for the production not only of the simple chemicals of the first industrial revolution, but also the growing and diversifying heavy chemicals (e.g. iron- and steel-making and explosives) of the second industrial revolution. These initial phases of sulphuric acid production—during the first and second industrial revolutions—in effect cemented the chemical's role in industrial production generally. Figure 1 highlights "the long-standing, close correlation" between sulphur consumption and industrial production in the US during roughly the interwar period.

Chemical fertilizer was one of the most important nodes of sulphuric acid consumption during the second industrial revolution. In Haber's (1958, p. 103) words, there was essentially a sulphuric acid triangle—and chemical fertilizer was one angle of this triangle. The other two angles were Leblanc soda and the extraction of metals (namely, copper and iron). The Leblanc manufacturers and the fertilizer manufacturers would consume sulphuric acid, while the sulphuric acid manufacturers would extract copper and iron from the ore of the pyrites by burning it (Haber, 1958, p. 103).[9] The place of chemical fertilizer in the so-called sulphuric acid triangle was not dependent on the extent to which the Leblanc process had been established (Lunge, 1891, p. 2). In European countries where the Lebalanc process had been established, superphosphate manufacturing replaced the Leblanc process as the main user of sulphuric acid by the turn of the 20th century (Haber, 1971, p. 105). Where the Leblanc process had never been established, as in Italy, Spain, and the US, large sulphuric acid works "were expressly built for the purposes of the superphosphate factories" (Haber, 1971, p. 105), and in countries with less developed chemical industries, sulphuric acid and superphosphates were "virtually synonymous" (Haber, 1971, p. 106).

[9]Lunge (1903, p. 1169) characterizes the market for sulphuric acid similarly: The two principal applications of sulphuric acid are alkalis (sulphate of soda and hydrochloric acid) and "superphosphates and other artificial manures". These applications combined make up nine tenths of sulphuric acid consumption (Lunge, 1903, p. 1169).

TABLE 1 Average consumption of primary chemical fertilizers, 1928–1933[a] (in thousands of metric tons[b])

	Germany	UK	France	US	Other—median[c]	All[d]— median
Phosphatic fertilizers						
Basic slag	2,042.4	223.1	619.2		48.9	421.2
Superphosphates	1,012.1	433.4	1,736.6	978.9	207.4	978.9
Nitrogenous fertilizers						
Nitrate of soda	73.0	41.5	354.2		48.0	60.5
Ammonium sulphate	522.8	156.1	382.3	542.8	78.3	382.3
Synthetic nitrogen	1,229.6	4.4	209.4	150.3	179.9	179.6

Source: Compiled from IIA (1940, pp. 1048–1055).

[a]Consumption equals production plus imports minus exports. These figures are estimates and do not reflect on average consumption of chemical fertilizer for the interwar period. The period 1928–1933 covers a period in which commodity prices generally declined sharply (Lamer, 1957, pp. 149–150).

[b]Phosphate rock production and trade are often calculated in metric tons and imperial (long) tons: the ratio of one metric ton to one imperial ton is nearly 1:1.

[c]The other category includes Belgium, Denmark, Holland, Italy, and Spain. The median measurement is used because of outliers, especially estimates of superphosphate consumption in Italy and Spain, which far exceeded the other countries in this category.

[d]The "All" categories included: Germany, France, the UK, the USA, and "Other".

As the chemical industry grew, the place of fertilizer manufacturers as a market for sulphuric acid grew. In Britain in 1865, fertilizer required only 11% of total output of sulphuric acid (of 380,000 tons) and by the early 1880s that percentage increased to more than one third of total annual British output (of around 900,000 tons) of sulphuric acid (Thompson, 1968, p. 72). In Japan in 1898, in the beginning phase of fertilizer manufacturing, fertilizer production required 37% of Japan's output of sulphuric acid, surpassing all other uses such as soda manufacturing and bleach-making (Molony, 1990, p. 32). On the eve of the First World War, in France superphosphate manufacturing consumed three quarters of the sulphuric acid made, and even in Germany, with its highly diversified chemical industry, the proportion was still 50% (Haber, 1971, pp. 105–106). Sulphuric acid consumption in the US attests to the continued importance of fertilizer to sulphuric acid markets in the interwar period: from 1925 to 1950, fertilizer consumed on average 28% of US sulphuric acid, surpassing the other major consuming industries–chemicals, and petroleum refining (Haynes, 1959, p. 289).[10] Without the fertilizer manufacturers at these phases of industrial sulphuric acid production, there would have been limited opportunities for an increase in the scale and the scope of sulphuric acid production in the metropolitan centres.

3.1 | Superphosphates

Superphosphate production had been "the world's first venture into the manufacture of chemical fertilizers" (US Department of Agriculture, 1964, p. 15) and had dominated the chemical manufacture of fertilizers until the rapid development of sulphate of ammonia (aka ammonium sulphate) from the 1870s onwards (Haber, 1958, p. 105). The production of sulphate of ammonia also emerged out of industrial processes: it was a by-product of coke ovens, which heated coal in the absence of air to generate coal gas, which also provided the energy for sulphuric acid production (Haber, 1958; Smil, 2001). Superphosphates and sulphate of ammonia were the two main chemical fertilizers produced until the First World War (Haber, 1971, pp. 117, 144–145, 153–155). Following the war, the class of chemical fertilizers kept growing—and in a greater number of countries in the so-called semi-periphery of Europe (Table 1). Of these chemical fertilizers, the market for superphosphates was on average far larger and wider geographically. The market for two of the other primary chemical fertilizers in the interwar period—basic slag

[10]Also, in the US superphosphate production became important to the burgeoning meat-packing industry in the Midwest. The meat-packing industry replaced dwindling bison bones with manufactured fertilizer, which became a subsidiary of the industry (Wines, 1985, p. 125).

(a phosphatic fertilizer that was also produced from industrial processes) and synthetic nitrogen—was, in contrast, confined largely to Germany alone.

Why was superphosphate production the entré into the manufacture of fertilizers, and why did it remain central to fertilizer manufacturing through the interwar period? The development of superphosphate manufacturing should be placed in the rapid development of mined mineral inputs in the decades preceding the second industrial revolution. When the international trade in Peruvian guano took off in the 1840s, there were important developments in the manufacturing of bone for fertilizer and discoveries of other inputs (coprolite in England and phosphate rock in the American Southeast) before and in the initial years of this trade (Grove, 1976; Thompson, 1968). In Britain by the late 1830s, John Bennet Lawes had developed and patented the technique for manufacturing "superphosphate of lime": bones were degreased and softened in hydrochloric acid (synthesized from sulphuric acid) and their liquor then treated with milk of lime to produce phosphates, which were then washed, dried, and collected (Threlfall, 1951). In 1842, Lawes built a factory in England for manufacturing superphosphate of lime, and by 1845 the bone-crushing factories of England were being converted into superphosphate manufactures (Blakey, 1973; Cushman, 2013). Commercial production of superphosphate began in Germany in 1853 and in the US by 1852 (Nelson, 1990, pp. 36–37; US Department of Agriculture, 1964, p. 35). In these initial years, its production required inputs from a fairly wide geographical reach. Arthur Albright, one of the first British companies to get into the phosphates business (first for the production of matches), imported bone ash from South America and then from the slaughterhouses of Galatz, the Ottoman Empire (Threlfall, 1951). Superphosphate production did not rise in prominence as a type of fertilizer traded commercially until phosphate rock replaced bone and coprolite (in England) with the development of phosphate rock frontiers, first in South Carolina, in the post–US Civil War period.

Phosphate rock departed significantly from coprolite and other phosphate sources used at the time. Phosphate rock deposits are geographically dispersed: deposits were mined domestically, in the metropoles, as well as in colonies (or territories that would be colonized) (Cook & Shergold, 1986; Gray, 1944; US Department of Agriculture, 1964). At the same time, deposits are concentrated so that large volumes of phosphates could be excavated from one mine. In the three phosphate rock frontier regions that dominated the international phosphate rock trade at the time (ca 1870 to the First World War)—the American South, French North Africa, and the South Pacific[11]—the deposits were of sedimentary marine origin, with high phosphate content (Cook & Shergold, 1986). All were fairly easy to exploit—requiring relatively low levels of capitalization as they were close to the ground surface and the phosphate ore was easily separated from other minerals (Cook & Shergold, 1986; Notholt, Sheldon, & Davidson, 1989). All frontier regions were colonies,[12] and thus, effectively instituted a coercive, racial labour regime—characterized by racialized/ethnicized hierarchies and coercion, debt peonage, and/or incarceration.[13] Also, the colonial administrations (and in the case of the American South, the state Reconstruction government and federal government) developed the transportation infrastructure that connected the frontier regions to the manufacturing centres. The American Southeast exported rock for manufacturing to the American Northeast and Western Europe, the French colonies of Tunisia, Algeria, and (later) Morocco exported to Western Europe, and colonies of the South Pacific exported largely to Japan, Australia, and New Zealand.

Phosphate rock, like coprolite, requires large amounts of sulphuric acid to turn the insoluble phosphate ore contained in the rock into soluble phosphates that plants can absorb. The ratio of phosphate to sulphuric acid is nearly 1:1 (Gray, 1944, p. 131; Lamer, 1957, p. 150). So the weight of any given superphosphate fertilizer is more than

[11] This assertion is based on estimates of phosphate rock production from Gray (1944), Clark and Sherman (1946), and Lamer (1957).

[12] The Reconstruction-era American South was arguably an "internal colony" of the US (see Jones, 1992).

[13] The coercive, racial labour regime was constitutive of fundamental shifts in global labour relations in the Reconstruction era. On labour in the South Carolina mines, see Shick and Doyle (1985), and on labour unrest in and around the mines, see Kelly (2008). On labour and labour unrest in the Florida mines, see Flynt (1968) and Blakey (1973). On new forms of labour in the Reconstruction-era American South generally, see Foner (1988) and Beckert (2015). On the migrant labour system in French North Africa, see Perkins (2014), and as constitutive of labour in the mines, see Jackson (2016). On labour in the Tunisia mines specifically, see Dougui (1995), and on the Algerian mines, see Prochaska (1990). On labour in the South Pacific frontier and the influence of the Pacific labour trade on the mining industry, specifically, see Shlomowitz and Doug (1992), Northrup (1995), and Cushman (2013).

double the weight of the phosphate from which it is made. At the same time, the phosphate content of the superphosphate is only slightly more than half of the phosphate content of the rock (Gray, 1944, p. 134). Given this weight – phosphate content difference, the international phosphate rock trade (largely between these main frontier regions and the manufacturing centres) was far more significant than the international trade in superphosphate fertilizer, as the following section details.

Given the large amount of sulphuric acid that the manufacture of superphosphate required, superphosphate manufacturers became integrated into domestic chemical industries. This integration followed a number of trends. In France and Germany it was the alkali industry that diversified into superphosphate production. The companies may or may not have been vertically integrated (with phosphate rock mines), which helps explain the imperative of securing phosphate rock abroad. In France, by 1900 the two largest superphosphate producers were among the two largest chemical companies, one of which, St. Gobain, will be addressed in fuller detail later (Haber, 1958, pp. 110–111). In Germany, the industry was not tied to the Leblanc process and diversified widely in these initial stages. Like France, in Germany superphosphate manufacturers became increasingly important to the industry (Haber, 1958, pp. 121–125). In the US, in contrast, there was no alkali industry and the chief markets for sulphuric acid manufacturers were the fertilizer, steel, petroleum, and explosive industries (Haber, 1958, p. 144). Initially, superphosphate factories were set up in the manufacturing centres of the Northeast (especially Baltimore), near to the availability of cheap sulphuric acid (Wines, 1985, pp. 104–106). In South Carolina, where the first large-scale production of phosphate rock occurred, mining companies soon became vertically integrated: they mined the rock and set up sulphuric acid plants near to Charleston, the closest city (Chazal, 1904). So while not every fertilizer manufacturer made its own sulphuric acid (cf. Lunge, 1891), the superphosphate manufacturer's demand for sulphuric acid allowed for other industries to grow as the scale and scope of sulphuric acid production increased, lowering the cost of sulphuric acid as an input in other industrial processes.

The cost advantages of diversifying into or from sulphuric acid production (through vertical integration etc.) can be explained in part by the investments required for sulphuric acid production. For example, what was considered the largest chamber in the US in the early 1870s—the Etiwan Works in Charleston, South Carolina—was capitalized at $350,000 (Chazal, 1904, p. 63) (equivalent to nearly $6.2 million in 2016). In order to best exploit the economies of scale and scope, over time the disparate units of sulphuric acid production in the US underwent a level of consolidation: sulphuric acid manufacturers expanded and diversified production into a growing range of chemical commodities—from sulphates (of potassium, magnesium, aluminium, etc.), acids (nitric, boric, etc.), ethers for chemical processes, cleaning/purifying materials, manufacturing, and so on (Lunge, 1903, p. 1,169). While the size of sulphuric acid production units on average steadily declined from 1880 through the interwar period,[14] by the eve of the First World War, three companies dominated the US superphosphate industry—all chemical companies, but not all manufactured their own sulphuric acid (Haber, 1971, pp. 175–176).[15]

The material connection between fertilizer manufacturing and the chemical industry demonstrates, building on Moore (2015, p. 135), that processes of chemification were a way to resolve the contradictions of this era—between expanded commodity production and growing capitalization. By interconnecting large-scale production units through a handful of chemicals, these industrial transformations multiplied forms of appropriation of unpaid work/energy, thus helping to keep levels of appropriation above levels of capitalization. Unpaid work/energy here includes the phosphates, which when combined with another chemical/form of energy turn into other forms of energy (e.g. superphosphate fertilizer). The sulphuric acid produced can then be turned into more energy by combining it with other materials. Of course, these ever-expanding levels of appropriation rested on frontier-making: imperial states carved

[14]The ratio of the number of sulphuric acid production units to gross production declined (1880–1931) from a high of 18.6 (thousands of short tons) in 1880 to 4.6 in 1931 (Haynes, 1959, p. 287). The falling scale of production can be explained in part by the development of a new production technology (contact), which began to compete with the established technology (chamber) within the industry.

[15]Haber (1971, p. 176) notes that the level of capital concentration in the US superphosphate industry at the time is remarkable, given the fact that not all the manufacturers made their own sulphuric acid (as was the case in Western Europe).

out frontiers of phosphate rock and sulphur-bearing materials and coal, and so on. As the next section explains, in the metropolitan centres control over frontier regions accomplished a number of things: (1) catapulting superphosphate manufacturing in the metropolitan centres; (2) forging the centre of a regional trade in manufactured fertilizers (an independent trade within greater Europe and the eastern US and a colonial trade between Japan and its colonies); and (3) expanding commodity production, especially of colonial crop substitutes, within the metropoles, through the application of chemical fertilizers and additional bought inputs.

4 | THE FIRST FOOD REGIME AND REGIONAL FERTILIZER TRADE IN THE METROPOLES

European imperial states dominated the international trade in phosphate rock and forged the centre of superphosphate manufacturing in the metropolitan centres of Europe. However, it was not only the European metropoles that benefited from the international division of labour through which phosphate rock became a commodity and was traded. Some industrializing countries such as Australia and Japan also experienced rapid superphosphate production and developed urban–industrial complexes by dominating phosphate rock mining regions. Characteristic of the urban–industrial complexes of the first food regime (ca 1870 to the First World War) were processes of rapid industrialization that brought together in a tight web national agricultures and national industries (Friedmann & McMichael, 1989; McMichael, 2013). The exponential increase in superphosphate production responded to and anticipated growing markets for chemical fertilizers. Following Britain's lead, imperial states were offshoring the production of wage goods—of cotton, sugar, wheat, tobacco, and so on—in new colonies. Also, existing farming regions in the metropoles began to increasingly rely on chemical fertilizers, either to remain competitive or for the rapid conversion of production to colonial crop substitutes—a shift that was propelled by protectionist policies to skirt competition. The manufacturing and trade in superphosphates fed into the urban–industrial complexes. The imperial states established favourable terms of trade—by trading manufactured fertilizers regionally—thereby accelerating the conversion of farming regions to commercial agriculture, which, in turn, supplied cheap foods and inputs for metropolitan industry.

European capital had dominated the French North Africa and South Pacific phosphate rock frontier regions and in the initial years the American Southeast frontier region. However, in terms of domestic manufacturing, estimates of superphosphate production illustrate that the two imperial states that dominated the main phosphate rock frontier regions—the US and France—maintained the highest production levels of all the metropoles through much of the interwar period (Figure 2; see also Appendix I).

What distinguishes the American Southeast frontier from the others is that the US industry (concentrated in the Northeast) was able to reverse the unequal terms of trade to some extent, whereby over time a greater percentage of the phosphate rock was manufactured within the US, and even within the Southeast, rather than exported to Europe. In the beginning of the South Carolina industry, nearly all the rock was shipped to northern and European superphosphate factories—and then shipped back to the South (Wines, 1985). Within a decade, following the development of manufacturing capabilities near to Charleston, phosphate rock exports dropped to about half of total production (Wines, 1985, p. 123). Of the remaining total, 34% was shipped to fertilizer manufacturers in the North, and 13% consumed locally/regionally (Wines, 1985, p. 123). As in South Carolina, in the initial years of production in Florida, all of the rock was exported and was based on contracts with European manufacturers, but, as the industry developed, exports as a percentage of total production fell: by the start of the First World War, about 40% was exported (Blakey, 1973, p. 34). Although the two major mines of the American South developed a level of manufacturing, the extent to which these industries were able to experience long-term benefits form industrial production differed remarkably. In contrast to Florida, which has been the longest-running, productive phosphate rock mining region in the world until now, South Carolina went through a rapid boom–bust cycle. The creation and expansion of an extractive industry built through a coercive, racial labour regime of freedmen, with capital flows moving out of the region to the North or across the Atlantic, in effect led to the “stillbirth” of the Reconstruction-era Charleston area (Shick & Doyle, 1985, p. 30).

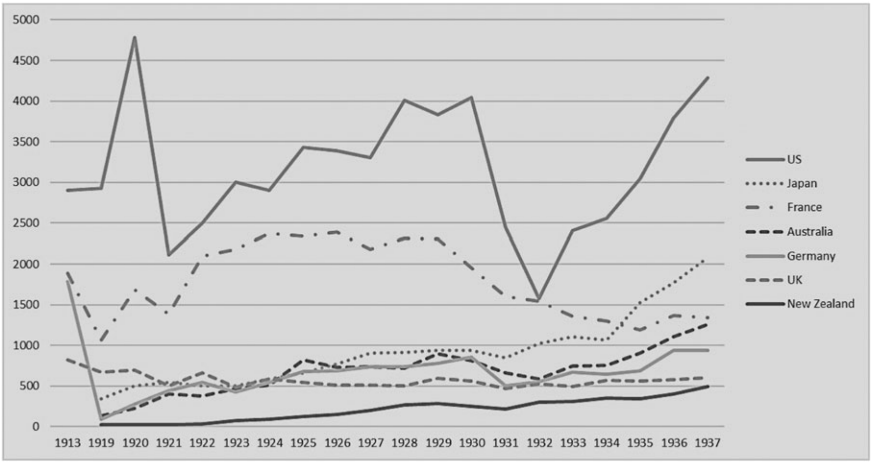

FIGURE 2 Estimated superphosphate production, 1913–1937 (in millions of long tons)
Source: Compiled from League of Nations (1927), Gray (1944), Haber (1971), and Daviet (1988)

In the North African frontier region, phosphate rock was entirely exported during the initial decades of production. Through the Compagnie Sfax-Gafsa, French investors dominated the industry in Algeria and Tunisia, but by no means crowded out other European investors (including British, German, Dutch, Belgium, and Italian) (Geopfert, 1925, p. 25; Levainville, 1924). In 1922, of the 500,000 metric tons from Algeria, about 42% went to France and 58% to the UK, Germany, and the Netherlands; and of the 2 million metric tons from Tunisia, 40% went to France and the rest to the UK, Belgium, and Italy (Levainville, 1924).[16] In contrast, in Morocco France monopolized the industry through the Office Cherifien des Phosphates (OCP), the state phosphate company established by the protectorate administration: Of the 8,300 metric tons produced in 1922, all were exported to France (Levainville, 1924; on the intention of the French administration to create a monopoly, see also de Bailliencourt-Courcol, 1933).

France experienced a remarkable transformation in fertilizer manufacturing as the North African frontier region developed. France's chemical industry developed late compared to those of the UK, Germany, and the US. While the industrializing powers had developed commercial-scale production of fertilizer by mid-century, by the end of the 1870s there were only three superphosphate factories in France (Daviet, 1988, p. 293). Although France did not have a monopoly over the Algeria and Tunisia deposits, phosphate rock imports from the colonies coupled with some local phosphate sources as well as US imports led to the growth of superphosphate production in France at a rate of about 7.25% a year between 1887 and 1913 (Daviet, 1988, p. 324). Between 1895 and 1900 alone, exports of superphosphate doubled and imports fell; by the turn of the century, France had become the largest superphosphate producer in Europe (Haber, 1971, pp. 17–18). In Gray's (1944, p. 23) words, the "golden age of French metropolitan phosphate production was undoubtedly from 1888 to 1908". Saint-Gobain, an investing partner in Compagnie Sfax-Gafsa, shifted increasingly towards fertilizer manufacturing during this period. The years 1890 until 1913—the years of the North African phosphate rock export boom[17]—were considered the "invincible years" for Saint-Gobain's primary product, superphosphate fertilizer (Daviet, 1988). In the decades leading up to the First World War, France caught up to the other industrializing powers in the production of superphosphates, and as Figure 2 illustrates (see also Appendix I), production far surpassed that of the other European producers and only began to wane beginning in the early 1930s.

Similarly, in Japan, Australia, and New Zealand, superphosphate production rose exponentially from 1919, following greater control over the South Pacific frontier region (Figure 2). The Anglo-German Pacific Phosphate

[16]According to Dougui (1995, p. 344), France maintained roughly a 40% market share of Tunisian rock, on average, during the 1899–1912 period.

[17]Production in Tunisia alone began at the end of the 19th century, and within just two decades exports reached more than 23 million metric tons (Levainville, 1924).

Company had controlled the mines on Nauru and Banaba (Ocean Island), the main phosphate-exporting islands, and exported the raw material to Western Europe, Japan, and Australia (Firth, 1973; Ohff, 2008). Following the First World War, however, Japan gained control of German Micronesia, and under the Nauru Island Agreement of 1919 the British Phosphate Commission (PPC)—a joint undertaking of the governments of the UK, Australia, and New Zealand—bought the phosphate deposits on Nauru and Ocean Island from the Pacific Phosphate Company (Cushman, 2013). Under this agreement, the BPC would mine the phosphate islands (Banaba, Nauru, Christmas Island, and Makatea) and Britain would supply low-priced phosphate to other countries such as Japan (Cushman, 2013, p. 128).

Both Australia and New Zealand had begun superphosphate production from local sources before the First World War—in Australia, from the bone char of sugar refineries in the 1880s; and in New Zealand, from low-grade domestic phosphate rock in the 1890s (Lamer, 1957, pp. 282, 285). However, superphosphate manufacturing did not take off until the formation of the British Phosphate Commission. During the long course of BPC phosphate production, from 1920 to 1981, Australia and New Zealand consumed 66% and 27%, respectively, of total phosphate rock traded (Cushman, 2013, p. 128). In Japan, it was only after the China War (1894–1895), after which imports of soybean-cake fertilizer from China fell, that superphosphate production increased steadily from 11 domestic manufacturers in 1898 to 159 by 1907 (Molony, 1990, pp. 31, 33). Long before Japan colonized the Micronesian islands during the First World War, Japan had at least been importing phosphate rock from the Marshall Islands (Cushman, 2013, p. 118). And then, following the war, throughout the interwar period about half of the country's phosphate rock imports came from the South Pacific region (Lamer, 1957, p. 676). The expanding commodity frontiers of phosphate rock fuelled the exponential growth in superphosphate production in the metropoles, which syncopated with expanded agricultural commodity production in a growing number of farming regions in independent, nominally independent, and colonized territories.

4.1 | National agricultures in the metropoles

Why was commodity production expanding in new and existing farming regions? In the first food regime, imperial states were systematically offshoring production (a process administered from the metropoles), which meant that existing farming regions in the metropoles were increasingly in competition with newer agro-exporting regions in the colonies. And this growing number of producers the world over became subject to the vagaries of a world-price-governed market for agricultural commodities (Beckert, 2015; Davis, 2001; McMichael, 2013). Wheat from North America in particular led to a fall in agricultural prices in Europe, compounding the Great Depression of 1873–1896 (Heywood, 1981; van Zanden, 1991). In response to the Great Depression and to competition from settler agricultural imports, Germany, Italy, and France instituted import tariffs and export subsidies to protect domestic agriculture (van Zanden, 1991, p. 227; Webb, 1982). European states had already begun a process of import substitution—reversing dependence on imports of select colonial crops through the domestic production of substitutes.[18] But by the 1870s, in Prussia under Bismarck, for example, very broad tariffs on imports and export subsidies had the effect of promoting agricultural intensification—that is, greater capitalization—as crop prices were kept above world prices. High-technology sectors (such as sugar beet), which required above average amounts of fertilizer, were promoted to be competitive in European markets. So the largest estate owners, the Junkers, who dominated sugar beet and grain production and benefited most from these protectionist policies, maintained an export market within Europe.[19] At the same time, these protections increasingly moved production of grains for export to production of grain and high-technology crops for the domestic market.[20]

In response both to competition and to state protections, chemical fertilizer became more widely consumed throughout farming regions in the metropoles. The market grew when the price of chemical fertilizer declined

[18]For example, by 1860, Prussia had already transformed from a net sugar importer to a net sugar exporter (Melillo, 2012, p. 1043).

[19]Cartels and export subsidies to promote the cartels characterized the European sugar market, until an international convention in 1902 put an end to all export subsidies (Webb, 1982, p. 316).

[20]By 1900–1901, Germany had become the world's largest sugar producer, with 22% of the world output (Webb, 1982, pp. 314–315).

precipitously from the 1880s onwards, following the rapid development of the Florida mines.[21] As the price declined, chemical fertilizer came to play an increasingly important role in these transformations in national agricultures in the metropoles during the first food regime through both an independent regional trade (in the eastern US and in Europe) and a colonial trade (between Japan and its colonies).

In the US by the 1880s, commercial fertilizer consumption more generally was concentrated on the eastern coast (along the Atlantic seaboard) (Wines, 1985, pp. 148–157). Here, consumption of superphosphate fertilizer in the American South is highlighted to underscore the point that agrarian capitalism took many forms—not just entrepreneurial capitalist agriculture. In the American South, planters had used guano and other commercial fertilizers before the Civil War, but it was not until after the Civil War that commercial fertilizer was used more widely (Beckert, 2015; Sheridan, 1979; Wines, 1985). The demand came from both former plantation owners and the new class of sharecroppers. War had damaged farming: there was "widespread destruction of work animals, farm buildings, and machinery" (Foner, 1988, p. 125). And cotton prices began declining in 1868. Both factors probably increased the demand for cheaper ways to restore productivity (Taylor, 1953). The planters, along with merchants, also pressured sharecroppers to purchase fertilizers through long-term credit schemes. The state had enacted crop lien laws whereby landowners and tenants obtained credit, and fertilizer use was seen as an assurance that sharecroppers would be successful enough to pay off debts. Among the commercial fertilizers consumed after the war, the market for superphosphate fertilizer grew exponentially. By 1870, just a few years after production began, the phosphate rock industry in South Carolina assumed "major importance" in fertilizer manufacturing in the US (Blakey, 1973, p. 9). Consumption of guano in the American South declined steadily after 1875 (Sheridan, 1979, p. 308), and by 1880 phosphate rock production in South Carolina was about ten times the amount of phosphatic guano imported—from the Caribbean islands (Wines, 1985, p. 82). In that same decade, most southern states had developed superphosphate manufacturing capabilities (Sheridan, 1979, p. 310). Although the estimated percentage of South Carolina phosphate rock consumed in the South is not sizable, the local market was significant to investments in local manufacturing capabilities given that, as has already been established, the long-distance trade in manufactured fertilizer was cost prohibitive. Plus, local production created possibilities for significant market expansion among southern farmers by keeping costs lower.

The US dominated the international phosphate rock trade, at least until the interwar period, but as the case of the American South demonstrates, the US was trying to break out of the European-dominated international division of labour whereby most phosphate rock traded ended up in the manufacturing centres of Europe. The European imperial states in effect secured their position as the centres of the regional superphosphate trade (in greater Europe) through the interwar period. Most of the phosphate rock manufactured in the metropolitan centres of Europe was imported, and much of the manufactured fertilizer was consumed domestically. Yet, the imperial states were able to maintain a positive trade balance (vis-à-vis the frontier regions) by exporting regionally the remaining manufactured fertilizer—the value of which exceeded the value of the imported phosphate rock. For example, most of the superphosphate manufactured in the UK and in France was consumed locally between 1907 and 1913,[22] and yet, the value of exports (largely of fertilizer) exceeded the value of imports (of raw materials such as phosphate rock).[23] In northern Germany at the turn of the 20th century, superphosphate manufacturers imported phosphate rock from North America and North Africa, and "had a considerable export business to Scandinavia" in the pre–First World War period (Haber, 1971, p. 118). In Spain, where sugar beet production spread, it was the sugar beet industry that produced and marketed fertilizers to sugar beet growers from the late 1880s (Simpson, 1995, p. 116). In Ukraine, where sugar beet

[21]In Belgium, chemical fertilizer prices fell by 20% in 1888, by another 10% in 1890, and by another 15% circa 1895 (Knibbe, 2000, p. 47). In the Netherlands, phosphate fertilizer prices fell by as much as two thirds between 1880 and 1890 (van Zanden, 1991, p. 231). Fertilizer prices fell "by an average 55 per cent in Germany between 1880 and 1905/13 […] and by 47 per cent in Britain between 1870 and 1910" (van Zanden, 1991, p. 231).

[22]In 1907 in Britain, 741,000 tons were consumed locally versus 115,000 exported, and in France 1,501,000 metric tons were consumed locally and 198,000 exported (Haber, 1971, pp. 145, 153).

[23]In Britain between 1907 and 1913, the value of exports was from 1.3 times to about 1.75 times that of imports (Haber, 1971, p. 136).

had also spread, phosphate rock was discovered in the 1880s in Podolsk, and the rock was manufactured into superphosphates for Ukrainian sugar-beet growers (Lamer, 1957, pp. 374–376). Protective policies to substitute colonial crops appear to have contributed to the regional growth of sugar-beet-producing areas, which were consumers of superphosphates. Through the regional trade, European imperial states were able to simultaneously grow the domestic market for chemical fertilizer and dominate the market within greater Europe.

In contrast to the independent regional superphosphate trading networks in the eastern coast of the US and in greater Europe, Japan forged a colonial (regional) superphosphate trade. This trade emerged out of the imperial policy of offshoring production to its colonies. Japan colonized Taiwan in the China War and Korea in 1910, turning both into agro-export estates—and major markets for chemical fertilizer. Agro-export production in Taiwan began with the sugar-cane programme (with sugar varieties from the Hawaiian Islands), and the Japanese established a landlord class, who were similarly “encouraged to direct villagers to adopt new seed varieties and better cultivation methods” (Lee & Chen, 1979, p. 83). The sugar industry took a prominent role in encouraging chemical fertilizer use among the landlords in conjunction with new seed varieties (Lee & Chen, 1979, p. 85). In Korea, as an agro-exporter of largely rice and cotton, fertilizer imports from Japan (and Manchuria) grew on average by 22% from 1910 to 1938 (Kang & Ramachandran, 1999, p. 789). Then, the Japanese built a nitrogen fertilizer plant in 1930 in (north) Korea, which was intended at least in part to realize the colonial government's failed “Program for Increasing Rice Production” of the 1920s, instituted after the Rice Riot in Japan in 1918 (Hwan Ban, 1979, pp. 109–110).

Although the regional trade in superphosphate that the imperial states forged was an enabler of the spread of cash-crop production, fertilizer manufacturing capabilities outside of the metropolitan centres remained minimal during the period covered in this paper (Lamer, 1957). Many states were primarily importers and not producers of chemical fertilizer. Figure 2 shows consumption of new and established classes of chemical fertilizers in the interwar period—and for many of the semi-peripheral states such as Poland and Yugoslavia, that meant combinations of production and imports (see also Clark & Sherman, 1946; Gray, 1944). Growth in the market for chemical fertilizer (and other “Green Revolution” technologies such as high-yielding seed varieties and irrigation projects) had been promoted not just by industry but by state agricultural development, often working in tandem with industry. Colonial and nominally independent states sought consultation from experts—agronomists, agricultural engineers, and so on—to promote the adoption of these technologies among farmers: see, for example, Van der Eng (1996) for the Dutch East Indies, Richards (1980) for Egypt, and Feeny (1982) for Thailand. Markets for chemical fertilizer in the colonized world did not grow in any substantial way until the interwar period—and that growth was highly uneven. Because the international trade in superphosphate fertilizer was minimal, the price of imported fertilizer was too high (Feeny, 1982; Richards, 1980; Van der Eng, 1996). Plus, without the capital to develop phosphate rock frontiers domestically or in colonies of their own, and/or being denied control over the great wealth beneath their soil—colonized states developed minimal superphosphate production. Without domestic manufacturing and given the limited international fertilizer trade, national agricultures and national industries were thwarted.

5 | CONCLUSIONS

The first food regime and the second industrial revolution were historical moments in the modern era (ca 1870 to the interwar period) that reproduced one another. Industrial transformations that permitted a long-term rate of return on investment (Chandler, 1990), in turn, enabled imperial states to expand commodity production and trade (through, in part, the manufacture of fertilizers), which lowered the costs of labour and manufacturing and, thus, made possible the expansion and diversification of industrial production. By bringing together these two moments, this study of chemical fertilizer adds another analytical dimension to understanding the new role of commercial agriculture in cementing the “urban–industrial complexes” (McMichael, 2013, p. 4) in the metropolitan centres by the interwar period. Imperial states heralded the commercialization of agriculture—by forging commodity frontiers of critical natural resources, funnelling these materials to be manufactured in the metropolitan centres, and trading the fertilizer locally and regionally. But the manufacture of fertilizer also created important synergies with other industrial processes, as one of three angles of the triangular market for sulphuric acid, which in turn helped lower their costs despite the rising capitalization of production.

In Moore's (2015) terms, the new relationship between agriculture and industry was born out of the twin processes upon which this long wave of accumulation rode: appropriation (of unpaid work/energy brought into the commodity system) and exploitation (of labour power). In this paper, I have asked how the scope, scale, and speed of appropriation of unpaid work/energy expanded in an unprecedented way during the latter half of the long 19th century (Moore, 2015, p. 135). I have addressed this question with the concept of chemification—processes by which imperial states gained territories (and land, labour, etc.) through industrial power built on assemblages of production, energy, and materials connected via a handful of chemicals. I have demonstrated these processes of chemification through an analysis of the materiality of the commodity studied (Mitchell, 2011): chemical (superphosphate) fertilizer. Materially superphosphates were interconnected to other chemical processes as their manufacture required considerable amounts of sulphuric acid, a main chemical in industrial production. Superphosphates were then materially connected to farming systems undergoing expanded commodity production by enhancing and quickening crop growth. Farming regions in the metropoles were the primary markets for chemical fertilizer as they faced growing competition in a world-price governed agricultural market—from North American grains and newer agro-exporting regions in colonized territories. This lens on chemical fertilizer shows the historically specific constellation of the state, Nature, labour, capital, and imperialism that contributed to a new role for commercial agriculture in building national industries in the metropolitan centres. And the building of national agricultures and national industries, and the intertwined relationship between them, made possible unprecedented levels of appropriation from the 1870s.

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APPENDIX I

ESTIMATED SUPERPHOSPHATE PRODUCTION, 1913–1937 (IN MILLIONS OF LONG TONS)

	1913	1919	1925	1930	1931	1936
Germany	1,790	95	681	851	501	935
UK	817	668	540	560	468	578
France	1,890	1,064	2,342	1,956	1,605	1,367
Italy	957	726	1,543	1,366	789	1,344
US	2,900	2,923	3,434	4,045	2,451	3,789
Japan		340	663	942	849	1,772
Spain	221	133	712	1,130	897	453
Australia		129	819	815	660	1,110
New Zealand		21	128	248	216	400
Netherlands	341	61	563	649	495	467
Belgium	443	50	403	362	251	284
Russia	156		65.1	386	513	1,236

Source: Compiled from Daviet (1988), Gray (1944), Haber (1971), and League of Nations (1927).