Nitrogen economy: the emergence of a synthetic fertilizer regime in New York State

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Abstract

Synthetic nitrogen fertilizer, synthesized from atmospheric nitrogen using the Haber-Bosch process, has been a fundamental pillar of conventional agriculture since the first decade of the 20h century. This dissertation, "Nitrogen economy: the emergence of a synthetic fertilizer regime in New York State" by Gabriel Coleman, investigates how changing discourses surrounding fertilization in the postwar United States led to exponential growth in fertilizer consumption that continued into the 21st century. The dissertation assembles a case study of New York State using agricultural newspapers, advertisements, expert publications, and educational texts available to New York farmers. This case study shows how synthetic fertilizers interacted with farm practices, forms of expertise, and other agricultural technologies to redefine the state's agricultural landscape. Synthetic nitrogen fertilizer is shown to have intensified industrial agriculture's dependance on fossil energy through the energy required to synthetize atmospheric nitrogen and the mutualistic relationship of synthetic fertilizer with other fossil-dependent technologies like irrigation and mechanization. The network of technologies, expertise, and practices that grew around synthetic nitrogen fertilizer in the postwar era represent New York's own Green Revolution, reflecting many of the practices and technologies implemented by Norman Borlaug and the Rockefeller Foundation in South America and Asia around the same time. The new regime of abundant soil fertility enabled by synthetic fertilizer's embodied fossil energy played a major role in shaping the postwar industrial agricultural landscape of New York State and the world.

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Introduction

Synthetic nitrogen fertilizer has been a fundamental pillar of conventional western agriculture since the first decade of the 20th century. The power to synthesize fertilizer from nitrogen from the atmosphere using the Haber-Bosch process, in concert with other agricultural developments like mechanization and irrigation, allowed global agricultural production to increase an average of 2.3 percent each year between 1950 and 2000.[1] This increased availability of nitrogen fertilizer has also disrupted the global nitrogen cycle, causing over 400 “dead zones” in the world’s oceans where the lack of oxygen caused by algae feeding off excess nitrogen makes it impossible for fish and other lifeforms to survive.[2] The power of this industrial process in the United States has always depended on fossil energy. Even in 1928 as the fate of the United States’ first two nitrogen fertilizer plants at Muscle Shoals was being discussed, political science researcher R. O. E. Davis thought it unwise to keep the hydroelectric potential of the Muscle Shoals plants tied to fertilizer manufacturing as “nitrogen fixation is more closely allied with coal than with hydroelectric power, [making] it more important for the economical development of the industry that the plants be close to coal producing centers.”[3] This dependance on fossil energy continues today. According to the International Fertilizer Association, the synthetic production of ammonia represents 4% of annual natural gas consumption in the United States and Europe and 40% of consumption in India.[4] This paper looks at the substantial increase of synthetic nitrogen consumption following the Second World War in order to see how this fossil-dependent abundance of nitrogen changed discourses around agricultural soil fertility and contributed to the dual crises of climate change and nitrogen pollution.

The research in this paper focuses primarily on New York State agriculture in the two decades following the Second World War. The geographic focus on New York grows from the use of primary literature from Cornell University’s Core Historical Literature of Agriculture Collection. New York State’s agricultural landscape makes an interesting case study as it

[1] Giovanni Federico, *Feeding the world : an economic history of agriculture, 1800-2000*, The Princeton economic history of the western world, (Princeton, N.J. ; Woodstock: Princeton University Press, 2005), 19.
[2] Andrew Zaleski, "The godfather of pollution," *New Scientist* (15 May 2021): 42.
[3] R. O. E. Davis, "Muscle Shoals, Nitrogen and Farm Fertilizers," *The Annals of the American Academy of Political and Social Science* 135 (1928): 164.
[4] "Raw Mineral Reserves," International Fertilizer Industry Association (IFA), updated 2002 Oct, 2008, accessed 5 Oct 2021, https://web.archive.org/web/20080424083111/http://www.fertilizer.org/ifa/statistics/indicators/ind_reserves.asp.

includes a variety of agricultural landscapes including pastured cattle, field crops, fruit orchards, and truck crops and was seen as somewhat of an agricultural backwater when compared to the rich soils of the Midwest and the innovation-focused farming of California's Central Valley. The temporal focus of the postwar decades represents the beginnings of a period of exponential growth in fertilizer production and consumption that continued through the end of the 20th century. World War II saw annual global synthetic nitrogen manufacturing capacity increase to 1.4 million tons compared to 380,000 tons in 1932. This capacity grew to 1.5 million tons by 1950, 5.5 million tons in 1960, and 19.5 million tons two decades later in 1982.[5] By focusing on the changes in fertilizer discourses through the 50s and 60s, this paper shows how new attitudes and ideas of soil fertility and fertilization created the correct conditions for this exponential growth.

Technical Background

Plants are celebrated as being relatively self-sustaining, needing only sun and water to survive. This may appear to be true, especially for the houseplant that, dutifully watered and placed in a sunny window, produces cheerful foliage and the occasional surprise of a flower or a new shoot. However, though the chloroplasts in a plant's leaves allow plants to get all the energy they need from solar radiation, their roots must forage in the soil for the materials used to build their bodies. Just as humans need a balanced supply of macronutrients like carbohydrates, fats, and protein with smaller amounts of vitamins and minerals to lead healthy lives, plants need specific materials or nutrients to grow. For plants, the "macronutrients" required include nitrogen, phosphorous, and potassium, and micronutrients, which can be thought of as "vitamins" and "minerals," include things like molybdenum, aluminum, and calcium. The reason why a houseplant doesn't appear to need anything other than sun and water is because all these nutrients naturally exist in soils in some concentration, especially in packaged potting soils.

For farmers who often foster plant growth from seed to maturity in a matter of months, soil fertility cannot be ignored. Macronutrients like phosphorous and potassium are present in some background level of concentration in most soils, depending on their presence in the parent rocks that soils are made from, but nitrogen is generally much more scarce.

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[5] John M. Potts, *Fluid fertilizers*, Bulletin Y ;185, (Muscle Shoals, Ala.: Tennessee Valley Authority, National Fertilizer Development Center, 1984), 49.

The scarcity of bioavailable nitrogen in soils is inherent to atomic qualities of nitrogen which determine the way it cycles through the biosphere. Nitrogen makes up 78% of the atmosphere but the molecular structure of atmospheric nitrogen, consisting of two triple bonded nitrogen atoms, is highly unreactive, making it impossible for plants to interact with and use. With a large amount of energy, lightning storms and specialized bacteria are able to break these triple-bonded nitrogen atoms apart, causing them to take the form of nitrogen ions like nitrate, nitrite, and ammonia where a single nitrogen atom bonds more weakly with hydrogen or oxygen. In contrast to nonreactive atmospheric nitrogen, these ions have either a negative or positive charge, making them highly reactive and easily taken up by plants or pulled around by water molecules. The fact that the small proportion of reactive or bioavailable global nitrogen is so incredibly mobile is the reason for its scarcity as it is constantly moving through soil, plant and animal bodies, rivers, and oceans.[6] The importance of nitrogen's scarcity was cemented in agricultural science in the 19th century by German chemist Justus von Liebig's "law of the minimum," an observation that plants only grow as much as a the least available nutrient allows. This means that if a plant has access to an abundance of phosphorous and potassium but only very little nitrogen, it will only grow as much as the nitrogen will allow and won't be able to use the full extent of the other elements. Conversely, introducing a large amount of nitrogen into the soil is usually the easiest way to stimulate plant growth as it is most likely to be the limiting nutrient. As explained by Verena Winiwarter in her *Environmental History of Soils,* Liebig's understanding of the elemental requirements of plant nutrition has been highly influential in defining agricultural best practices through the present day, emphasizing elemental plant nutrients above all other factors in determining soil fertility.[7]

The Haber-Bosch process for synthesizing nitrates from atmospheric nitrogen was invented by Fritz Haber in the 1910s.[8] The process involves combining pressurized hydrogen gas with pressurized air in the presence of an iron catalyst. Air is 78% nitrogen and this high pressure forces the atmospheric nitrogen molecules to break apart and bonds with hydrogen to create

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[6] R. Thomas Sanderson, "nitrogen," in *Encyclopædia Brittanica* (Chicago: Encyclopædia Brittanica Inc., 5 Nov 2020). https://www.britannica.com/science/nitrogen/; Michael B. Thompson, David M. Gates, and John N. Thompson, "biospere," in *Encyclopædia Brittanica* (Chicago: Encyclopædia Brittanica Inc., 16 Nov 2020). https://www.britannica.com/science/biosphere.

[7] Verena Winiwarter, "Environmental History of Soils," ed. Mauro Agnoletti and Simone Neri Serneri, 1st ed., *The Basic Environmental History* (Cham: Springer International Publishing : Imprint: Springer,, 2014). 114.

[8] Meredith McKittrick, "Industrial Agriculture," in *A companion to global environmental history,* ed. John Robert McNeill and Erin Stewart Mauldin (Oxford: Wiley-Blackwell, 2012), 415.

ammonia. The Haber-Bosch process substituted two other methods of nitrogen synthesis used at the time, the arc process and cyanimide process which were both significantly more energy intensive.[9] Today, nitrogen synthesized using the Haber-Bosch process represents 97% of all nitrogen fertilizers.[10]

Intersecting Histories and Related Literature

The history of synthetic fertilizers after World War II is only one piece of a larger history of fertilization and industrialization within agriculture. Farmers were first familiarized with the idea of adding fertilizer products to their fields in the early 19th century with the introduction of Peruvian guano, the accumulated feces of seabirds on rocky islands, and sodium nitrate from the northern deserts of Chile. Farmers referred to these stores of bioavailable nitrates as "artificial" fertilizers, in contrast with the natural or organic forms of fertilizer that supported what author Gregory T. Cushman refers to as the "ecological old regime" where limited nitrogen not only limited the growth of plants but the accumulation of wealth in societies.[11] As Cushman claims, the introduction of these Pacific sources of nitrogen to European and American agricultural systems removed these ecological limits to agricultural productivity and societal abundance. Edward T. Melillo's research into the exploitation of Chilean nitrate and Peruvian guano connects this new "open" system of agriculture, where local nutrient recycling was substituted for external inputs, to changing labor regimes. In Melillo's analysis, this abundant new source of nitrogen relied on the coerced labor of Chinese migrants in Peru and *engauche* laborers in Chile, whose energy was commodified through geographical displacement from their homelands.[12] These artificial sources of nitrogen set the stage for the later introduction of synthetic nitrogen, with South American sources of nitrate replaced by the even more abundant source of atmospheric nitrogen and the coerced labor of displaced peoples replaced by the commodified energy of coal, oil, and natural gas.

The interwar period, between the invention of the Haber-Bosch process during World War I and the nitrate production boom triggered by World War II was also key to the

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9 Davis, "Muscle Shoals, Nitrogen and Farm Fertilizers," 159.
10 "Raw Mineral Reserves."
11 Gregory T. Cushman, *Guano and the opening of the Pacific world : a global ecological history*, Studies in environment and history, (Cambridge ; New York: Cambridge University Press, 2013), 38.
12 Edward D. Melillo, "The First Green Revolution: Debt Peonage and the Making of the Nitrogen Fertilizer Trade, 1840–1930," *The American Historical Review* 117, no. 4 (2012): 1030-31.

development of synthetic nitrogen. Arnaud Page's research on the interwar expansion of synthetic nitrogen within the British Empire shows that, though production capacity was limited by price hikes instituted by an international cartel of manufacturers and the hesitation of government to invest in state manufacturing capacity, synthetic nitrogen's abundance and ability to increase yields led the British government to see it as shorthand for global development and prosperity during the interwar years.[13] After pressure to increase munitions manufacturing led the government to double Britain's nitrate manufacturing capacity between 1936 and 1943, synthetic nitrogen's political characterization as a force for global agricultural modernization further enabled the exponential increase in consumption that is the subject of this paper.[14]

Synthetic fertilizer is intimately woven through the larger history of agricultural industrialization and mechanization. Meredith McKittrick's survey of industrial agriculture shows how the "technological package" of fertilizers, agricultural machines, irrigation, and pesticides developed in conversation with one another to rationalize farm labor, crops, and the land itself.[15] In her book on the evolution of farm machinery through the 20th century, author Deborah Fitzgerald explores how the adoption of these farm implements allowed farm labor itself to be mechanized, rationalized, and augmented by agricultural machinery, changing the way farmers conceived of their own labor and efficient operation of the farm.[16] Andrew Watson's research into irrigation on the High Plains makes the connection between agricultural industrialization and fossil energy explicit by showing how the rationalization and efficiency brought by irrigation depended on an abundant external source of fossil energy.[17] Synthetic fertilizer runs between these histories, being both a fossil fuel intensive external source of agricultural productivity and a force in the rationalization and mechanization of agricultural land and labor.

The "technological package" of industrial farming to which McKittrick refers supported what has been termed the Green Revolution, the effort to introduce high-yielding varieties of

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[13] Arnaud Page, ""The greatest victory which the chemist has won in the fight (...) against Nature": Nitrogenous fertilizers in Great Britain and the British Empire, 1910s-1950s," *History of Science* 54, no. 4 (2016): 389, 97.

[14] Page, ""The greatest victory which the chemist has won in the fight (...) against Nature": Nitrogenous fertilizers in Great Britain and the British Empire, 1910s-1950s," 396.

[15] McKittrick, "Industrial Agriculture," 421.

[16] Deborah Kay Fitzgerald, *Every farm a factory : the industrial ideal in American agriculture*, Yale agrarian studies series, (New Haven, London: Yale University Press, 2003), 88-89.

[17] Andrew Watson, ""The Single Most Important Factor": Fossil Fuel Energy, Groundwater, and Irrigation on the High Plains, 1955-1985," *Agricultural History* 94, no. 4 (2020).

cereal crops, bred by Norman Borlaug with aid from the Rockefeller Foundation, to South America and Asia in the second half of the 20th century.[18] Synthetic fertilizer is an essential element of the Green Revolution in two ways. First, the high-yielding varieties that are the hallmark of the Green Revolution rely on abundant supplies of nitrogen to reach competitive yields. Second, the expectation that fertilizer could rationalize the productivity of any soil justified Borlaug and the Rockefeller Foundation's efforts to transpose industrial agricultural practices across continents. Nick Cullather's research on the Green Revolution highlights the underlying political motivations of the Green Revolution, to counter communism in Asia by spreading America's capitalist prosperity through abundant food.[19] The role of politics in the Green Revolution reflects Arnaud Page's findings on the importance of nitrogen fertilizer to the British government as a means and measure of global development decades earlier.[20] Jonathan Harwood has advocated for an "enlarged" idea of the Green Revolution throughout his research on European crop breeding for higher yields beginning in the late 19th century and similar development projects since.[21] The industrialization of New York State is a strong case for this analytical enlargement of the Green Revolution as a category. All the aspects of a Green Revolution are present in New York but this history exists beyond the traditional geographical framework of South America and Asia and the temporal framework of the 50s and 60s, with many industrial aspects like mechanization and fertilization becoming established earlier in New York and their corresponding high-yielding crop varieties not being adopted until the dawn of the 70s.

Though all the texts mentioned above give voice to synthetic fertilizer as an aspect of agriculture's modernization, industrialization, and globalization, relatively little research has focused explicitly on synthetic fertilizer as a force of industrialization in its own right. Therefore, this work uses synthetic fertilizer to weave together histories of the Green Revolution, agricultural industrialization, and fossil energy, showing how an abundance of synthetic nitrogen plays a primary role in each of them.

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[18] McKittrick, "Industrial Agriculture," 421.
[19] Nick Cullather and American Council of Learned Societies., *The hungry world America's Cold War battle against poverty in Asia* (Cambridge, Mass.: Harvard University Press,, 2013).
[20] Page, ""The greatest victory which the chemist has won in the fight (...) against Nature": Nitrogenous fertilizers in Great Britain and the British Empire, 1910s-1950s," 397.
[21] Jonathan Harwood, *Europe's green revolution and others since : the rise and fall of peasant-friendly plant breeding* (London ; New York: Routledge, 2012), xv.

Outline

The following chapters addresses the development of synthetic fertilizer from three thematic perspectives. The first chapter, *A Great Powerful Tractor,* uses the opposition between industrial users of synthetic fertilizer and proponents of organic farming to show how the introduction of synthetic nitrogen caused a drift of what was considered *natural* farming to privilege scientifically and economically defined practices. The second chapter, *Fertilizer Facts,* investigates how fertilizer's dominance moved the center of agricultural expertise from networks of farmers to collections of university researchers and manufacturers, restructuring how agricultural labor was conceived. *Nitrogen Solutions,* the third chapter, maps the various practices nitrogen fertilizers induced farmers to adopt, from liquid fertilizers to high-yielding varieties, to show how their interconnections intensified the use of fertilizers in the field. These themes are brought together in the conclusion in an analysis of the case study of farm fish ponds to determine how well farmers and experts would have understood the threat of eutrophication caused by excess nitrogen.

A Great Powerful Tractor: the agricultural paradigm of synthetic nitrogen

Introduction

The extensive adoption of synthetic nitrogen fertilizer in the mid 20th century was the culmination of over 100 years of intensification in agricultural soil management. Imports of Peruvian guano and later Chilean nitrate were a boon to American agricultural productivity. However the relatively high prices of these amendments and competition for nitrates by other industries checked the degree to which farmers were able to rely on exotic nitrogen. Agricultural fertilizer accounted for only 13% of Chilean nitrate imports, competing with explosives which made up 41% of demand, other chemical manufacturing which represented 25% and dyestuffs which used 12%.[22] As Edward D. Melillo shows in his research on artificial fertilizers, this scarcity prompted new American colonial projects like the Guano Islands Act which allowed the United States to appropriate any unclaimed guano islands it discovered.[23] During the First World War, demand for explosives increased pressure the nation's nitrate supplies, prompting the United States Congress to construct two nitrate plants near Muscle Shoals, Alabama along the Little Tennessee River. The first plant was small and experimental, using a modified version of the recently developed Haber-Bosch process. The second larger plant relied on the cyanamide method of nitrogen fixation, a more energy intensive but better understood process.[24]

Though the second larger plant was only completed after the armistice was signed, farmers saw the potential impact of inexpensive synthetic nitrates on their livelihoods. In 1921 a farmer took to the pages of the *Rural New Yorker*, a weekly newspaper serving the interests of farms and country-dwellers in the state of New York, to urge congress to invest an additional $30,000,000 to re-construct and expand the experimental synthetic nitrate plant. In the article the author points to Germany's transformation from importing 110,000 tons of Chilean nitrate to manufacturing enough fertilizer to export upwards of 500,000 tons, claiming that the expanded plant at Muscle Shoals would be "a great, powerful tractor—not something to be fed, but something to feed the people."[25]

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[22] Robert U. Ayres, Leslie W. Ayres, and Vicky Norberg-Bohm, Industrial Metabolism of Nitrogen, Center for the Management of Environmental Resources, INSEAD (Fontainebleau: INSEAD, 1 Oct 1993).
[23] Melillo, "The First Green Revolution: Debt Peonage and the Making of the Nitrogen Fertilizer Trade, 1840–1930," 1044-45.
[24] Davis, "Muscle Shoals, Nitrogen and Farm Fertilizers," 159.
[25] "Is it a white elephant or a big tractor?," *The Rural New-Yorker* (New York), 2/6/1921 1921.

Despite the urging of farmers, the expanded capacity of the Muscle Shoals plant was not realized. The plants and corresponding hydroelectric facilities at the Wilson Dam attracted the attention of private interests like Henry Ford who promised to further develop the plants fertilizer manufacturing capacity, but was eventually incorporated into the Tennessee Valley Authority in 1933. To the detriment of its fertilizer manufacturing facilities, the intention of adopting Muscle Shoals into the TVA was to further exploit the hydropower potential of the Tennessee River rather than expand its nitrogen synthesis potential.[26] In addition to this lack of comprehensive public fertilizer manufacturing capacity, private chemical companies kept fertilizer prices high by forming a series of cartels like the International Nitrogen Association that, echoing oil industry tactics, effectively controlled the price of synthetic nitrates through the 1930s.[27]

In the buildup to World War II, demand for nitrates to be used in the manufacture of explosives increased enough to finally cause an expansion of manufacturing capacity, with production in the United States growing to 1.4 million tons per year compared to the 830,000 tons generated in 1932 and Canadian production increasing from 50,000 tons in 1938 to 170,000 tons a decade later.[28] This placed farmers in a difficult position. Wartime pressure on food production and higher crop prices prompted farmers to intensify production by tilling more acres and increasing fertilizer usage while at the same time the manufacturing of gunpowder and explosives limited the amount of fertilizer available for farmers to spread. Fertilizer manufacturers took full advantage of this precarious position, placing prominent ads in the January 1945 issue of Rural New Yorker, urging farmers to "order early," purchasing all their fertilizer for the year before supplies run short. These ads make a great effort to show the chemical companies as a partner to the United States government and farmers in aiding the war effort, referencing the guidance of the War Food Administration in their calls for urgency and even, in the case of the Virginia-Carolina Chemical Corporation, recasting their VC trademark in the patriotic slogan "I'm ready to grow Victory Crops."[29] To the readers of the *Rural New-*

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[26] Preston J. Hubbard, "The Muscle Shoals Controversy, 1920-1932," *Tennessee Historical Quarterly* 18, no. 3 (1959): 196.
[27] Page, ""The greatest victory which the chemist has won in the fight (...) against Nature": Nitrogenous fertilizers in Great Britain and the British Empire, 1910s-1950s," 390.
[28] Potts, *Fluid fertilizers*, 49; Page, ""The greatest victory which the chemist has won in the fight (...) against Nature": Nitrogenous fertilizers in Great Britain and the British Empire, 1910s-1950s," 394.
[29] "Order Early," *The Rural New-Yorker* (New York), 6 Jan 1945, 20; "Take Your Fertilizer Now," *The Rural New-Yorker* (New York), 6 Jan 1945, 14; "I'm ready to grow Victory Crops," *The Rural New-Yorker* (New York), 6 Jan 1945, 10.

Yorker, these advertisements communicated that heavy fertilization wasn't just worth the investment given the high prices fetched for crops during the war, but that partnering with fertilizer manufacturers was a patriotic duty.

World War II's effect of increasing the manufacturing capacity of synthetic nitrates and acquainting farmers with the profit-boosting potential of regular fertilization continued after the declaration of an allied victory. Fertilizer sales in New York state increased steadily from roughly 500,000 tons in 1945 to over 600,000 tons a decade later while prices remained favorable throughout the same period, climbing more slowly than the costs of labor, machinery, and feed.[30] A decade after the end of the Second World War, Cornell University's New York State College of Agriculture, which regularly reported trends in fertilizer supplies, prices, and practices in a dedicated section of their annual *Cornell Recommends for Field Crops* report, declared that "1954 and 1955 marked the first time that dealers have had all the nitrogen fertilizer farmers wanted."[31] As Giovanni Federico argues in his research into the economic history of agriculture, the trend of increased capacity and lower prices would have made nitrogen fertilizer the most economically rational way for farmers to maintain soil fertility and, crucially, to increase farm profits year on year.[32] With fertilizer shortages a thing of the past, the question turned to how to best adjust to this new constant in the fields of New York and the United States.

This chapter investigates how the newfound abundance of synthetic nitrogen called into question ideas of what was considered *natural* farming. Analyzing the debate between proponents of organic agriculture who decried synthetic fertilizer and industrial farmers who readily adopted them will show how the characterization of synthetic fertilizers as "working with Mother Nature" by experts and manufacturers alike caused the *nature* of agriculture itself to be redefined.

A Field for Fanatics

1950 marked the one-hundredth anniversary of the *Rural New Yorker*'s first publication. The paper marked the occasion with a special retrospective issue that included retellings of the history of the paper alongside accounts of the past hundred years of vegetable growing,

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[30] *Cornell Recommends for Field Crops*, vol. 1953 (Ithaca, N.Y.: New York State College of Agriculture, 1952), 18; *Cornell Recommends for Field Crops*, vol. 1957 (Ithaca, N.Y.: New York State College of Agriculture, 1956), 18.
[31] *Cornell Recommends for Field Crops*, vol. 1955 (Ithaca, N.Y.: New York State College of Agriculture, 1954), 19.
[32] Federico, *Feeding the world : an economic history of agriculture, 1800-2000,* 83.

pasturing, and every aspect of agricultural production. The history of fertilization, penned by Vincent Sauchelli, a researcher at the Davison Chemical Corporation, lays out the well-trodden history of soil nutrition: that for most of human history farmers relied on legumes, manure, the signs of the moon, and backbreaking communal labor until Justus von Liebig created phosphorous fertilizer from bones and sulfuric acid. This discovery led to the modern world of today where farmers look to soil surveys and agricultural science to know how much of which fertilizers each crop needs. Sauchelli's history omits Fritz Haber's invention of the nitrogen synthesis process, perhaps out of a postwar sensitivity around German wartime innovation, but he does turn to the global in his closing remarks on the future importance of fertilization. According to Sauchelli, "the pressure of populations all over the world" demonstrates the need for more efficient and productive global agricultural systems, and those systems depended on inexpensive and abundant synthetic fertilizer.[33]

Even beyond this anniversary issue, many contributors to the *Rural New Yorker* in 1950 carry a retrospective interest when it comes to discussing agricultural practices. Some, like Sauchelli look back on the last 100 years of scientific progress with pride and optimism and others with a nostalgia for the rapidly receding past and anxiety around the trajectory of modern industrialized agriculture. This Janus-like division manifests quite clearly within the debate between organic practices and fertilization. W.H.W., a farmer writing from Delaware County, Pennsylvania, dismisses the methods of a New York organic farmer who spreads 20-40 tons of manure per acre in lieu of fertilizer by saying "such a practice today is not practical nor necessary." Responding in a following issue, W.H.K., a proponent of organics from Suffolk County, New York, wonders if you can "find anyone who thinks that the flavor of present day apples is equal to that of New York State apples produced 50 years ago."[34] Both contributors openly recognize the importance of organic matter to continuously productive soil and neither deny that that maintaining soil fertility without synthetic fertilizer is an involved and careful process, but with one looking forward and the other looking behind, each sees the other as blind to the true nature of things. W.H.W. humorously evokes this analogy of blindness in his

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[33] Vincent Sauchelli, "Progress in Fertilizers in the Past One Hundred Years," *The Rural New-Yorker* (New York), 7 Jan 1950, 50.
[34] W. H. W., "Chemical Fertilizers and Organics," *The Rural New-Yorker* (New York), 18 Feb 1950, 217; W. H. K., "Organics Help Flavor," *The Rural New-Yorker* (New York), 18 March 1950, 292.

contribution, comparing proponents of organic agriculture to an old man who cannot see the spots on his apples for need of new glasses.[35]

Picking out these conversations is not an effort to determine which side is correct but to understand how farmers in similar situations came to such strong and opposing views of agricultural practice. The anxiety of the organic farmer is clear: over the course of a few decades, agriculture had transitioned from an occupation in constant conversation with natural limits where manure and wheat straw needed to be carefully collected and reintroduced into the soil, to an occupation of unlimited plenty where, as long as a farmer could afford to invest in fertilizer and did not let their soil blow away, they could come away harvesting a profit. Organically inclined farmers were suspicious of this simple substitution. For them, fertilizer was too easy a solution and whether it was earthworms, humus, health, or taste, they felt something had to be missing.

This suspicion couldn't have only been shared by organic producers as it was strong enough to form the backbone of Chilean Nitrate marketing tactics during the immediate postwar period. During and following WWII, sodium nitrate from Chile's Atacama Desert was marketed as "*Natural* Chilean Nitrate" alongside ad copy claiming "Chilean Nitrate of Soda was created by tremendous *natural* processes. It is completely natural… the only *natural* nitrate in the world" (emphasis in original).[36] Because farmers still categorized sodium nitrate an *artificial* fertilizer and most organic farmers would have preferred to use organic fertilizers like manure and legume crops, its boosters thought it useful to boast of its origins in the mines of the Chilean desert to differentiate it from the increasingly available *synthetic* nitrogen generated by the Haber-Bosch process. Chilean nitrate does have natural advantages for the farmer, like the 34 minor nutrients its advertisements say it provides to plants, but it had natural limits to those attempting to profit from its sale. Its most notable limit is that its extraction relied on a great deal of human labor who, like coal miners, could sabotage the system of extraction and export by withholding their labor, a topic explored in Melillo's history of nitrate extraction in Chile and Peru.[37] Synthetic nitrogen, on the other hand, could be manufactured domestically and substituted human labor for an uninterrupted stream of cheap fossil energy, leaving Chilean nitrate at a disadvantage in the

[35] W., "Chemical Fertilizers and Organics," 217.
[36] "The Great Pasteur Never Saw Chile's Nitrate Desert, But...", *The Rural New-Yorker* (New York), 3 Feb 1945, 67.
[37] Melillo, "The First Green Revolution: Debt Peonage and the Making of the Nitrogen Fertilizer Trade, 1840–1930," 1042.

burgeoning postwar fossil economy. The substitution of human labor for fossil energy reflects Timothy Mitchell's observation that oil's ability to flow under its own pressure allowed for the skilled human labor that was so essential to coal extraction to be eliminated from the accumulation of fossil energy.[38]

If proponents of organics were anxious about losing the intangible pieces of older agricultural practices, then the forward-looking farmers who felt compelled to defend the use of fertilizer must have feared the return of certain aspects of older agricultural regimes. It wasn't only, as Sauchelli put it, "the dung pile and peasantry," that farmers hoped to escape, but the looming specter of hunger and starvation.[39] In a December 1950 testimony before a special House committee, Dr. Richard Bradfield, head of Cornell's Agronomy department called claims that fertilizer could be bad for American health "nonsense."[40] To back up his dismissal, Bradfield claimed that the healthiest nations (the United States, Scandinavia, Belgium, and the Netherlands) are the ones who use the most synthetic fertilizer where the unhealthiest nations (Latin America, Asia, and Africa) rely on manure and legumes, which he refers to as organic fertilizers. Bradfield explained that it wasn't the lower quality of organic fertilizer but its scarcity that led national health to suffer due to the prevalence of starvation.[41] There were certainly larger divides between the Global North and the Global South at the time than fertilization practices, but for proponents of modern fertilization practices, all of these cultural and economic differences were contained in the idea of hunger. As Nick Cullather discusses in his research on the politics of the Green Revolution, the United States and its farmers had won the war by adopting the technological regime of synthetic fertilizer, and those who opposed it were not simply stuck in the past, they were against a system of agricultural diplomacy built on an entirely new, simpler and more rational kind on nature.[42]

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[38] Melillo, "The First Green Revolution: Debt Peonage and the Making of the Nitrogen Fertilizer Trade, 1840–1930," 1504; Timothy Mitchell, *Carbon democracy : political power in the age of oil* (London: Verso, 2011), 36.
[39] Sauchelli, "Progress in Fertilizers in the Past One Hundred Years," 50.
[40] Harry Lando, "Washington Outlook," *The Rural New-Yorker* (New York), 16 Dec 1950, 875.
[41] Lando, "Washington Outlook," 857.
[42] Cullather and American Council of Learned Societies., *The hungry world America's Cold War battle against poverty in Asia*, 70.

Natural Nitrate

In the debate between organic and synthetic agriculture, there are contributors that find themselves somewhere in between and are able to identify with aspects of both perspectives. Herman A. Bennick is one of these people, a regular contributor to the *Rural New-Yorker* who wrote a series of columns in the late 1940s and early 50s called "European Episodes" where he lends his unique perspective as a farmer from the Netherlands to the paper's Northeastern American audience. His column in the March 18, 1950 issue recounts his personal history with fertilizer, growing up listening to his father share what he had heard about the *learned* German man, Justus von Liebig. Bennick is sympathetic to the organic cause and is willing to accept that the overzealous use of synthetic fertilizers may adversely affect the microbiological life within the soil and laments the need to "increase and increase again" the amount of fertilizer used to keep the soil at its former levels of productivity. But even in recognizing how use of fertilizers may have harmed the soil on which he derives his livelihood, Bennick does not characterize synthetic fertilizer as detrimental:

> I cannot see the chemical fertilizing elements as poison. When the wise Creator deposited huge layers of potash in Germany, phosphate in North Africa, nitrate in Chile and nitrogen in our air, we can accept that this was done with a purpose and, to the blessing of mankind in the end of the last century, Justus von Liebig apparently found that purpose.[43]

This is the unique position of synthetic fertilizer that contributed to its wide acceptance: its elemental simplicity combined with the benevolent role of providing nutrients to plants and by extension humans, elevates it above other chemical products like pesticides and food additives that were more readily criticized during the same time. For instance, during the same hearing in which Dr. Bradfield dismissed fertilizer's negative effects, food additives were found to endanger consumer health and pesticides were deemed "poisonous if improperly used."[44] Where pesticides and herbicides were easy to villainize as agents of death, and food additives were unfamiliar synthetic products worthy of suspicion, synthetic fertilizers avoided scrutiny as

[43] Herman A. Bennick, "European Episodes Part xviii: For Land's Sake," *The Rural New-Yorker* (New York), 18 March 1950, 302-03.
[44] Lando, "Washington Outlook," 857.

they were made up of the same molecules as organic fertilizers and were used to increase life rather than extinguish it. Despite looking with a critical eye, Bennick sees fertilizers as a uniquely benevolent gift, bestowed upon the Earth by the hand of a Christian God, and revealed to us by the hand of the scientist, von Liebig in his telling. This combination of religion and science was useful to the United States' newfound ambitions for conquering the world's hunger problem: the invocation of the divine connects the colonial ambitions of the Guano Islands Act to other religiously justified colonial projects like America's expansion under the premise of Manifest Destiny. This is especially notable in Bennick's attribution of the world's phosphate and nitrate deposits, notably those in the Global South, as belonging to mankind rather than their respective nations. The invocation of science also serves to cast the use of synthetic fertilizers as the uniquely modern, intellectual, and therefore Western, form of agriculture. For instance, ad copy and the rhetoric of the *Rural New-Yorker*'s contributors, often mentions fertilizer in the same breath as "book farming" soil retention methods like contour strips, windbreaks, and crop residue. This characterizes fertilizer use as an essential best practice of the well-educated farmer.[45] Even Chilean nitrate's boosters sought to benefit from the association of their *completely natural* product with modern western science by associating Chile's sodium nitrate deposits with the father of pasteurization, Louis Pasteur. Though Pasteur did not play a role in discovering or exploiting Chilean nitrate, advertisers still attempt to connect his innovation to their product by claiming that his bacterial research may provide an explanation for the origins of Chile's nitrate deposits.[46]

If nitrogen was divinely bestowed in the atmosphere and scientifically isolated by the Haber-Bosch process, the rhetorical allure of synthetic fertilization was not that it allowed farmers to escape from the natural constraints and complications of nutrient cycling, as proponents of organics may have viewed it, but to reorganize and simplify the metabolic processes of agricultural production to make them more rational and efficient. According to our organics-skeptic opinion writer W.H.W., synthetic nitrates were not really foreign to the soil but instead were the pure concentrated form of the same nitrates to which all organic materials

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[45] Sauchelli, "Progress in Fertilizers in the Past One Hundred Years," 52; Roy L. Warren, "Soil Improvement Dividends," *The Rural New-Yorker* (New York), 16 Sept 1950, 674; "Armour's Big Crop Fertilizer Pays Off in Your Farm Program!," *The Rural New-Yorker* (New York), 1 Dec 1945, 564.
[46] "The Great Pasteur Never Saw Chile's Nitrate Desert, But...", 67.

eventually breaks down.[47] As Giovanni Federico claims, the many interfaces between metabolic and geological processes that make agriculture what it is prevent agriculture from fully modernizing in the sense that farmers would be able to separate themselves from “nature.” [48] In his book *We Have Never Been Modern*, Bruno Latour characterizes modernization as an effort to separate human action from the constraints of nature. Latour theorizes that these efforts to disentangle ourselves only serve to embed us more deeply in geophysical processes, creating hybrids of humanity and nature like the deterioration of the ozone layer or the proliferation of ocean microplastics.[49] Agriculture has always been a tangle of human intention and ecological processes and farmers in the postwar decades would have understood that their intervention into the nutrient cycling of the soil would take the form of a Latourian hybrid, just as other interventions like the incorporation of manure or Chilean nitrate had. The rhetorical project of justifying synthetic fertilizer as *natural* was therefore an effort to use this tangle of cultural technology and environmental dynamics to broaden the scope of what was considered natural to include scientific and industrial interventions like synthetic fertilizers.

The promise of synthetic agriculture was not to liberate the farmer from nature but to liberate nature from the *dung pile and peasantry*; to make the biological processes on which agriculture relied cleaner and simpler. This cleaner kind of agriculture could be more easily scaled and exported around world to face the looming food crises Sauchelli alludes to. This modern remaking of nature is reflected in the names of new synthetic fertilizer formulas that flash across the pages of the *Rural New-Yorker* during the 50s and 60s, like “Gro-Green Liquid Fertilizer and Nitrogen Nutrients” and fertilizer from “’NA-CHURS’ Plant Food Company.” Like the image of a bucolic field or a smiling cow pasted on a tin of vegetables, these hyphenated brands serves to evoke a product that is of a different nature, a friendly, sanitized nature custom built for the modern industrial world.[50]

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[47] W., "Chemical Fertilizers and Organics," 217.

[48] “In spite of technical and institutional progress, agriculture has retained some peculiarities, mainly relating to its unique relationship with the environment…” Federico, *Feeding the world : an economic history of agriculture, 1800-2000*, 222; Bruno Latour, *We have never been modern* (Cambridge, Mass.: Harvard University Press, 1993), 11.

[49] Latour, *We have never been modern*, 11.

[50] "Make $75 - $200 weekly," *The Rural New-Yorker* (New York), 1 Jan 1955, 4; "Grow The Best Crops with "NA-CHURS" Liquid Fertilizer," *The Rural New-Yorker* (New York), June 1965, 1.

Conclusion

Firman E. Bear, head of Rutgers University's Soil Department in New Jersey writes in the 1942 edition of his textbook *Soils and Fertilizers*, which is listed as recommended reading in several issues of the *Rural New-Yorker*, "if the problem of the economy of nitrogen has been solved, the task of maintaining the soil at a high level of productivity has been very materially simplified."[51] Though Bear uses the term *economy* to refer to the ability to retain nitrogen in the soil and minimize loss to leaching, the economy of nitrogen in the postwar period increasingly came to mean the profit a farmer could gain by liberally fertilizing their soil. This shift in meaning follows the abrupt shift in scarcity that came with wartime increases in synthetic nitrate manufacturing capacity. Before the dawn of the 20th century, and even before the Second World War, nitrogen would have been the most common limiting nutrient according to Liebig's law of the minimum across most soils. With expanded access to cheap nitrates synthesized from the Earth's atmosphere, nitrogen, over the course of a couple decades, became the most abundantly available nutrient and farmers found themselves living in that simplified version of agriculture Bear spoke of.

However, just as plants need energy from the sun to build their bodies from nutrients in the soil, the ability to break atmospheric nitrogen's triple bonds in order to form nitrates suitable for plant consumption came with a large energetic cost. Though the first venture into nitrogen synthesis in the United States was tied to the Congress's hydroelectric developments along the Tennessee River during World War I, even by the late 1920s the manufacture of synthetic nitrogen was more closely associated with fossil energy in the form of coal.[52] Though the abundance of synthetic nitrates seemed to literally materialize out of thin air, the high manufacturing capacity that allowed for the radical simplification of agriculture depended on an abundant supply of inexpensive fossil energy, initially from coal and later from gas and oil This underwriting of agricultural productivity by the infusion of fossil energy is repeated across agricultural industrialization, turning agricultural landscapes from net energy sources to net energy sinks as discussed in Germán Vergara's research on fossil fuel's role in the industrialization of Mexico.[53]

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[51] Firman E. Bear, *Soils and Fertilizers*, 3rd ed. (New York: John Wiley & Sons, Inc., 1942), 169.
[52] Davis, "Muscle Shoals, Nitrogen and Farm Fertilizers," 164.
[53]Germán Vergara, *Fueling Mexico : energy and environment, 1850-1950,* Studies in environment and history, (Cambridge, United Kingdom ; New York, NY: Cambridge University Press, 2021), 203.

Disagreements between adherents to organic agriculture and proponents of fertilization in the pages of the *Rural New-Yorker* can be seen as conflicts between an older system of economy defined by natural environmental limits and a new economic system defined by limitless growth of both profit and plants supported by inexpensive and abundant supplies of fossil energy. Timothy Mitchell's research on the societal impacts of fossil energy shows that this economic system of unlimited growth was itself dependent on the rise of the seemingly endless supply of oil as a major commodity.[54] Crucially, the simple and benevolent character of synthetic nitrate *naturalized* this system of limitless growth, reshaping ideas of what were considered natural best practices around the new phenomenon of nitrogen abundance. The "great powerful tractor" hoped for by the 1921 contributors to the *Rural New-Yorker* did not come in the form of Congressional support for the nitrate plant at Muscle Shoals, but it arrived nonetheless – turning over the agricultural landscape of New York and the United States as a whole.

[54] Mitchell, *Carbon democracy : political power in the age of oil*, 176.

Fertilizer Facts: Sources of Agricultural Expertise

Introduction

The wide adoption of synthetic fertilizers not only changed the way in which agricultural landscapes were understood, but also the primary sources of agricultural knowledge and its methods of dissemination. In New York State, Cornell University's agricultural extension offices, the USDA, and even fertilizer manufacturers took on a new roles in determining and disseminating best practices for all aspects of farming including methods of maintaining and increasing soil fertility. The reason for this expanded role has much to do with the changing relationship of the farmer to the farm and its soil.

As established in the previous chapter, the rise of synthetic nitrogen fertilizer reimagined the nature of soils as something clean and elemental rather than complex, biological, and tied to natural limits. The nature of soil became one that was best understood in the scientific language of chemistry and the economic language of inputs and outputs, languages that would have been foreign to many farmers. In the preface to the 1942 edition of *Soils and Fertilizers*, author Firman Bear clarifies that the reader should be "familiar with the ordinary vocabularies of [chemistry, botany, geology, and physics]" in order to grasp the nuances of soil management discussed in its pages.[55] The United States Department of Agriculture, whose regularly published *Farmers' Bulletin* had previously focused on the nuances of raising particular crops or livestock, began publishing issues in the 1950s on how to cut costs and increase profits on the farm in light of the fact that "knowledge of the simple principles of business management is becoming as essential a part of the farmer's 'stock in trade' as his familiarity with modern techniques of crop and livestock production."[56] Synthetic fertilizer recharacterized soil as something that was best understood through the languages of chemistry and economics, languages in which farmers needed to gain fluency.

New understandings of the soil were not the only force driving farmers to adopt a new way of seeing and managing their farms, nor were they the first. Deborah Fitzgerald's research on the industrialization of agriculture in the United States addresses the efforts of agricultural

[55] Bear, *Soils and Fertilizers*, vii.
[56] Neil W. Johnson and Metron S. Parsons, *Planning the Farm for Profit and Stability*, (Washington D.C.: U.S. Department of Agriculture, 1956), 32.

engineers to rationalize agricultural production starting in the first half of the 20th century. Fitzgerald demonstrates how the efforts of agricultural engineers to efficiently arrange farm buildings and the introduction of agricultural machinery brought industrial concerns like labor efficiency to the farm.[57]

Despite its gradual industrialization, farming remained a relatively independent line of work. Where a factory worker had their position's physical parameters, responsibilities, and quotas set by a manager or executive, farmers were in charge of implementing modern and scientifically verified business practices on their own farms. As Fitzgerald's research shows, the industrialization of farming during first half of the 20th century left the farmer with less time on their hands rather than more – making it difficult for them to implement best practices on their own, even if they wanted to.[58] In the August 1945 issue of the *Rural New-Yorker*, Ed Rhodes, a farmer in Big Flats, New York lamented that "these days we have too little time to visit our neighbors, although we could probably learn better ways of doing our farming if we would visit them." Rhodes shares many of the same interests as the agricultural engineers in Fitzgerald's research, labor saving methods and efficient arrangement of farm buildings, but felt cut off from the farm-to-farm knowledge networks he had previously relied upon.[59]

Without the aid of these networks, farmers turned to a variety of external resources to make sure all aspects of the farm, including the soil and the crops themselves, were operating as efficiently as possible. The network of institutions farmers came to rely on, the agronomists, engineers, and economists working for state extension services, dealers and manufacturers, characterized synthetic nitrogen as Mother Nature's reward, won through the efforts of science and prescribed with the aid of scientific methods like soil tests and farm experiments. The scientific rigor with which fertilizers were handled made synthetic fertilizers the ultimate symbol of agricultural innovation, one that innovative farmers and several companies were proud to associate themselves with.

This chapter will show how the reconstruction of soil fertility around synthetic fertilizer forged a new support network to replace the farm-to-farm network Ed Rhodes refers to. This network included educational institutions, government experts, and companies who promoted the

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[57] Fitzgerald, *Every farm a factory : the industrial ideal in American agriculture*, 89.
[58] Fitzgerald, *Every farm a factory : the industrial ideal in American agriculture*, 118.
[59] L. H. W., "In Tune with the Times," *The Rural New-Yorker* (New York), August 1945, 364.

use of scientifically vetted fertilizers and nutrient management strategies to farmers. The chapter will also address how new fertilizer regime and forms of knowledge also fundamentally changed the relationship of farmers to the soil and to their own labor.

Data Collection

The push for farmers to adopt modern techniques, master the business principles, and gain fluency in scientific vocabulary often appeared alongside a denouncement of previous or different ways of running or advising the farm. In the USDA Farmers' Bulletin issue *Planning the Farm for Profit and Stability*, authors Neil Johnson and Metron Parsons warned that "relatively few farmers make a formal plan by the methods described in this bulletin… [In] areas where nature is not so bountiful and in periods of great instability it would pay most farmers to examine their farm business more closely."[60] The 1956 edition of Cornell University's annual pamphlet *Cornell Recommends for Field Crops* declared that "a farmer who sticks to the old practices… is severely handicapped as compared with the well-informed farmer who uses wisely the best combination of cropping practices."[61]

Knowing the soil in a specific and measurable way, that is through the lens of industrial fertility management, would require an immense data gathering project conducted by agricultural universities like Cornell and farmers alike. Soils in New York had long been characterized as poor yielding. The most commonly cited reason was how long they had been continuously used for farming. As the site of the United States' first colonies, northeastern soils were the longest cultivated in the nation and had already become "badly run down because of lack of fertilizers" by the time of the American Revolution.[62] Farmers understood that continuous cropping without attempts to reintroduce organic matter and soil nutrients would cause soil productivity to decline, but agricultural experts characterized traditional strategies employed to maintain soil fertility; leaving acres fallow, turning under green manure crops like clover, and incorporating manure and urban waste into the soil, as insufficient to keep up with the intensity of agricultural production.[63]

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[60] Johnson and Parsons, *Planning the Farm for Profit and Stability*, 32.
[61] *Cornell Recommends for Field Crops*, Vol. 1955, 1.
[62] Ulysses P. Hendrick, "Agriculture In New York State," *The Rural New-Yorker* (New York), 7 January 1950, 38.
[63] Hendrick, "Agriculture In New York State," 38; William A. Albrecht, "Soils and Their Minerals: How They are Influenced by Time," *The Rural New-Yorker* (New York), 7 January 1950, 56.

This gap in productivity was attributed to the composition of the soil itself. New York State's soil was generally characterized as podzolic, referring to the leaching of minerals from the upper layer of the soil by acidic rainwater over time, leaving soils acidic and nutrient poor.[64] Additionally, much of New York State's soils derived from parent materials with very little limestone, leaving them more prone to acidity, which was intolerable for certain crops like wheat.[65] Firman Bear describes soil composition differences as reflecting "the adaptabilities of soils to various crops and… their relative capacities to produce the same crop."[66] Farmers and farm researchers alike found the northeast's podzolic soils, combined with the region's cool moist climate, suitable to growing permanent pasture grasses for dairy cows.[67] However, most discussion of New York's soils more often emphasized the "relative capacities to produce the same crop," part of Firman Bear's characterization, comparing New York's ability to yield crops like corn and wheat to that of other soils like the Midwest's prairie soils. The map from *Soils and Fertilizers* shown below contrasts the East and West of the United States, with the West's rocky and sandy soil being too low in organic matter and clay to be agriculturally productive. Soils in Eastern states including New York are too weathered with too much clay and acidity to be productive. Midwestern soils are shown as the happy medium at the peak of the productivity bell curve with high levels of organic matter and clay and low acidity. Though the map depicts different soil types within regions of the United States, the overlaid bell curve and line graphs serve to simplify the nation's highly variable landscape to a series of continuities. (Fig. 1) [68]

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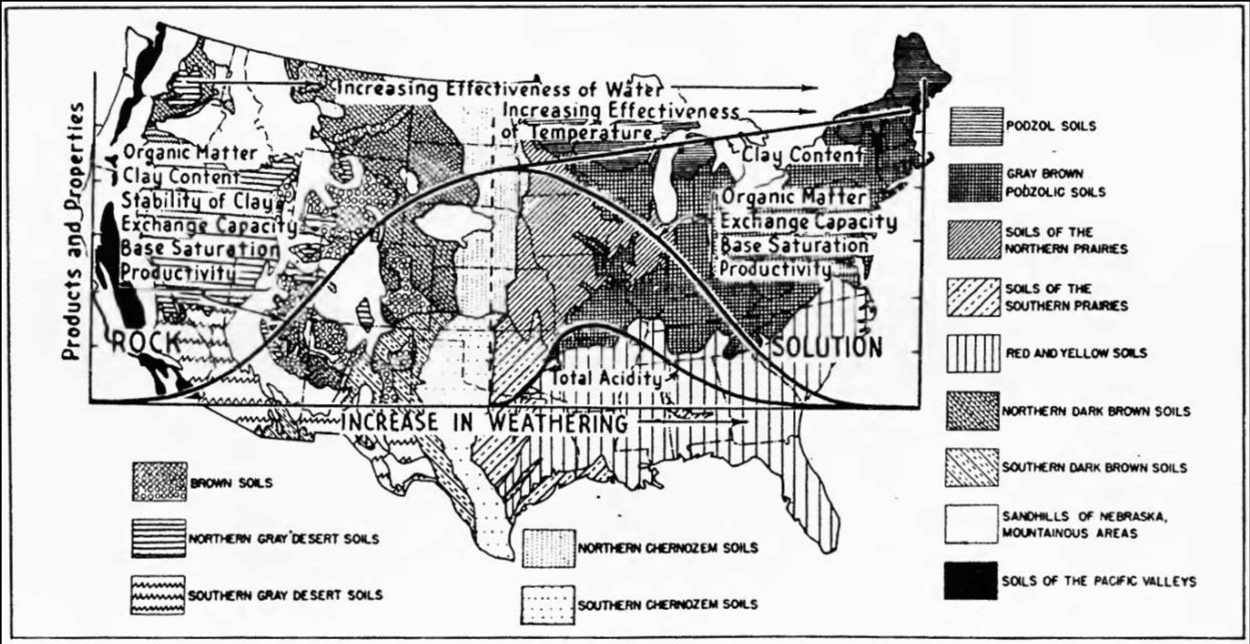
[64] Bear, *Soils and Fertilizers*, 44.
[65] *Cornell Recommends for Field Crops*, vol. 1951 (Ithaca, N.Y.: New York State College of Agriculture, 1951), 14; Bear, *Soils and Fertilizers*, 109.
[66] Bear, *Soils and Fertilizers*, 36.
[67] Martin R. Cooper, *Getting started in farming*, 2nd, (Washington D.C.: U.S. Department of Agriculture, 1957), 4.
[68] Albrecht, "Soils and Their Minerals: How They are Influenced by Time," 56.



The curve shows soil development in terms of the soil's support of higher animal life. The increasing rainfall, in going from west to east, means better soi's to feed us until it brings on soil acidity, or fertility removal, which is east of the 97th meridian. Only the mid-continent supported the meat-producing bison originally. Today it is providing the high protein wheat and beef cattle.

Figure 1: Map published in the *Rural New-Yorker* showing the variable effectiveness of United States soil in supporting animal life. The Northeast's soils are portrayed as being acidic, weathered, and lacking in organic matter when compared to the Midwest.[69]

The application of soil amendments in the form of lime and fertilizer were an obvious solution to New York soil's perceived deficiencies and long history of agricultural exploitation. Throughout the 1940s and 50s, the USDA completed a national soil survey, giving extension officers and farmers a detailed depiction of the variability of soil nutrients and composition within a county and even on a single farm. Cornell's extension service used this information, alongside the ever increasing number of soil tests aggregated by Cornell, to prescribe dosages of fertilizer and lime to bring each farm's soil into optimum productivity, rather than to dictate which acres are best suited to which agricultural practices.[70] In other words, a detailed understanding of the heterogeneity of soil composition and fertility served only to guide farmers in how to most efficiently bring New York's agricultural land up to a homogeneous standard of high productivity. This contradictory thrust towards rationalization relied upon the continuing

[69] Albrecht, "Soils and Their Minerals: How They are Influenced by Time," 56.
[70] Bear, *Soils and Fertilizers*, 39; *Cornell Recommends for Field Crops*, vol. 1960 (Ithaca, N.Y.: New York State College of Agriculture, 1960), 4.

availability of inexpensive nitrogen fertilizer at prices low enough that farmers would still be able to make a profit while purchasing large amounts of fertilizer.

Soil tests were the primary tool used by extension agents to advise farmers how to fix their soil. Farmers were directed to take soil from various areas and depths of their field and send them into Cornell University's testing laboratory to be analyzed. Though crops like rye, soybeans, oats, and clover could tolerate more acidic soil conditions, farmers attempting to grow wheat and corn had more difficulty with New York State's acidic soil. The solution to this problem was the addition of crushed limestone, more regularly referred to as lime, in order to increase soil pH to a more tolerable level.[71] Tests for soil acidity, "just what the farmers had been looking for," according to a county agent quoted in Cornell University's *Cornell Recommends For Field Crops*, were first introduced during the 1952 farming season. Farmers had already steadily increased their use of limestone, applying 900,000 tons in 1951 compared to 100,000 tons in 1934, but a soil test would allow farmers to see the acidity of their fields for themselves rather than relying on Cornell's generalized calls for "more lime."[72]

These pH soil tests were followed by the introduction of potassium and phosphorous tests in 1953 and total organic matter in 1954. Cornell's soil testing laboratory was expanded to allow for the greater influx of tests in 1954 and again in 1957. Annual soil tests increased from 1800 in 1950 to over 50,000 eight years later.[73] Interestingly, Cornell never introduced a soil test for nitrate, since the nutrient's tendency to be washed out of soil if it was not immediately taken up by plants made an accurate laboratory soil test impossible. Despite this, Cornell still reported nitrate suggestions alongside soil test results, extrapolating the recommended amount of nitrogen to be applied from cropping histories farmers submitted with their soil tests. Despite soil tests being a highly specific and individualized form of analysis, Cornell published aggregated soil test and nitrogen data annually in *Cornell Recommends for Field Crops* alongside generalized recommendations for the state based on the year's results.[74]

In his research on sources of agricultural expertise, Frank Uekoetter has discussed the large uncertainties in soil testing methodology, most notably that soil nutrient concentrations can

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[71] Bear, *Soils and Fertilizers*, 109.
[72] *Cornell Recommends for Field Crops*, Vol. 1952, 14.
[73] *Cornell Recommends for Field Crops*, Vol. 1957, 19; *Cornell Recommends for Field Crops*, vol. 1954 (Ithaca, N.Y.: New York State College of Agriculture, 1953), 21; *Cornell Recommends for Field Crops*, Vol. 1953, 19; *Cornell Recommends for Field Crops*, vol. 1961 (Ithaca, N.Y.: New York State College of Agriculture, 1961), 28.
[74] *Cornell Recommends for Field Crops*, Vol. 1961, 28.

vary considerably across a field's surface and at different depths.[75] This uncertainty did not go unacknowledged in the resources available to New York farmers. Firman Bear, writing in 1942, cautions that soil sampling should be done "under the direction of someone who appreciates the limitations of the quantitative method of study" and ultimately advises that a soil test should be evaluated alongside a superficial observation of soil color, texture, and general knowledge of which crops grow well in the area.[76] *Cornell Recommends…* describes how the university's phosphorous test is "reliable in the upper range, but is difficult to interpret at low levels" and caution farmers to carefully follow written instruction and sample "from areas which represent the true field conditions."[77] However, as Cornell's soil testing program increased in size, acknowledgements of uncertainty appeared with less frequency, as did the associated scientific rigor of the laboratory with the introduction of tests the farmer could conduct and interpret themselves in 1959.[78]

It is unclear how farmers' production decisions would have been guided by insights gained from the battery of soil tests and maps available to them. Cornell indicates that a soil test showing a high concentration of a certain nutrient, would tell farmers that "emphasis should be placed on other nutrients," but the aggregated data published by Cornell never includes an instance when farmers are seen to be applying too much of a specific nutrient.[79] In the case of lime, New York's first soil test and primary soil amendment, soil tests never resulted in a change to Cornell's recommendation to use more lime, even over a decade after the first soil test were rolled out. Instead, limestone was recast as an aid to fertilizer efficiency rather than to the plants themselves, with "Lime Makes Fertilizer Pay" written boldly on the 1959 soil tests (Fig. 2).[80] As popular as the individualized analyses of soil tests became over the 1950s, their adoption appears to be most useful as a tool to familiarize farmers with an increasingly abundant use of fertilizers rather than a detailed description of a field's character.

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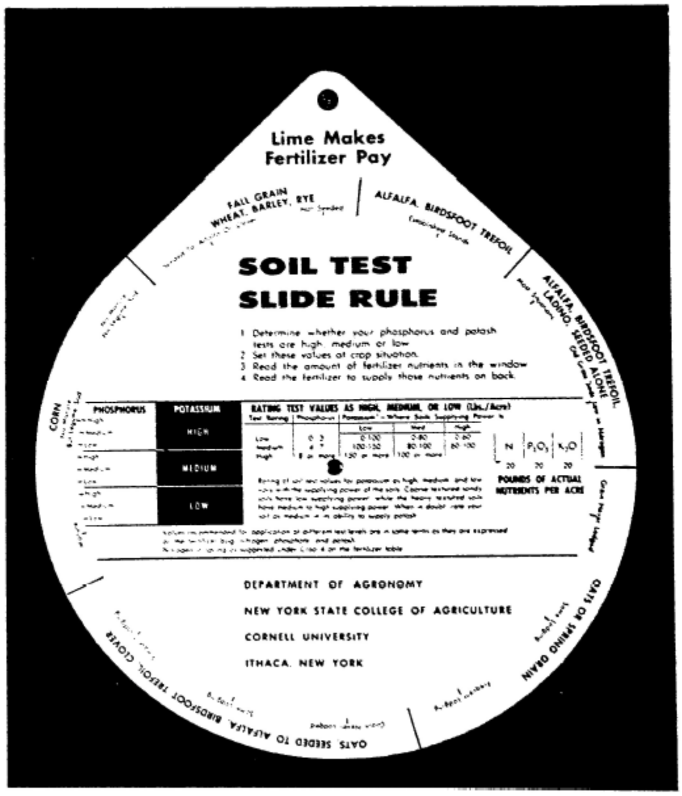
[75] Frank Uekoetter, "Know Your Soil: Transitions in Farmers' and Scientists Knowledge in Germany," in *Soils and societies : perspectives from environmental history*, ed. John Robert McNeill and Verena Winiwarter (Isle of Harris: White Horse Press, 2006), 332.
[76] Bear, *Soils and Fertilizers*, 53-54.
[77] *Cornell Recommends for Field Crops*, Vol. 1954, 21; *Cornell Recommends for Field Crops*, Vol. 1953, 19.
[78] *Cornell Recommends for Field Crops*, vol. 1959 (Ithaca, N.Y.: New York State College of Agriculture, 1959), 19.
[79] *Cornell Recommends for Field Crops*, Vol. 1953, 19.
[80] *Cornell Recommends for Field Crops*, Vol. 1959, 3.



Soil test slide rule helps farmers interpret their own soil test results

Figure 2: Soil test key from Cornell's Department of Agronomy, used by farmers to interpret the results of their soil tests. "Lime Makes Fertilizer Pay" is written at the top of the key to emphasize the importance of limestone to managing soil acidity.[81]

The final analytical tool the extension service used to inform farmers was the agricultural experiment. Cornell University's experiment stations in Ithaca and Geneva, New York were established in 1879 and 1923 respectively and conducted research into crop breeding, pest prevention, and all aspects of agriculture.[82] The stations' experiments into fertilizer use reflect the traditional field experiments described by Frank Uekoetter in his chapter *Know Your Soil*, where plots of the same crop were given different combinations of a standard dosage of nitrogen, phosphorous, and potassium, with the control getting no fertilizer at all. As Uekoetter explains, these experiments "showed whether the individual nutrients contributed significantly to plant growth, but did not allow any conclusion on the amount needed."[83] Pictures of these experiments

[81] *Cornell Recommends for Field Crops*, Vol. 1959, 3.
[82] W. I. Myers and W. B. Ward, "New York State College of Agriculture," *The Rural New-Yorker* (New York), 7 January 1950, 62.
[83] Uekoetter, "Know Your Soil: Transitions in Farmers' and Scientists Knowledge in Germany," 331.

are scattered throughout the pages of *Cornell Recommends for Field Crops*, a stunted bunch of pasture that has received no fertilizer next to another bunch that has received a hefty dose of nitrogen fertilizer and is flourishing as a result (Fig. 3).[84] The experiments showcased in the bulletin do not make an effort to compare different dosages, analyses, manufacturing processes, or alternate sources of nutrients like manure or green manure crops. As with the soil maps and soil tests, the primary takeaway from Cornell's fertilizer experiments is that more fertilizer will allow farmers grow more abundant crops. Whether the method is soil tests, soil surveys, or agricultural experiments, the primary goal of the extension service when it came to soil fertility management was to help farmers become more comfortable with the abundant application of synthetic fertilizers. Associating synthetic fertilizer with the credibility of laboratory and field research also served the interests of fertilizer manufacturers and advertisers as well as advertisers for other agricultural products.

[84] *Cornell Recommends for Field Crops*, vol. 1958 (Ithaca, N.Y.: New York State College of Agriculture, 1958), 19.

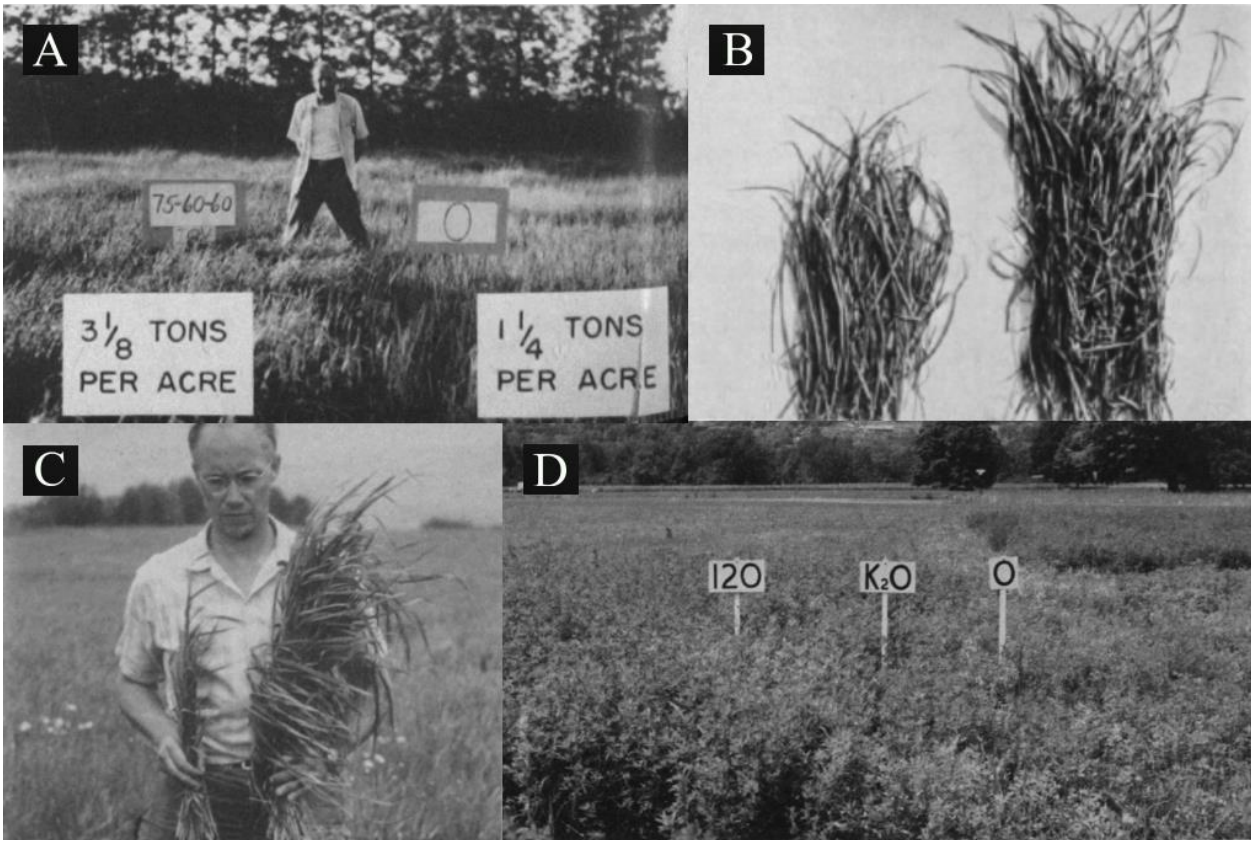


Figure 3: Images of fertilizer experiments conducted at Cornell's agricultural experiment stations. A) Timothy grass meadow: left treated with 70lbs nitrogen, 60lbs phosphorous, and 60lbs potassium and right received no fertilizer.[85] B) Smples of orchardgrass: left grown without nitrogen, right with nitrogen.[86] C) Samples of timothy: Both received 50lbs/acre each of phosphorous and potassium. Left received no nitrogen, right received 75lbs/acre nitrogen.[87] D) the "vigorous" alfalfa on the left recieved 120lbs/acre of potash where the "thinning" alfalfa on the right recieved none.[88]

Marketing Modernity

It is worth noting that the intended audience for bulletins like *Cornell Recommends for Field Crops* were leading farmers, farm advisors, and dealers who would have guided farmers on which fertilizers and other supplies would most benefit their crops. It makes sense then that the recommendations contained in these bulletins privileged information that would allow dealers to sell more fertilizers as opposed to experiments into alternatives means of maintaining soil fertility.

[85] *Cornell Recommends for Field Crops*, Vol. 1957, 18.
[86] *Cornell Recommends for Field Crops*, vol. 1956 (Ithaca, N.Y.: New York State College of Agriculture, 1955), 20.
[87] *Cornell Recommends for Field Crops*, Vol. 1958, 18.
[88] *Cornell Recommends for Field Crops*, vol. 1962 (Ithaca, N.Y.: New York State College of Agriculture, 1962), 26-27.

Dealers were not the only people to benefit from the scientific methods associated with experiment stations. Fertilizer manufacturers drew explicit attention to extension agents in their advertisements, prompting farmers to get in touch with their county extension office or seek out a soil test in order to "select the fertilizer best suited to your soil needs."[89] The effort of manufacturers to associate themselves with the scientific rigor of the agricultural extension demonstrates that manufacturers were willing to stake their profits on the fact that extension services would, in most cases, recommend more fertilizer be used rather than less. That being the case, there was a fair chance their product would be the one within reach when the farmer went to pick up more fertilizer. Manufacturer Agrico even went as far as duplicating the work of Cornell's soil test lab, promising to send a company agronomist to potential clients in order to conduct soil tests and give farmers personalized fertilizer recommendations.[90]

The allure of scientific soil management techniques was so powerful that unrelated agricultural advertisers sought to associate their own products with the scientific rigor of the experiment station and the soil test. The New York Artificial Breeders' Cooperative used an advertisement in the April 1965 issue of the *Rural New-Yorker* to associate their herd analysis services with the scientific rigor of a soil test:

> When you use the right fertilizer and lime—in just the right amounts—you get the most out of your soil. And to get the most out of your herd, you should analyze your herd breeding program.[91]

The Ford Motor Company's *Ford Almanac* is the most extreme example of this. Beginning in 1954, Ford worked with John Strohm, associate editor of the *Country Gentleman* farm magazine, to produce an annual series of nontraditional almanacs filled with stories on innovation-focused topics like atomic crop breeding, labor-saving gadgetry, and countless stories on the promises of fertilization.[92] With all of its pages of helpful tips and tricks, the Almanac still

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[89] "quality pasture fertilizer gives you extra value," *The Rural New-Yorker* (New York), 18 Feb 1950, 221; "Before You Buy a Pound of Fertilizer," *The Rural New-Yorker* (New York), 20 Feb 1960, 14-15.
[90] "Discover your soil's real grow power with the Agrico Program of sound fertilizer recommendations," *The Rural New-Yorker* (New York), February 1965, 114; "The Agrico Difference...", *The Rural New-Yorker* (New York), March 1960, 24-25.
[91] "It Always Pays to Analyze," *The Rural New-Yorker* (New York), 2 April 1955, 255.
[92] *The Ford Almanac*, ed. John Strohm (New York: Simon and Schuster, 1954).

partly functioned as advertising for Ford with the center section of each issue devoted to showcasing Ford's newest car and truck models in country settings. But the larger intention of the *Ford Almanac* was to sell an idea of farm life that centered on the farmer as an innovator, an essential part of the agriculture industry, tinkering with industrial products like fertilizers, tractors, and pesticides to make them more efficient and find additional opportunities for their use.[93]

Ford highlighted farmers who embodied this ideal of the innovative efficient grower with their annual Efficiency Awards which were promoted in the *Ford Almanac* as well as the *Rural New-Yorker*. The awards were given to growers of different major crops who came closest to or exceeded the goals set in the Almanac for highest bushels/acre and lowest cost/acre. The enormous fertilizer inputs of these *high-efficiency* farmers, as much as 250 pounds of ammonium nitrate/acre for Max Shaul, the New York farmer who won the Ford Almanac's 1965 Corn Award, were heralded as models for optimizing the productivity of their soil.[94] Whether or not readers were motivated by the Farm Efficiency Awards or put any of the Almanac's suggestions into practice, the *Ford Almanac* associated the automotive giant with the archetype of the innovative industrial farmer, not just as a fellow tinkerer working to annually improve their car models but as an essential piece of a reimagined farm-to-farm knowledge network, invested in "swapping ideas" and building a productive and profitable agricultural landscape for all companies and farmers involved.[95]

The Agricultural New Working Class

The scientific understanding of soil productivity brought about by synthetic fertilizer continued the process of removing the farmer from their land that had already begun with the mechanization of agriculture. The use of synthetic fertilizer in managing and regulating soil fertility allowed agricultural labor to be absorbed into "the new working class," a term coined by sociologist Serge Mallet to describe workers in the chemical manufacturing industry whose role was to supervise the largely automated processes of chemical synthesis rather than complete repetitive fragmented tasks as part of a Ford-style assembly line. This kind of work collapsed the

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[93] *The Ford Almanac*, Vol. 1955, 100-110.
[94] *The Ford Almanac*, ed. John Strohm (Golden Press, Inc., 1964), Vol. 1965, 117; "Farm Efficiency Awards," *The Rural New-Yorker* (New York), January 1965, 12.
[95] *The Ford Almanac*, Vol. 1955, 100.

roles of laborer and supervisor as chemical workers, who remained at the bottom of the hierarchy, were tasked with supervising the automated labor of the plant rather than completing the discrete tasks of synthesis themselves.[96] In his research on the development of democracy within the fossil economy, author Timothy Mitchell connects this automated supervisory labor with the liquid flow of oil's embodied energy through the petrochemical industry.[97]

Workers in a fertilizer factory could be considered part of the new working class, supervising the flows of nitrogen and hydrogen gasses as they formed ammonia under pressure generated by a constant flow of fossil energy. Farm labor was similarly *technicized* by the abundance of cheap nitrogen fertilizer, the work of the farmer being to calculate how much of each nutrient input to add based on soil test results and the crop to be grown.[98] The recharacterization of farming as an occupation of business and science grew from the new responsibilities of farmers, like workers in a chemical plant, to supervise the chemical flows of fertilizer nutrients in the process of synthesizing crops. The farmer's primary concern under this new labor regime was to balance the cost of inputs like seed, tractor fuel, and fertilizer with profit gained from crop sales. The 1957 USDA Farmers Bulletin on cutting farm costs demonstrates this recharacterization of responsibilities with a checklist of questions farmers should ask themselves like "Are your yields above those of similar farms in the neighborhood? Have you checked your fertilization rates? Do you try to use the latest proven production practices?"[99] Questions like these demonstrate the changing role of the farmer, from being in the field working with the soil to raise crops to standing above and outside the field and monitoring the flow of nitrogen as the farm system converted it to crops.

Conclusion

Throughout 1965, a series of columns written by William V. Whitney entitled "Fertilizer Facts" appeared in the *Rural New-Yorker*, giving general advice about how to efficiently and correctly use nitrogen fertilizer as a way to increase farm profits. The columns included no promotion of one brand over another save for the authorship note at the end of each column

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[96] Serge Mallet, *Essays on the new working class*, trans. Dick Howard and Dean Savage ([S.l.]: Telos Pr., 1975), 38-41.
[97] Mitchell, *Carbon democracy : political power in the age of oil*, 152.
[98] Mallet, *Essays on the new working class*, 41.
[99] J. B. Claar et al., *Cut the costs that cut your farm profits*, (Washington D.C.: U.S. Department of Agriculture, 1957), 12.

stating that Whitney was the director of the farm services department of the Royster Guano Company.[100] This style of benevolent educational advertisement demonstrates how closely incorporated into agricultural knowledge production fertilizer manufacturers were in the postwar United States. Government organizations like state agricultural colleges and the USDA were not seen as gatekeepers, protecting farmers from potentially dishonest manufacturers and salespeople, but as cooperating with manufacturers to teach farmers how to correctly incorporate the increasing variety of mixed synthetic fertilizers into their agricultural practices.

The origin of commercially available anhydrous ammonia reflects this process. Citrus farmers Eugene and John Prizer, concerned by the high labor requirements of applying granulated nitrogen fertilizer to orchards, worked with Shell Chemical Company chemist Ludwig Rosenstein and University of California agronomist D. R. Hoagland to develop a liquid fertilizer that could be applied using irrigation equipment. In 1943 the Tennessee Valley Authority supported the efforts University of Mississippi experiment station researcher D. B. Andrews to adapt these anhydrous ammonia application methods for agriculture in the South and Midwest.[101] A decade later in 1956, the USDA published special issue of the *Farmers' Bulletin* to promote an $100 liquid fertilizer pump developed by the TVA in cooperation with several state agricultural universities with the intention of allowing small farmers to profit from the new technology.[102]

These examples of collaboration between federal agencies, state colleges, chemical companies, and farmers indicate that there was little debate about whether an agricultural regime dependent on widespread synthetic fertilization was the way to move forward. The abundance of cheap nitrates generated profits for farmers, governments, and major manufacturers alike. The work of chemical company advertisers and state agricultural universities was not to convince farmers of one product or method of nutrient management over another, but to educate farmers on how to properly and efficiently apply fertilizers in order for them to increase profits. Synthetic fertilizer transposed the expectation of infinite economic growth that Timothy Mitchell shows to be dependent on the perceived abundance of inexpensive fossil energy to agricultural production. The enormous atmospheric source of nitrogen reflected the supposedly infinite fossil fuel feedstocks used to synthesize it into nitrate fertilizer, permeating the soil with the expectation of

[100] Allan V. Whitney, "Fertilizer Facts," *The Rural New-Yorker* (New York), Jan 1965, 19.
[101] Potts, *Fluid fertilizers*, 65-66.
[102] Charles W. Gantt, W. C. Hulbert, and Henry D. Bowen, *Hose pump for applying nitrogen solutions*, (Washington D.C.: U.S. Department of Agriculture, 1956).

endlessly increasing productivity from an endless source of nutrients. With no limit to the crops that could be cycled through the soil with the aid of synthetic fertilizer, everyone from the manufacturer to the farmer would be able to profit from this newfound abundance.[103]

In their push to promote a scientifically and economically rooted form of soil management, the textbooks, pamphlets, and advertisements investigated here are never dismissive of the connection of the farm to the natural world or the validity of other fertilization methods. The same USDA *Farmers' Bulletin* that admonished farmers who neglect to make a formal business plan admitted poetically that "the song of the lark in the fragrance of a calm sunny morning may outweigh in the farmer's book of debits and credits the metallic clink of a few extra dollars."[104] Likewise, Firman Bear's *Soils and Fertilizers* acknowledges that using manure rather than fertilizer results in greater retention of organic matter and higher production in the long term. His following endorsement of fertilizer is one of efficiency. Despite the advantages of manuring, a farmer could approach the same yields by applying a significantly smaller amount fertilizer.[105] This supports the argument that a synthetic regime of fertilization was seen as an evolution in the *nature* of farming rather than a break from it. As *USDA Farmers' Bulletin* authors Johnson and Parsons state in the 1956 edition on farm planning for profit, "Mother Nature is most rewarding when we work with rather than against her."[106]

Frank Uekoetter, characterizes German farmers as victims of agriculture's industrialization, having "surrendered jurisdiction over soil fertility and plant nutrition to outside experts" while they were preoccupied with their ever proliferating assortment of agricultural machinery.[107] In New York, the knowledge sources farmers came to rely upon were not seen as outside forces but as partners in farm management. Even a large manufacturer like Agrico was invested enough to send an agronomist to stand in a farmer's field, test their soil, and help them make a farm plan. This profit-driven yet cooperative nature of agricultural industrialization continues today, as indicated by Nathan Rosenberg and Bryce Stucki's article for the Law and Political Economy Project. Rosenberg, a scholar at the Harvard Food Law and Policy Clinic, and Stucki, and agricultural journalist and researcher, argue that, contrary to the common narrative of

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[103] Mitchell, *Carbon democracy : political power in the age of oil*, 139.
[104] Johnson and Parsons, *Planning the Farm for Profit and Stability*, 3.
[105] Bear, *Soils and Fertilizers*, 147.
[106] Johnson and Parsons, *Planning the Farm for Profit and Stability*, 4.
[107] Uekoetter, "Know Your Soil: Transitions in Farmers' and Scientists Knowledge in Germany," 335.

industrial farmers being at the mercy of agricultural conglomerates like Cargill and Tyson, farmers benefit from these industrial networks at the expense of exploited agricultural laborers and environmental degradation, having a 21 percent higher median income than the national median.[108] The reorganization of agricultural knowledge around a system of synthetic fertilization, rather than swindling farmers out of their formerly agrarian knowledge systems represented an induction of the farmer into the fossil-energy dependent new working class. Not all farmers embraced the soil test or Ford's industrial innovator archetype, and many like Ed Rhodes bemoaned their lost farm-to-farm knowledge networks. But the farmers who listened to the suggestions of the county extension agent and modeled the practices of Farm Efficiency Award winners would have reaped convincing enough a reward.

[108] Nathan Rosenberg and Bryce Wilson Stucki, "Don't Trust the Antitrust Narrative on Farms," *The Law and Political Economy Project* (10 May 2021).

Nitrogen Solutions: Innovation and Intensification

Introduction

The cooperative network of knowledge production and dissemination between state agricultural universities, fertilizer manufacturers, federal agencies, and farmers allowed for the rapid diffusion of synthetic fertilizer technology in the postwar decades. In 1955 alone farmers in New York saw the development of high-analysis fertilizers, liquid fertilizer solutions, and a new rye cultivar bred to more efficiently convert synthetic nitrogen into biomass.[109] Adapting to these rapid changes in inputs and recommendations required farmers to invest in new agricultural machinery, water and land management practices, and ideas of efficiency and waste.

The network of infrastructure, both mechanical and biological, and the practices and values they embodied, created what Christopher Jones refers to in his research on United States fossil energy infrastructure as a "landscape of intensification. "[110] Jones claims that landscapes of intensification emerge when infrastructure developed to make use of an abundant energy source creates additional demand, forging a positive feedback loop of energy consumption and extraction. Fertilizers are a material source for plants rather than an energetic one, but the liquid commodity flows of nitrogen fertilizer and the fossil energy required in its manufacturing process led fertilizer to be increasingly mischaracterized as a source of energy, culminating in Norman Borlaug's celebration of fertilizer as the "fuel that has powered [the Green Revolution's] forward thrust."[111] The agricultural landscape of intensification in the postwar United States consisted of high-analysis fertilizers, liquid nitrogen fertilizer, and high-yielding small grain varieties, which allowed crops to be synthesized in ever greater quantities from an increasing amount of energy-intensive nitrogen fertilizer. This chapter discusses each of these technologies and the practices and values they embodied in order to explore how they impacted the energy intensity of New York's agricultural landscape.

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[109] *Cornell Recommends for Field Crops*, Vol. 1956, 18-19; Carl Ross, "Tetra Petkus Rye Is Different," *The Rural New-Yorker* (New York), 17 Sept 1955, 576.
[110] Christopher F. Jones, *Routes of power : energy and modern America* (Cambridge: Harvard University Press, 2014), 189.
[111] Norman E. Borlaug, *The green revolution, peace and humanity : Nobel peace prize acceptance speech Dec. 10th, 1970* (Washington, D. C.: Population Reference Bureau, 1971), 462.

High-Analysis

A fertilizer's *analysis* is the weight percentage of the nutrients in the product. Starting in the 20th century, nutrient percentages were described using a three number code showing the respective percentages of nitrogen, phosphorous, and potassium. Thus, a one hundred pound bag of 4-8-0 fertilizer would include four pounds of nitrogen, eight pounds of phosphorous, and no potassium. As reported by *Cornell Recommends…* in 1955, the average total percentage of these nutrients (nitrogen, phosphorous, and potassium combined) in New York fertilizers had steadily increased from 22.90% in 1940 to 26.04% in 1954, a change the bulletin attributes to the manufacturers' attempts to combat higher transportation and labor costs by adding more fertilizer nutrients per pound needing to be shipped.[112]

The actual nitrogen that makes up granulated fertilizer takes the form of soluble salts like sodium nitrate and potassium nitrate which carry the potential to "burn" or damage seedlings if they come into close contact. Fertilizer burn became an increasingly common problem when high-analysis fertilizers gained traction in 1950s as farmers tended to apply the same or only a slightly smaller amount of fertilizer to their field when the nutrient concentrations in the bag may have as much as doubled.[113] *Cornell Recommends for Field Crops* discussed high-analysis fertilizers annually from 1955-1960, including conversion tables to help farmers calculate which amount of different fertilizer concentrations to apply and information on practices like fertilizer banding.[114] Fertilizer banding involved placing a band of fertilizer granules a few inches to the side and below where seeds were planted. This allowed plants to access fertilizer nutrients as the granules dissolved without risking fertilizer burn by making direct contact with the seed (Fig. 1).[115] Banding required farmers to invest in specialized farm machinery or fertilizer attachments for planters, which reinforced the practice of banding and by extension the use of high-analysis fertilizers.[116]

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[112] *Cornell Recommends for Field Crops*, Vol. 1956, 19.
[113] *Cornell Recommends for Field Crops*, Vol. 1957, 19.
[114] *Cornell Recommends for Field Crops*, Vol. 1958, 20; *Cornell Recommends for Field Crops*, Vol. 1955, 19; *Cornell Recommends for Field Crops*, Vol. 1957, 19; *Cornell Recommends for Field Crops*, Vol. 1960, 26; *Cornell Recommends for Field Crops*, Vol. 1959, 19.
[115] *Cornell Recommends for Field Crops*, Vol 1958, 20.
[116] "Thee Jobs at Once with the OLIVER Superior 26 Drill," *The Rural New-Yorker* (New York), 17 March 1945, 166.

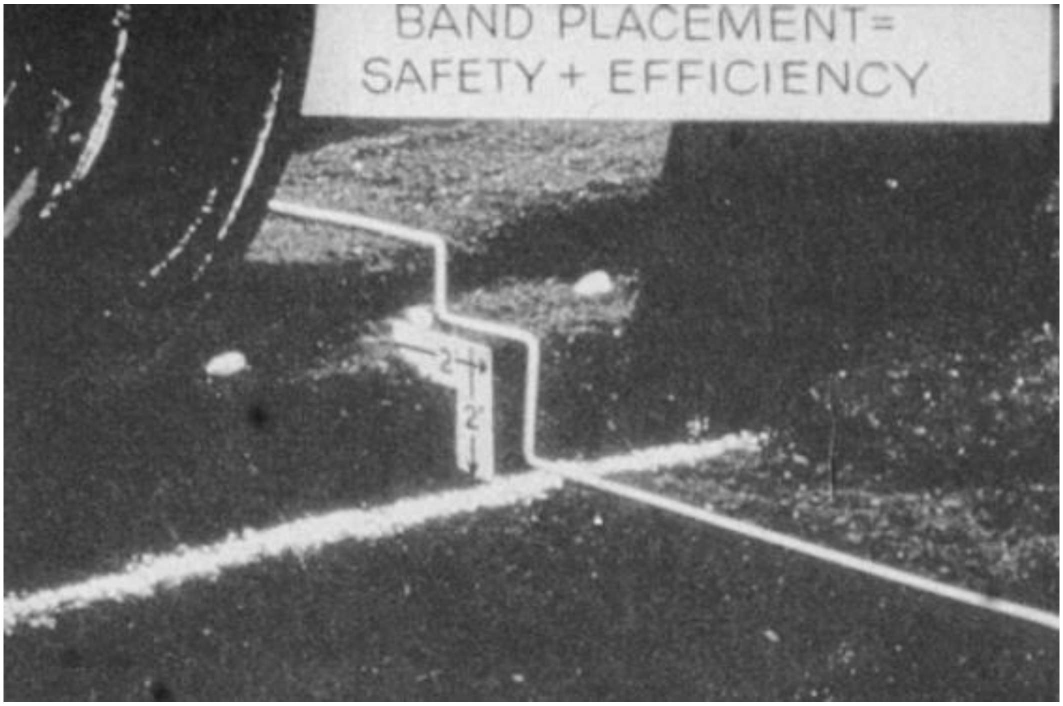

Figure 4: A fertilizer banding attachment for a planter lays a band of fertilizer two inches to the side and below the seed , a method that embodied safe and efficient use of high-analysis fertilizers.[117]

Practices like banding demonstrate how higher fertilizer concentrations instilled values of precision and soil nutrient conservation. *Cornell Recommends…* characterized higher concentrations as a benefit to the farmer as it allowed them to be more precise in their fertilization by calculating how much fertilizer, diluted with specified amounts of limestone and broadcast at a certain rate, would create the ideal nutrient concentrations for the crops they were growing.[118] At the same time, high-analysis fertilizers needed to be treated with precision because their high concentration of soluble salts posed a potential danger to crops if applied carelessly. The practice of banding was not an effort to get farmers to use less fertilizers but an allegedly safer way to enable farmers to apply the larger amount of nitrogen concentrated in high-analysis fertilizers. Likewise, the value of precision attached to granular fertilizers was not an attempt to get farmers to apply smaller targeted amounts of fertilizer, but to make sure farmers were getting value out of the larger concentrations of fertilizer they applied.

Liquid Fertilizers

[117] *Cornell Recommends for Field Crops*, Vol 1958, 20.
[118] *Cornell Recommends for Field Crops*, Vol. 1956, 19; *Cornell Recommends for Field Crops*, Vol. 1957, 19.

The parallel innovation of liquid fertilizer not only destabilized the practices and mechanical infrastructure that granulated fertilizer supported, but the ideas of waste and precision attached to granulated fertilizer. This disruption is attributed to the material phase-change of fertilizers from a solid to a liquid. Practices of fertilizer banding and the accurate calculation of soil nutrient concentration associated with high-analysis granulated fertilizer relied on the fact that the nutrient components of fertilizer granules were dispersed through the soil and taken up by crops in an accurate and predictable way. In contrast, the nitrogen in liquid fertilizers tended to flow across and through the soil rather than stay static, disrupting the values of precision and accuracy that were attached to solid fertilizers.

Though *Cornell Recommends for Field Crops* first mentioned liquid fertilizers in 1954, the bulletin's authors were reluctant to embrace the development. Despite "farm magazines" being "full of stories on the use of liquid fertilizers," *Cornell Recommends…* found that, when compared to granulated fertilizers, the slightly higher cost did not outweigh their labor saving potential, especially for smaller famers who would not be able to afford the additional investment in equipment.[119] This is consistent with the critical tone with which the bulletin addressed the "fantastic claims" of fertilizer products or practices that appeared in less academic publications.[120] One such practice is fall application of nitrogen fertilizer. A primary reason why nitrogen is often so scarce in soils is that the solubility of nitrates allows them to be carried away by runoff or groundwater.[121] Application of nitrogen fertilizer in the fall could save labor the following spring when wet soil would make it more difficult to bring equipment through. However, the usefulness of fall fertilization relied on the expectation that the nitrogen applied in the fall would remain in the soil through the winter. *Cornell Recommends…* indicated in its 1956 and 1959 issues that fall fertilization was a wasteful practice in the Northeast, as New York's wet climate meant any nitrogen applied in fall ran the risk of leaching out over winter at the farmers' expense.[122]

Liquid fertilizer recast nitrogen's solubility as an advantage rather than a danger. Instead of having to be placed precisely like granules did, liquid fertilizer would follow water directly down to the plant's roots where they would be taken up more easily and avoid the risk of

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[119] *Cornell Recommends for Field Crops*, Vol. 1955, 19; *Cornell Recommends for Field Crops*, Vol. 1956, 18-19.
[120] *Cornell Recommends for Field Crops*, Vol. 1956, 19.
[121] Winiwarter, "Environmental History of Soils," 83.
[122] *Cornell Recommends for Field Crops*, Vol. 1956, 19; *Cornell Recommends for Field Crops*, Vol. 1959, 18.

damaging the seedlings. Though in the mid-1950's, authors of *Cornell Recommends for Field Crops* discouraged the use of liquid fertilizer as a bad investment for most farmers, perspectives had shifted by 1962 when the bulletin found that "there is profit in supplying field crops with adequate amounts of nitrogen" and that "in many cases, nitrogen solutions cost less than dry material… require less handling, and can be custom spread in many areas of the State."[123] The change in the cost of liquid fertilizers resulted from the large increase in manufacturing capacity during the time. According to a report published by the Tennessee Valley Authority's National Fertilizer Development Center, the number of liquid mixed fertilizer manufacturers operating in the United States jumped from seventy two to over five hundred between 1955 and 1962 with annual tons of fertilizer manufactured increasing from 27,500 to 800,000 during the same period.[124] Back in 1955 at Cornell's Farm and Home Week, researcher Keith Kennedy had forecast this drop in price, showing that liquid fertilizers would be cheaper to produce per pound of nitrogen than granular fertilizers, with 41% nitrogen solution coming in at 10-11 cents and anhydrous ammonia at 12.5 cents while the cheapest granular fertilizer, ammonium nitrate, cost 13.5 cents.[125]

The change in *Cornell Recommends…* recommendations regarding liquid fertilizer shows that the concerns around investing in the new form of fertilizer was an issue of money rather than efficiency or precision. As evidenced by their stance against fall fertilizer application, the potential of nitrates to leach away remained a concern, but as long as prices remained low enough for farmers to stay profitable investments in liquid fertilizer could be justified. This represented another piece of the feedback loop of intensification, with the value of precision in fertilizer application being discounted for a product that, enabled by an increase in the manufacturing capacity of inexpensive liquid fertilizer, reduced labor costs by spreading fertilizer throughout the field rather than in a targeted band. Though liquid fertilizer had its advantages in decreased labor costs and its disadvantages in less precise application, it was ultimately the lower cost of liquid fertilizers that underpinned their increased adoption.

Complementary Infrastructure

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[123] *Cornell Recommends for Field Crops*, Vol. 1962, 27.
[124] Potts, *Fluid fertilizers*, 6.
[125] "At Cornell's Farm and Home Week," *The Rural New-Yorker* (New York), 4 March 1955, 274.

Even with lower prices, liquid fertilizers still required farmers to invest in new application machinery. Justification for these investments came in finding multiple uses for application equipment. In some cases, this involved the ability to apply other liquid products, like a sprayer-boom attachment that advertised its ability to spray herbicides and pesticides to fields and livestock in addition to spreading liquid fertilizer.[126] In other cases, the investment in new equipment and liquid fertilizer complemented one another, as was the case with irrigation equipment. Liquid fertilizer had been associated with irrigation since the invention of the Prizer applicator in 1928 which dissolved solid fertilizer to be broadcast through California's citrus orchards using irrigation water.[127] The synergy between these two emerging technologies allowed irrigating farmers to employ fertilizer solutions without having to purchase a specialized applicator. At the same time, fertilizers provided an additional selling point for irrigation equipment, embodying, as grower Charley S. Taylor put to the *Rural New-Yorker* "not two, but three purposes in one," the three purposes being the provision of moisture, nitrogen, and potassium to "the root zone of the plants."[128] The applicability of liquid fertilizers was made easier by the hydraulic management of the field. Well drained soils and the use of drainage tiles to eliminate wet spots made it much easier to keep liquid fertilizer from running off or concentrating unevenly in the field.

Andrew Watson's research into the irrigation of croplands in the High Plains of the United States demonstrates the dependance of irrigation systems on fossil energy. Like fertilizer, irrigation systems increased crop yields by rationalizing agricultural landscapes. Watson's research shows how this rationalization depended on fossil energy, specifically energy from the Hugoton-Guymon natural gas field which was used to extract fossil water from the Oglala aquifer in order to increase yields in the relatively arid High Plains. [129] Though agriculture in New York State was not as irrigation dependent as in the High Plains, the synergy between liquid fertilizer, a product of fossil energy itself, and irrigation forms its own positive feedback within the agricultural landscape of intensification. Liquid fertilizer and irrigation systems both enabled an increase in intensity from the other, creating an additional collective demand for

[126] "Easy Low-Cost Insect, Weed Control," *The Rural New-Yorker* (New York), 4 March 1955, 211.
[127] Potts, *Fluid fertilizers*, 5.
[128] Charley S. Taylor, "Irrigation on Livestock Farms," *The Rural New-Yorker* (New York), 4 March 1955, 157.
[129] Watson, ""The Single Most Important Factor": Fossil Fuel Energy, Groundwater, and Irrigation on the High Plains, 1955-1985," 12.

energy and fossil resources. Crucially, this energy intensive synergy between fertilizer and irrigation constitutes two thirds of what Giovanni Federico, in his economic history of agriculture, refers to as “the most important case of complementarity,” otherwise known as the Green Revolution.[130] However, the high yielding wheat varieties that would make judicious use of the abundant and regular supplies of water and nitrogen would not emerge in New York until the 1960s.

Liquid nitrogen fertilizer contradicted the ideals of precise and efficient use associated with granulated fertilizer. The use of irrigation equipment to spray liquid fertilizer through a field contrasts sharply with the target placement of a fertilizer band next to and below a row of seeds. Even dripped or sprayed directly into a furrow, there was still the potential for liquid nitrogen to leach deeper into the soil than a plant’s roots would reach.[131] However, liquid fertilizer’s lower price point, the investments in application equipment made by its adherents, and the novelty of the technology, disrupted the conservative values attached to granulated fertilizer enough to allow for wildly inefficient practices like leaf feeding to be entertained.

Leaf feeding, or foliar application of fertilizer, was addressed several times by experts and farmers alike during the advent of liquid fertilizers. In 1950, the *Rural New-Yorker* published Cornell professor of pomology Damon Boynton’s summary of the “widespread interest” around leaf feeding and the results of his experiments with the process.[132] The 1954 issue of *Cornell Recommends for Field Crops* addresses a column to dismissing the “extravagant claims” made about leaf feeding.[133] Despite their dismissal, Charley S. Taylor’s 1955 Rural New-Yorker article on irrigation addresses leaf feeding as one of the “unusual uses for sprinklers” farmers could avail of.[134]

In Damon Boynton’s piece, he acknowledges the inefficiency of the practice, pointing out that “one-fourth to one-half the spray material directed at the leaves of a thoroughly sprayed tree never gets there, or drips off them before drying occurs,” though he does concede that the solution that slips off the leaves would enter the soil to be absorbed by the plant’s roots.[135] His acknowledgement that spraying may not offer farmers the control over nitrogen fertilization they

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[130] Federico, *Feeding the world : an economic history of agriculture, 1800-2000*, 103.
[131] B.A. Brown, "Lime - Wheelhorse of the Soil," *The Rural New-Yorker* (New York), 1 Jan 1955, 76.
[132] Damon Boynton, "Foliage Nitrogen Sprays," *The Rural New-Yorker* (New York), 1 April 1950, 336.
[133] *Cornell Recommends for Field Crops*, Vol. 1955, 18.
[134] Taylor, "Irrigation on Livestock Farms," 190.
[135] Boynton, "Foliage Nitrogen Sprays."

desire falls short of a condemnation of the practice, and he concludes that "there is much that is yet to be learned about this possible new use for urea."[136] *Cornell Recommends…* takes a less optimistic view, pointing out that though "plants appear to have a large leaf area for spray application," they generally have a larger root surface area that is better suited to the absorption of nutrients. The bulletin also warns that foliar application of fertilizers could burn the leaves if the fertilizer is not significantly diluted, "[requiring] several applications at large gallonage per acre."[137]

Though neither Cornell nor Boynton endorse the practice of spraying foliage with fertilizer, the pervasiveness of the topic despite a lack of affirmative research and the exasperation with which Cornell decries the practice demonstrates how completely liquid fertilizer captured the imagination of midcentury experts and farmers, even seven years before the product's price dropped low enough to be endorsed by the agricultural extension services. This indicates the extreme nature to which agricultural innovation disrupted conventional understandings of agroecosystems. If manure and legumes could be replaced by liquid nitrogen harvested from the air and farmers could make a profit growing corn on sandy soil, feeding plants through their leaves did not seem so implausible.

This technological optimism is reflected in a 1955 Gulf Oil advertisement in the *Rural New-Yorker.* The advertisement compares innovations in motor oil with innovations in fertilizer, using the tagline "New liquid fertilizer is <u>pumped</u> into the soil!" (emphasis in original). The advertisement draws attention to changes in the material composition of fertilizer to lead readers to the conclusion that liquid, in fertilizer and in oil, is the mark of modernity:

> Look how the fertilizer is being applied nowadays! First it was the *solid* type of plant food; then a *gas* – anhydrous ammonia. This had to be put into the soil with special machinery. Today it's a *liquid* that not only fertilizes, but can be mixed with weed killers and insecticides and applied in one operation. Farmers are using this type of fertilizer more and more these days and the reasons are obvious. They are competitive in price. Better machinery is becoming available for putting them in. And they can be handled

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[136] Boynton, "Foliage Nitrogen Sprays."
[137] *Cornell Recommends for Field Crops,* Vol. 1955, 18.

> with ease – pumps do all the work, there is no lifting and carrying. Liquid fertilizing is one more great step forward in modern farming.[138] (emphasis in original)

Like Ford Motor Company publishing the *Ford Almanac*, Gulf's praise of liquid fertilizers' modernity associated their product with its futuristic and affordable technology. Gulf could also rest assured that the machinery used to apply these fertilizers would require a regular supply of motor oil. Companies like Gulf and Ford did not only associate themselves with fertilizers for the advertising opportunity, but used their presence to define what "modern" farming meant, a network of fossil fuel dependent inputs and innovations that would, in concert, increase overall energy demand. But the connection between oil and liquid fertilizer goes beyond an advertised association. Timothy Mitchell, in *Carbon Democracy* compares synthetic fertilizer to oil, showing how both forms of fossil energy "appeared to remove… limits to growth:" oil's invisible abundance seemingly removing resource limits to economic growth and fertilizer's hidden embodied energy appearing to remove the limits of what could be produced on a smaller or lower fertility plot of land.[139] Liquid fertilizer was also seen as a labor-saving technology with less labor needed to transport and apply liquid fertilizer than granulated fertilizer, just as oil's extraction and transportation required less labor than that of coal.[140] This scheme of seemingly infinite agricultural growth with a shrinking labor force is the driving force of the feedback loop of agricultural intensification, relying on an abundant enough source of fertilizer nitrogen that even spraying it on plant foliage in the hopes that it will be absorbed did not seem so wasteful.

Yorkstar

Fertilizer burn and leaf burn from foliar application were not the only dangers posed to crops by synthetic nitrogen. Most plants took up this new abundance of nutrients and happily converted it into additional biomass, seeds, and fruits to be harvested, but some reacted poorly to too much nitrogen in the soil. Certain fruit trees were adversely affected by an overabundance of nitrogen like McIntosh apples which could suffer poor coloration if overfertilized and Northern Spy apples whose tendency to develop "bitter pit syndrome," caused by an imbalance of water in

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[138] "What's new in farming?," *The Rural New-Yorker* (New York), 5 Nov 1955.
[139] Mitchell, *Carbon democracy : political power in the age of oil*, 139-41.
[140] Mitchell, *Carbon democracy : political power in the age of oil*, 36.

the tree, was exacerbated by excess nitrogen.[141] The most prevalent problem caused by too much nitrogen was the tendency of small grains like wheat, rye, and barley to "lodge" or tip over in the field. Small grains had always been prone to lodging in the face of high winds or inclement weather, but the extra nutrients provided by synthetic fertilizers caused the plants to grow taller stems and heavier seed heads which hung much more precariously.[142]

The risk of lodging meant that, while farmers could spread ever increasing amounts of fertilizer on corn, soybeans, and pasture, fertilization of small grains needed to be approached cautiously, causing these crops to miss out on the higher yields heavy fertilization promised. The precarious nature of small grain fertilization is reflected in the fertilizer tables provided in *Cornell Recommends for Field Crops*. The table of recommended pounds per acre of fertilizer is split for wheat and other small grains into two sections, indicating that more nitrogen should only be applied in areas of low-fertility where lodging has not occurred in the past.[143] In 1952, the bulletin boldly recommended that farmers top-dress their wheat crop, applying extra nitrogen to crops after they have already begun growing, promising up to twelve dollars per acre in extra profit.[144] Two years later a column in *Cornell Recommends…* asked "was wheat top-dressing overdone?" and cautioned farmers again that, though top-dressing can increase yields, it should not be applied on higher fertility soils or in wetter areas of a field.[145]

The susceptibility of small grains to lodging ran counter to the promise of synthetic fertilizer to rationalize the soil and bring all acres to a higher standard of productivity. Wheat's tendency to lodge highlighted the differences within a field, requiring farmers to adjust to small soil fertility differences across their field when applying fertilizer rather than broadcasting fertilizer more generally and assuming crops would perform relatively the same. The "package" of complementary Green Revolution technology referred to by researchers Meredith McKittrick and Giovanni Federico in their respective texts on agricultural industrialization: synthetic nitrogen fertilizer, irrigation, and pesticides, was already taking shape in New York State during

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[141] Boynton, "Foliage Nitrogen Sprays," 336; L. D. Tukey, "Fruit Questions," *The Rural New-Yorker* (New York), 16 April 1955, 281.
[142] McKittrick, "Industrial Agriculture," 421.
[143] *Cornell Recommends for Field Crops*, Vol, 1951, 12.
[144] *Cornell Recommends for Field Crops*, Vol. 1951, 14.
[145] *Cornell Recommends for Field Crops*, Vol. 1954, 18-19.

the 1950s.[146] In the case of small grains, it was the crops themselves that need to be calibrated to function within this new agricultural regime.

Tetra Petkus rye was the first instance of a widely grown crop in New York State specifically adapted to heavy fertilization. This new strain of rye, first discussed in the *Rural New-Yorker* in 1954, was developed in Germany by treating seed with colchicine which doubled the plant's number of chromosomes from two to four. This mutation resulted in stiffer straw and stronger roots, making the crop highly resistant to lodging. Tetra Petkus could not only stand a heavier dose of nitrogen but required it, needing as much as "40 to 60 pounds per acre, and even more, depending on the preceding crop and the general fertility level of the soil" to achieve competitive yields.[147] In this way, crops like Tetra Petkus functioned as a piece of infrastructure in the agricultural landscape of intensification's feedback loop. These high-yielding varieties, developed in response to an abundance of nitrogen fertilizer, required much more fertilizer than other rye cultivars so much that farmers would accidentally underfeed Tetra Petkus when they first grew the crop, even when applying 400lbs/acre of 3-12-6 fertilizer as a Maryland farmer discussed in the *Rural New-Yorker* did. Though Tetra Petkus represented the first time Green Revolution technologies fully assembled in New York State, its use cases were fairly narrow. The new cultivar was not used as a food crop, instead being mostly grown as forage and silage for livestock and occasionally functioning a cover crop. Additionally, Tetra Petkus's German origin meant that its imported certified seed came at a higher cost to farmers, limiting the amount of farmers able to grow it.[148]

Developing a domestic variety of fertilizer tolerant wheat had been a high priority for Cornell University since the mid 1950s. The 1962 issue of *Cornell Recommends…* reported "hundreds of semi-dwarf wheats—some as short as 21 inches—in the wheat breeding project at Cornell" and announced Avon, a new winter wheat variety two inches shorter than Genesee, the most widely grown variety at the time. Avon's higher grain production and resistance to lodging prompted Cornell to advise farmers to consider the widely grown Genesee wheat a second choice.[149] Three years later the bulletin teased a new development, announcing that "after more

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[146] McKittrick, "Industrial Agriculture," 421; Federico, *Feeding the world : an economic history of agriculture, 1800-2000*, 103.
[147] Ross, "Tetra Petkus Rye Is Different," 576.
[148] Ross, "Tetra Petkus Rye Is Different," 576.
[149] *Cornell Recommends for Field Crops*, Vol. 1962, 19.

than a decade of intensive work, Cornell is putting the finishing touches on shorter wheat varieties."[150] More developments were shared in 1966, with two promising "medium-short" varieties undergoing increases in seed production, and in 1967 announced that a single winter wheat variety, shorter than Genesee by seven inches, may be put up for sale in the following year.[151] After a decade of dramatic buildup, Yorkstar was announced in 1968 as "the big news in small grain varieties," with seven inch shorter straw and ten percent higher yields than Avon and Genesee. In the 1968 bulletin, *Cornell Recommends…* suggested that Yorkstar "should cut heavily into the present dominant acreage of Avon and Genesee."[152]

Norman Borlaug's first high yielding dwarf wheat variety was developed in the 1950s and yield increases from the Green Revolution had been observed in Mexico and Asia since the mid-1960s.[153] Though the traditional narrative of the Green Revolution depicts the United States exporting industrial agriculture practices to South America and Asia, the highly anticipated development of dwarf wheats in New York and the accelerated nature of Cornell's breeding program shows how the successes of high-yielding varieties rippled back to the United States, creating momentum for further agricultural intensification. Varieties like Tetra Petkus, Avon, and Yorkstar demanded steadily higher inputs of nitrates, incentivizing farmers to purchase greater amounts of fertilizer and invest in new infrastructure like fertilization and irrigation equipment. Taken together, these investments collectively and continuously increased the demand of New York's agroecosystem on external fossil energy sources.

Conclusion

The introduction of the Northeast's first high-yielding wheat was not the peak of the region's agroindustrial intensification. In the same issue of *Cornell Recommends for Field Crops* in which Yorkstar was announced, the bulletin shared preliminary field test results for improved barley varieties yielding 75-100 bushels/acre.[154] Likewise, the nationwide increase in liquid

[150] *Cornell Recommends for Field Crops*, vol. 1965 (Ithaca, N.Y.: New York State College of Agriculture, 1965), 12.
[151] *Cornell Recommends for Field Crops*, vol. 1966 (Ithaca, N.Y.: New York State College of Agriculture, 1966), 12; *Cornell Recommends for Field Crops*, vol. 1967 (Ithaca, N.Y.: New York State College of Agriculture, 1967), 40.
[152] *Cornell Recommends for Field Crops*, vol. 1968 (Ithaca, N.Y.: New York State College of Agriculture, 1968), 12.
[153] McKittrick, "Industrial Agriculture," 412.
[154] *Cornell Recommends for Field Crops*, Vol. 1968, 12.

fertilizer production seen through the mid-1960s was only the inflection point of its increase, with annual total tonnage of liquid mixed fertilizer rising to almost five million by 1980, more than five times the amount manufactured in 1965.[155]

Though claims of efficiency, primarily of labor, motivated many of the innovations discussed in this chapter, the increasing energy intensity embodied in these developments show these claims to be false. Germán Vergara's book *Fueling Mexico* finds a similar incongruency within the nation's Green Revolution. Vergara points out that the introduction of fossil fuels into Mexican agriculture opened up what had previously been a closed energy system which had used the labor of humans and animals to generate slightly more energy in food than was consumed in production. The introduction of fossil fuel-tethered technology like farm machinery, irrigation systems, and synthetic fertilizer "inverted the former energy ratio," creating a demand for inputs of fossil energy where the system previously generated a surplus.[156] Andrew Watson's research into irrigation of the High Plains connects this inverted energy ratio to another version of Christopher Jones's landscape of intensification, showing that abundant inputs of fossil energy used in irrigation led farmers to switch to growing corn, a more water-intensive crop.[157]

The tangle of practices and technologies that took root in New York during the 1950s and 60s demonstrates how each technological innovation in the feedback loop of intensification pushed New York agriculture's energy ratio deeper into the negative. High-analysis fertilizers carried with them a higher proportion of energy intensive synthetic nitrogen and required the investment in specialized planting machinery. Liquid fertilizers saved labor in application but operated with an increased potential for nitrogen to flow to places where it couldn't be used by crops. The investment in application machinery created additional energy demand and often involved complementary energy-intensive practices like irrigation and the spraying of pesticides and herbicides. Finally, the incorporation of high-yielding varieties like Tetra Petkus rye and Yorkstar wheat allowed for small grains to be incorporated into fertilization practices and demanded much heavier fertilizer applications to reach competitive yields. Though the resulting agricultural landscape seemed to operate like an efficient and well-oiled machine in terms of

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[155] Potts, *Fluid fertilizers*, 6.
[156] Vergara, *Fueling Mexico : energy and environment, 1850-1950*, 202-03.
[157] Watson, ""The Single Most Important Factor": Fossil Fuel Energy, Groundwater, and Irrigation on the High Plains, 1955-1985," 651; Jones, *Routes of power : energy and modern America*, 189.

profit and yield, when energy inputs are considered, industrial agriculture in New York State operated at a net loss.

Conclusion: Fish Food

In 1969 the Tennessee Valley Authority's National Fertilizer Development Center published a report entitled *Effects of Fertilizers on Water Quality*; a collection of research abstracts from studies relevant to the relationship of fertilizers like synthetic nitrogen to the health of surface and groundwater. J. M. Soileau, head of the Center's Soils and Fertilizers Research Branch, opens the report by stating:

> Within the last year or two there has been much discussion in the popular press and in scientific meetings regarding the possible contamination of the Nation's water supplies as a result of the use of agricultural fertilizers Almost without exception, voiced judgements have been based on a minimum of scientific data. [158]

The intention of the TVA's report was not to come to a definitive conclusion about the environmental impacts of fertilizers but to collate a bibliography studies relevant to the problem in order to better understand the "overall contribution that fertilizer use has on the chemical quality of our Nation's water supplies."[159]

This report would lead the reader to believe that the potential of excess nitrogen fertilizer to cause the eutrophication of waterways was not well understood before the end of the 1960s. The primary literature consulted in this paper seems to reflect this claim, as any discussion of nitrogen's impact beyond the boundary of the farm or the experiment station is conspicuously absent. However, the potential of fertilizer to leach out of the field was well understood and, as discussed in the previous chapter, the authors of Cornell Recommends for Field Crops decried practices that would lead to excess leaching like the fall application of nitrogen fertilizer.[160] As discussed earlier, concern around leaching was more economic than environmental, preoccupied with the fact that nitrogen was leaving the boundary of the farm rather than the fate of leached nitrogen beyond the farm's boundary. Therefore, in order to grasp how well farmers, extension officers, and researchers at institutions like the Tennessee Valley Authority understood the

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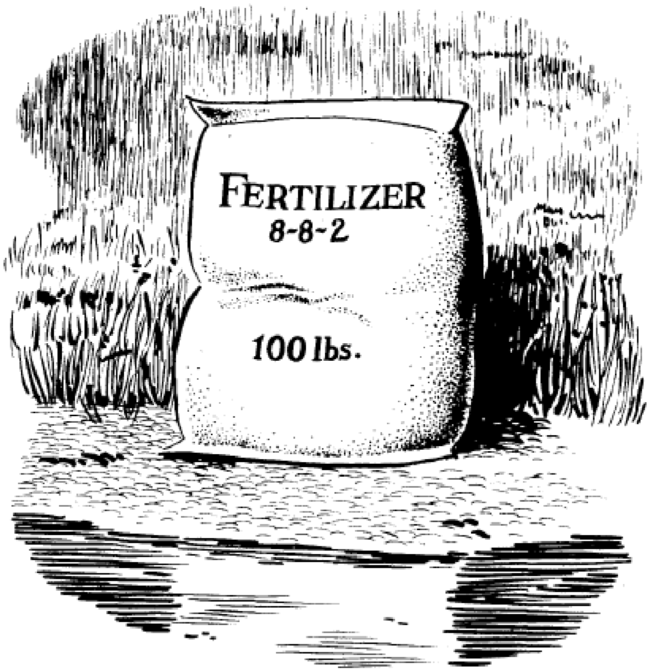
[158] *Effect of Fertilizers on Water Quality*, National Fertilizer Development Center (Muscle Shoals, AL, 1969), 2.
[159] *Effect of Fertilizers on Water Quality*, 2.
[160] *Cornell Recommends for Field Crops*, Vol. 1956, 19; *Cornell Recommends for Field Crops*, Vol. 1959, 18.

aquatic impacts of fertilizer it becomes important to seek out an aquatic system within the boundaries of the farm. The following pages bring together arguments from the previous chapters to analyze the use of fertilizers in fish ponds and what the practice demonstrates about farmer and expert understandings on the impact of nitrogen pollution.

The building and maintenance of farm fish ponds was a popular topic in the decades following World War II, appearing in the *Rural New-Yorker*, the *Ford Almanac*, and in several issues of the *USDA Farmers' Bulletin*, the earliest of which was published in 1943. These publications lauded the fish pond as a way to make profitable use of otherwise unproductive land while gaining added advantages like recreation and water for livestock.[161] All a farmer needed to build a farm pond was a small depression with soil that could hold water, materials to build a small dam to impound water, and fertilizer.[162]



Use fertilizer to grow more fish.

Figure 5: An image of 8-8-2 fertilizer included in the 1955 *USDA Farmers' Bulletin*. 8-8-2 and 8-8-4 were the standard fertilizer concentrations for fish ponds advertised in the *Ford Almanac* and the *Rural New Yorker*.[163]

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[161] *The Ford Almanac*, Vol. 1955, 157.
[162] Verne E. Davison, *Farm Fishponds for Food and Good Land Use*, (Washington D.C.: U.S. Department of Agriculture, 1947), 15.
[163] Verne E. Davison, *Managing Farm Fishponds for Bass and Bluegills*, (Washington D.C.: U.S. Department of Agriculture, 1955), 8; *The Ford Almanac*, Vol. 1965, 21; "What's New In Farm Products," *The Rural New-Yorker* (New York), July 1960, 12.

Fertilization was central to the maintenance of the fishponds, both in growing enough algal biomass for fish to grow and in killing off unwanted plant species. Verne Davison, a biologist and author of several Farmers' Bulletins on fish ponds, compares fertilizing ponds for algal growth to fertilizing pasture for livestock.[164] In reality, while fertilizing pasture fed cows directly, fertilizing ponds supported an entire food chain: the fertilizer growing blooms of algae which would be consumed by insects and other invertebrates which themselves would be eaten by fish. In his research on irrigation on the High Plains Andrew Watson points out that very little of the energy consumed by cattle is actually converted into biomass, and the same is true of this fish pond food chain.[165] A small proportion of the energy insects gain by feeding on algae is converted into their biomass and a similarly small proportion of the energy fish obtain from those insects becomes biomass, making pond fertilization a terribly inefficient system for generating food. This shows fertilized fish ponds to be another piece of industrial agriculture's feedback loop of intensification explored in the previous chapter using Christopher Jones's landscape of intensification concept and Germán Vergara's idea of the inverted energy ratio of industrial agriculture.[166] Just like a high-yielding wheat cultivar like Yorkstar, fish ponds use up the abundant supply of fertilizer nitrogen while their inefficient means of synthesizing biomass increases the fertilizer required to produce each additional pound of fish.

Fertilizer was also used, counterintuitively, to kill unwanted plants in fish ponds. Waterweeds, including plants like water hyacinth and water lilies, were considered undesirable in fish ponds as they consumed fertilizer nutrients without contributing to the fertilizer-fish food chain and gave fish a place to hide from the farmer and other fishers. Additionally, if waterweed were allowed to decompose, the decomposer bacteria would use up the pond's oxygen, creating an anoxic environment that could kill fish in the pond. Farmers could rid their ponds of these weeds by fertilizing late in the growing season to trigger a bloom of filamentous algae, otherwise known as pond scum, which would block sunlight from reaching the bottom of the pond, starving the waterweeds. [167] Biologist Lawrence Compton, author of the 1943 Bulletin on fishponds, acknowledges the counterintuitive nature of fishpond management strategies:

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[164] Davison, *Farm Fishponds for Food and Good Land Use*, 7.
[165] Watson, ""The Single Most Important Factor": Fossil Fuel Energy, Groundwater, and Irrigation on the High Plains, 1955-1985," 651.
[166] Jones, *Routes of power : energy and modern America*, 189; Vergara, *Fueling Mexico : energy and environment, 1850-1950*, 203.
[167] Davison, *Managing Farm Fishponds for Bass and Bluegills*, 11.

> Successful fishpond management involves procedures that are contrary to most commonly accepted ideas on fish culture… The elimination of rooted plants is perhaps the most revolutionary of these practices, for it has long been felt that such plants were essential to the production of fish.[168]

Compton's assurance that counterintuitive practices happen to be the best practices reflects the argument made in the first chapter that fertilization wasn't seen as unnatural, but as creating a more simple and efficient nature, one that adhered to scientific and economic rationality. This new nature characterized waterweeds as wasteful and extraneous and algal blooms as useful and efficient. The technicization of agricultural labor, explored in the second chapter in relation to Serge Mallet's concept of the new working class, is also reflected in the fertilizer-dependent fish pond.[169] While constructing a fish pond required significant physical labor, its maintenance focused on making adjustments to the concentration of fertilizer nutrients in the water as the automated pond system converted fertilizer into fish.

As with use of fertilizers in the field, the choice between organic and synthetic fertilizers in fish ponds represented contrasting perspectives on what was considered efficient and natural. The common guidance through the 1950s and 60s was that organic fertilizers such as manure, hay, and cottonseed meal were inconsistent in their nutrient concentrations and caused blooms of filamentous algae, which was useful when killing waterweeds but was otherwise considered undesirable. This made synthetic fertilizers the better choice as their nutrient concentrations were consistent, measurable, and less likely to produce pond scum.[170] However, Compton's earlier 1943 bulletin shows organic fertilizers to be more efficient at growing fish than synthetics, with the potential to double fish production while only slightly increasing pond fertility. As Compton explains, this is due to the fact that fertilizers like cottonseed meal could be eaten by fish directly and the organic matter components of organic fertilizers could be consumed directly by insects and other invertebrates.[171] While organic fertilizers would have still increased fertility to some

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[168] Lawrence V. Compton, *Techniques of Fishpond Management*, (Washington D.C.: U.S. Department of Agriculture, 1943), 1-2.
[169] Mallet, *Essays on the new working class*, 38-41.
[170] Davison, *Farm Fishponds for Food and Good Land Use*, 8-9.
[171] Compton, *Techniques of Fishpond Management*, 18.

extent, the organic materials were also able skip steps of the food chain, making organic fertilizers more energy efficient despite their lower and more variable nutrient concentrations. As for the issue of pond scum, the 1943 bulletin characterizes the appearance of filamentous algae as a sign to stop fertilizing, rather than an inevitable side-effect of organic fertilizer. The changing attitudes towards organic and synthetic fertilization reflect the transition between fertilization regimes discussed in the first chapter as well as role of experts in encouraging synthetic fertilizer use as discussed in the second chapter.

These publications demonstrate that many dynamics of the contemporary crisis of eutrophication caused by fertilizer runoff were well understood by agricultural experts and farmers alike. Experts understood as early as 1943 that fertilizer would trigger algal blooms in aquatic environments and the practice was encouraged with specific fertilizers marketed for the purpose.[172] Farmers understood that decomposing plant matter caused by a sudden excess of nutrients would lead to anoxic conditions dangerous for fish, though in fish ponds this was more associated with waterweeds than with algae.[173] Experts and farmers even understood watershed dynamics and runoff. For instance, in the 1955 *Farmers' Bulletin*, author Verne Davison encourages farmers to practice soil conservation practices on the fields upstream from their fish pond in order to prevent excess erosion and runoff from upsetting the productivity of the fishpond stating that "Erosion and runoff… can be controlled most effectively at their source—*on the land where the rains fall*" (emphasis in original).[174] Despite the invisibility of land beyond the boundary of the farm, the dynamics of nitrogen runoff and its impacts on aquatic ecosystems was well understood by farmers and experts alike.

Knowing this, the 1969 Tennessee Valley Authority report's attempt to bring together scientific research to address the "minimum of scientific data" and "disagreement among agricultural and environmental scientists" around the issue of fertilizer pollution, comes across as disingenuous.[175] If the USDA understood how fertilizer behaved in aquatic environments, it is reasonable to assume that the TVA's National Fertilizer Development Center, whose research program began when the Authority was established in 1933, did as well.[176] Seen this way, the

[172] "What's New In Farm Products," 12.
[173] Compton, *Techniques of Fishpond Management*, 4.
[174] Davison, *Managing Farm Fishponds for Bass and Bluegills*, 25.
[175] Potts, *Fluid fertilizers*, 3.
[176] Hubbard, "The Muscle Shoals Controversy, 1920-1932," 211.

TVA's massing of 700 abstracts about everything from the nitrogen content of Danish soils to the effect of irrigation on salinity looks like an attempt to manufacture uncertainty in order to delay decision making and regulation, a strategy that Naomi Oreskes and Erik Conway's book *Merchants of Doubt* shows was used to great effect in the same period by the tobacco industry in the face of lung cancer, and a decade later by the fossil fuel industry in the face of global warming.[177]

That a large influential fertilizer research center would make use of the same publicity tactic that would later be used by the fossil fuel industry is unsurprising given the similarities and interaction between fossil fuel and fertilizer industries covered in the previous chapters. The abundant supply of a previously scarce nutrient reshaped the agricultural landscape of New York and the United States just the way abundant coal, oil, and petroleum reshaped economies, infrastructure, and energy consumption habits. As fossil energy infrastructure made other energy systems obsolete, the elemental and benevolent nature of nitrogen fertilizer allowed the scientific and economic modernization of agriculture to be characterized as a modern natural hybrid, where earlier practices of nutrient management were cast as antiquated and their adherents sentimental.[178] As coal and oil created new forms of labor, fertilizers allowed farmers to be further inducted into the new working class, their new responsibility of monitoring the flow of synthetic nutrients from the soil into plant bodies guided by a cooperative network of universities, government agencies, and corporations, all profiting from the abundance of synthetic nitrogen.[179] As fossil energy infrastructure created landscapes of intensification, fostering continuous exponential growth in consumption and supply of cheap energy, cheap nitrates created an agricultural landscape of consumption where everything from the soil's hydrology to the plants themselves were reengineered for their use.[180]

The climate crisis, created by the fossil fuel industry, and the eutrophication crisis, resulting from industrial agriculture's reliance on synthetic fertilizer, also share the same blueprint. In both cases a planetary cycle is disrupted by the exploitation of a previously inaccessible resource by Western industry. Mechanical and social infrastructures around the act

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[177] Naomi Oreskes and Erik M. Conway, *Merchants of doubt : how a handful of scientists obscured the truth on issues from tobacco smoke to global warming* (New York: Bloomsbury Press, 2010), 34, 178.
[178] Jones, *Routes of power : energy and modern America*.
[179] Mitchell, *Carbon democracy : political power in the age of oil*.
[180] Jones, *Routes of power : energy and modern America*.

of exploitation become entrenched and when the disruption gives rise to an environmental crisis, stagnate any pushes for action and accountability. Synthetic nitrate manufacturing's overwhelming dependance on fossil energy means that the crisis of nitrogen pollution is itself implicated within the climate crisis. This means calls to rethink agricultural systems of soil fertility represent climate as well as a water concerns.

The postwar abundance of synthetic fertilizer changed everything about conventional agriculture, from the way fertilizer was constructed within nature to the sources of expertise relied on by farmers and the very plants growing in the soil. These changes laid the groundwork for the exponential growth in global nitrogen fertilizer consumption that continues today. The anti-fossil fuel slogan "you can't eat oil" may technically be true, but the history of synthetic fertilization coupled with the fact that half of the nitrogen in the average person's body was synthesized using the Haber-Bosch process shows that we've been eating oil for generations.

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