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Early Warnings on Industrial Agriculture: What Lessons for the Next Food Systems Transformation?

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ABSTRACT

We hear a great deal today about the need to transform global food systems to make them more sustainable and equitable. What we hear less about are the early critiques that emerged in the previous transformation to industrial agriculture in the late 19th and early 20th centuries. The advent of farm mechanization, the synthesis of nitrogen fertilizer, the hybridization of seeds, and the development of chemical pesticides all faced harsh criticism as they were first introduced. This paper explores the early critiques of industrial agriculture, showing that concern about its social and ecological consequences has deep roots. The paper makes the case that the current debate over the future of agriculture can benefit from a deeper appreciation of this earlier history, which demonstrates a continuity regarding some of today's ideas about what is required for

in part due to major world events as well as massive changes in landholding patterns, which have changed narratives about industrial agriculture. Moreover, the early critics did not yet fully grasp the power of technological lock-ins, which may help to explain industrial agriculture's advance over the past century and a half, even in the face of important and popular critiques.

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Introduction

There is a growing consensus on the need to transform food systems to make them more sustainable and equitable. These calls are largely a reaction to the consequences of a previous food systems transformation – the industrialization of agriculture that took place from the mid-19th to the mid-20th century. The process of agricultural industrialization led to enormous changes in both the social and ecological aspects of farming, contributing to environmental harm and inequalities within food systems ([Clapp, 2025](#)). Since that time, the industrialization of farming systems has continued to evolve to the highly mechanized, digitalized, chemical-dependent, and biologically engineered version that is typical on most large-scale farms today ([Bronson, 2022](#)).

Although there are plenty of critiques of modern farming systems, current debates rarely reference early critiques of industrial agriculture that warned of most of the very problems we are grappling with today. Most of us are familiar with Rachel Carson's critiques of pesticides in her 1962 book *Silent Spring* ([Carson, 1962](#)). But what we do not often realize is that Carson's warnings came after numerous other popular critiques that have received far less attention in the current literature. The initial steps toward fully industrialized farming – mechanization and the subsequent rise of fossil powered tractors, the rise of commercial fertilizers, the hybridization of seeds, and the development of synthetic chemical pesticides – each faced harsh public criticism as they were rolled out. These early concerns included: the monopoly power of large machinery firms; displacement of poor farmers from farmland; reliance on petroleum instead of animals and humans for energy; soil compaction and erosion from plowing and tractor use; labour conditions from fertilizer mining; soil harm from fertilizers; biodiversity loss from seed hybridization; and health and environmental harm from chemical pesticides. These critiques were important because, at the time they were first articulated in the mid-to-late 1800s to the early 1900s, between 20 and 50% of the US labour force was engaged in farming, and as such, these were widely discussed issues in public discourse.

Perhaps we do not hear as much about those earlier critiques because they ultimately did not halt the march of the industrial farming model, which has come to dominate farming in industrialized countries today. But if we fast forward to the current era, we see a growing chorus of concern from all sides of the political spectrum about some of the same problems associated with industrialized food production that worried its early critics. Additional concerns have since been added to the list: the greenhouse gas emissions associated with fossil fuel reliant farm machinery and synthetic fertilizers, the health implications of heavy herbicide use, concerns about the health and ecological consequences of

agricultural biotechnology and genome editing, and the loss of farmers' autonomy in the face of agricultural digitalization, among others.

These concerns have sparked an important discourse in recent decades about how food systems must be made more sustainable and equitable ([Béné, 2022](#); [Stone, 2022](#)). What is different today is that the need to reform food systems – and in particular methods of farming – is not in question. The costs are widely recognized, with extensive scientific evidence making the case. The particulars about the precise way forward, however, are hotly debated. Powerful interests argue that only minor adjustments to the industrial agricultural model are needed to reduce its environmental and social costs – such as further digitalization and gene editing to improve resource efficiencies. Others call for a complete system transformation that includes a widespread adoption of agroecology – a more ecological and socially grounded agricultural production system ([Anderson et al., 2021](#)). What is interesting about this debate is that some of the earlier critiques have now become widely accepted as problematic for food systems, but the responses to them have varied widely.

This paper explores the early discourses about the costs and critiques of industrial agriculture, illustrating that concern about its social and ecological consequences has deep roots. I argue that the current debate over the future of agriculture can benefit from a deeper appreciation of this history. Insights from this earlier period demonstrate a continuity regarding some of today's ideas about what is required for more sustainable and equitable food production. But at the same time, it also shows that some of the points raised in earlier critiques have not had the same long-term resonance, in part due to massive changes in farming – such as land consolidation and mechanization – that may seem irreversible, as well as huge shifts in narratives about agriculture's role in society, especially in wartimes. Moreover, by focusing on the potential harms of specific inputs, the early critics did not yet fully grasp the power of technological lock-ins across industrial agricultural inputs, which may help to explain industrial agriculture's advance over the past century and a half, even in the face of important and popular critiques.

The Early Rise of Industrial Agriculture

It is important to first contextualize the early critics of industrial agriculture by mapping out exactly what it was that they were reacting against. Industrial agriculture typically refers to the package of industrial inputs that enabled large scale farming – farm machinery, fertilizer, improved seeds, and chemical pesticides. The emergence of this type of farming would require an entire book to

explain ([Clapp, 2025](#)), and here I attempt only a very brief, and undoubtedly incomplete, summary.

The march toward industrialized agriculture arguably began with farm mechanization in the 1830s-40s. The invention of the mechanical reaper by Cyrus McCormick in the US in 1831, as well as similar inventions by others around the same time, marked an important moment in agricultural transformation because it allowed for a large amount of land to be harvested using very little labour in a relatively short period of time ([Ott, 2014](#); [Phillips, 1956](#)). Although it took several decades for the large-scale manufacture of reapers to constitute a major change in the organization and practice of farming in North America, by 1848 McCormick had built a massive reaper works factory in Chicago, and farmers flocked to buy one of the contraptions, at the time, horse-drawn – and even went into debt to do so. Because labour was a scarce resource, the reaper enabled farmers to sow and harvest more crops, encouraging them to expand the size of their farms to pay for the labor-saving machine. The steel-tipped plow, first fashioned by John Deere in 1836, was also transformative, allowing farmers to more efficiently till large fields ([Broehl, 1984](#)). By the early 1900s, the farm machinery sector was one of the biggest industries in North America, with just a few firms dominating the market for reapers and plows ([Broehl, 1984](#); [Kramer, 1964](#)). The advent of the internal combustion engine in the early 1900s further revolutionized the sector, leading to further mechanization on farms and a growing reliance on fossil energy to fuel those machines ([Phillips, 1956](#)).

The mid-1800s was also the time when scientific understanding of the nutrients necessary for optimal plant growth came of age, with recognition, spurred by the work of Justus von Liebig, that plants require nitrogen, phosphorus, and potassium (N, P, and K) for healthy growth ([Liebig, 1840](#)). This scientific reckoning led to the rise of a global market for fertilizer amendments, first focused on nitrogen-rich Peruvian guano and phosphate rock from the Southern US and Morocco, as well as mined potash from Germany ([Melillo, 2012](#); [Wines, 1985](#)). The depletion of guano reserves spurred research into nitrogen synthesis, which Fritz Haber and Carl Bosch perfected in 1909 and subsequently commercialized for BASF. This technological feat had a major impact on farming and transformed concern and debate over soil fertility and sources of fertilizers by ensuring an abundant supply of nitrogen fertilizer to make up for weary soils ([Johnson, 2016](#); [Smil, 2001](#)). Indeed, as soil was increasingly being worked by machines and on a larger scale, farmers were eager to use synthetic fertilizer to enable continuous cultivation to boost their incomes to be able to afford farm machinery.

State-sponsored research into seed improvement in the United States from the late 1800s resulted in the rise of a private seed industry, and by the 1920s, the hybridization of seeds ([Fitzgerald, 1990](#); [Kloppenborg, 2004](#)). Hybrid and

improved seeds quickly became the third pillar of industrialized agriculture, as it became increasingly normal for farmers to purchase seeds rather than save them from the previous year's harvest. Although there is some dispute over whether hybrid maize had higher yields than conventional seeds, they were adopted by farmers during the 1930s drought in North America because they had stiffer stalks and withstood drought conditions ([Fitzgerald, 1993](#)). These same features enabled hybrid seeds to take on more applications of synthetic fertilizer without lodging (falling over due to rapid upward growth), also a bonus for farmers. The combination of mechanization, synthetic fertilizer, and hybrid seeds enabled farmers to plant their crops in closer rows, effectively increasing their crop harvest on the same amount of land. With the US government putting restrictions on the amount of land that could be harvested during the Great Depression in the 1930s, the planting of hybrids soared to the extent that, within a few decades, nearly all the corn grown in the US was of hybrid varieties ([Fitzgerald, 1990](#)).

With more and more acreage grown in monoculture fields, crops became increasingly susceptible to pests. Pest infestations grew in North America and Europe from the mid-1800s as farmers increasingly used fertilizing agents rather than leaving fields fallow, resulting in repeated opportunities for pests to move from field to field. Combined with growing international trade in foodstuffs, especially grains, pests also moved across North America and Europe by train and across the ocean on ships ([Bosso, 1988](#)). As farm fields became more susceptible to pests with industrial farming methods, organic chemistry researchers stepped up efforts to synthesize chemicals from coal tar – effectively waste materials from the coal industry – to use for pest control. Their efforts resulted in organochlorine pesticides such as DDT and lindane, highly toxic organophosphate chemicals such as parathion and malathion, as well as herbicides such as 2, 4-D ([Dunlap, 1981](#)). Farmers readily adopted these industrial chemical pesticides into their farm practices to address pest problems that resulted from continuous monocultural planting.

By the 1950s and 1960s, the transition to this industrial form of agriculture was largely complete. These four industrial farm inputs were complementary and part of a package – making it difficult for farmers to pick and choose some and not others. In other words, it was all or nothing. A farmer could not farm large tracts of land with hybrid seeds using horse traction and no fertilizer or pesticides. Once farmers adopted the system, they became effectively locked into using it. It is also worth noting that the story of the rise of industrial agriculture and its lock in is as much a story of corporate dominance in the sector as it is about the technologies that comprise it ([Clapp, 2025](#)). As this model became more deeply entrenched, there were early warnings from its critics about the social and

ecological consequences of this farming model. Many of these criticisms focused on individual inputs as they rolled out, as outlined in the following sections.

Early Critiques of Farm Machinery

The costs associated with the widespread adoption of farm machinery were increasingly recognized in public discourse in the last quarter of the 1800s. The Grange Movement in the 1860s-70s harshly criticized farm equipment manufacturers for their monopoly power over key models of machinery ([Broehl, 1984](#)). The Grangers accused those firms of market abuse that resulted in higher prices and reduced choice for farmers ([Martin, 1873](#)). Gaining popular support across the United States in this period, the Grange movement sought to reclaim farmers' political voice that they felt they had diminished with the advance of industrialization ([Buck, 1913](#)). But while the Grangers attempted to produce their own machinery with the aim of selling it at a lower cost than the large manufacturers, they ultimately were unable to compete, and the movement wound down by the late-1800s.

The critiques of the farm machinery sector went beyond concern about monopoly power. By the early twentieth century, especially after the introduction of diesel-powered tractors, there was a growing debate over the shift away from horses as a main source of power for traction ([Ellenberg, 2000](#); [Jasny, 1935](#)). Tractor advocates advertised the labour-saving benefits of self-propelled tractors, which they also claimed saved farmers money by reducing costs associated with keeping animals, such as setting aside fields to grow feed, housing animals in separate barns, and paying labourers to care for animals. Defenders of horses, on the other hand, pointed out that switching to tractors meant farmers had to purchase all new implements, such as plows, because those designed to be pulled by horses would not work with the new tractors ([Fitzgerald, 2003](#), p. 99). One horse advocate noted around 1920,

"We believe all tractors are bad, only some are worse than others. When it comes down to actual facts in dollars and cents, we believe that any farmer who disposes of his horses and intends to do all of his farmwork with tractors, will eventually 'hit the rocks,' and that he is only working for the man who sells the tractors, for as soon as he had made enough wheat or other farm products to pay for his tractor, it will be necessary for him to purchase another" (quoted in [Ellenberg, 2000](#), p. 552).

Some critics highlighted the relative energy efficiency of horses vs. tractors and even foresaw a day when fossil energy would be depleted:

"The economic importance of the horse may increase with the passage of time, with the depletion and eventual exhaustion of the petroleum resources, which are being depleted at a greater rate than the people generally realize. Attempts are being made, and rightly, to blend gasoline with alcohol. But alcohol as a fuel may not be able to compete with the original feed from which the alcohol was made. The feeds can, perhaps, be more efficiently converted to work by a horse than by an engine after the conversion of the feed into alcohol" (Brody & Trowbridge, 1937, p. 24).

Nonetheless, tractor adoption advanced quickly in the first decades of the 20th century, spurred by the First World War. As Fitzgerald points out (2003, p. 94), many farmers adopted tractors at this time as part of the wider war effort to increase food production. Studies of comparative costs of tractors vs. horses emerged to explain tractor diffusion ([Ellenberg, 2000](#); [Gaines & Crowe, 1950](#); [Jasny, 1935](#); [Nourse, 1930](#)).

Yet as tractor adoption accelerated, some critics pointed out the role of farm mechanization in displacing farm labourers, sharecroppers, and tenant farmers from the land ([Nourse, 1930](#)). Most of those who were displaced were from marginalized groups, including people of colour, who farmed the land for others, but often did not hold legal title to it. Anna Rochester, in her 1940 book, *Why Farmers are Poor*, drew a direct connection between tractors and growing poverty:

"Uncounted thousands have been driven off the land. Tractors are obliterating the boundaries of little sharecropper plots in some of the older cotton regions, tossing families from the poverty of extreme exploitation into the worse destitution of complete unemployment" (Rochester, 1940, p. 10).

In other words, tractors effectively served as barriers to the success of those who were displaced ([Beale, 1991](#)).

As tractor adoption spread, land concentration accelerated. The farm population in the US, for example, declined by 25 percent between 1920 and 1945 ([McMillan, 1949](#), p. 24). As farmers adopted more powerful machines to work their land, they often sought to expand their farm size to lower their marginal cost of farm machinery per unit of land. As farmers sought to purchase more land, however, critics pointed out that many went into debt and found themselves more exposed to agricultural market volatility ([Fitzgerald, 2003](#), p. 93; Olmstead & Rhode, 2001; Rochester, 1940, p. 171). One analyst at the time decried farmers'

"subsequent loss of traditional self-sufficiency and autonomy" (McMillan, 1949, p. 26). Increased mechanization on ever larger farms also contributed to overproduction, which led to lower prices that ultimately hurt farmers' incomes. As one farmer noted at the time: "Tractors cause the over production . . . and it encourages corporate farming, which is a great drawback for agriculture. It crowds the small farmer and the beginner out of the game" ([Ellenberg, 2000](#), p. 562).

In the US, Black farmers were especially disadvantaged by these dynamics. It was around 1920 that the number of Black farmers in the United States began to decline, just as tractor adoption ramped up ([Olmstead & Rhode, 2001](#); [Taylor, 2018](#)). During the Great Depression in the 1930s, critics pointed to farm mechanization as a source of economic inequality, exacerbated by insufficient employment opportunities in cities to absorb excess labour, contributing to racial tensions ([Hamilton, 1939](#); [U.S.D.A., 1940](#)).

The implements pulled by tractors, such as plows, were also subject to criticism as early as the mid-1800s because of their impact on soil structure and fertility. While these concerns about plows date back thousands of years, the polished iron and steel tipped moldboard plows were specifically called out for accelerating soil loss in North America ([Lal et al., 2007](#)). The wider impact of land clearing with these more modern plows cannot be easily disentangled from the dynamics that encouraged the widespread use of this technology in the first place. Colonial expansion and settlement by people of European origin were major forces in the violent displacement of Indigenous peoples from their traditional lands. And global market expansion for crops such as wheat and maize further encouraged European settler colonialism in North America ([Holleman, 2017](#)). Farmers also sought to expand production to provide a buffer against volatile commodity prices. As these dynamics unfolded, the firms that manufactured plows profited handsomely, but their role in this process has been largely overlooked.

Polished iron and steel moldboard plows contributed to soil degradation in several ways. Cutting deep into the soil to turn it over, these tools played a role in fracturing soil structure and causing tillage erosion by moving soil from one part of the field to another, especially on slopes. Once disturbed in this way, soils were at increased risk of further erosion from water and wind. Cutting into the soil also killed beneficial life forms in the soil, such as earthworms, fungi, and other living organisms. Extensive tillage also contributed to a decline in soil organic matter, even though it also played a role in temporarily raised mineralization of key nutrients that could boost soil fertility ([Lal et al., 2007](#), p. 4). Indeed, the damage to soil from over-plowing has been widely linked to the 1930s Dust Bowl. Critics pointed out that the storms led to the loss of some 350 million tons of topsoil in storms so severe that, in some cases, they carried soil from the US Midwest to locations as far as Chicago and New York (Faulkner,

1945; [Lal et al., 2007](#); [Sears, 1935](#)). In his 1943 book *Ploughman's Folly*, critic Edward H. Faulkner decried the widespread use of tractors and plows for their role in compacting and eroding the soil:

"We have equipped our farmers with a greater tonnage of machinery per man than any other nation. Our agricultural population has proceeded to use that machinery to the end of destroying the soil in less time than any other people has been known to do in recorded history. This is hardly a record to be proud of" (Faulkner, 1943, p.5).

Although Faulkner's ideas were not widely accepted in the scientific community at the time ([Schofield, 1944](#)), his plea to conserve soil by dramatically reducing tillage became widely accepted in subsequent years.

Early Critiques of Commercial Fertilizers

In the early days of commercial fertilizer in the 1840s-60s, there was public critique of the harsh working conditions in the guano and phosphate mines ([Melillo, 2012](#)). The guano industry, for example, was notorious for deceiving workers from Asia into indentured servitude. Working conditions were harsh, and many took their own lives. As noted in a 1855 *New York Times* editorial:

"Under a scorching tropical sun, doomed to severest toil seven days in the week, the cruel lash quivering in their bleeding, shrinking flesh, whenever from failing health or exhausted strength they lag in their tasks, furnished with poor and scanty fare, and breathing in a poisonous atmosphere, imagination can scarcely paint elsewhere so miserable an existence" (New York Times, 1855).

The human cost of the fertilizer industry, however, was often overshadowed by advocates of the fertilizer industry, who saw it as necessary to ensure food security. Because these costs were often experienced at a distance from the main fertilizer markets in Europe and North America, the fertilizer industry, as a result, was able to externalize the social costs of mineral extraction.

The development of processes to produce synthetic nitrogen and the mechanization of processes to mine phosphates and potash led to a shift in labour regimes in the industry and a growing reliance on fossil fuels as a key resource in the sector. With this change came a dramatic increase in the use of nitrogen-based fertilizers, especially in those countries that had access to synthetic production technology. During the First and Second World Wars, the use of synthetic fertilizers was widely promoted on national security grounds, to reduce

dependence on imported foods as well as to advance the technology of nitrogen synthesis, which was also used in bomb-making ([Conford, 2002](#)). The main public concern at the time was about the power of the dominant firms in the fertilizer sector to set the price, as cartels were rampant in the sector ([Clapp, 2025](#)).

The advent of synthetic nitrogen fertilizers also brought ecological critiques. One prominent critique came from Paul Sears in his widely read 1935 book, *Deserts on the March*. Sears lamented the rapid pace of soil fertility loss on US farmland, which he argued made it "unfit" for agriculture. He saw constant replenishment of fertility loss with chemical fertilizers as dangerous: "To mine the soil persistently and trust to heavy doses of chemical fertilizer when it becomes exhausted is to disregard the plain and explicit warning of nature." ([Sears, 1935](#), pp. 29, 128, 67). Similarly, prominent British agricultural scientist Sir Albert Howard was also highly critical of synthetic fertilizers. "Artificials," he warned (referring to synthetic fertilizer), damaged living organisms that played a necessary role in composting soil organic matter. Howard also foreshadowed lock-ins across the inputs, seeing growing artificial fertilizer use as a product of "the imperative demands made on the farmer by the invention of machinery" ([Howard, 1947](#), p. 71). Howard also decried the ties between the large fertilizer firms and the British Ministry of Agriculture, accusing the latter of being merely the "salesmen of the contents of the fertilizer bag" because of its subsidization of farmers to purchase synthetic fertilizers (Howard, 1947, p. 76). As he noted in his 1946 book, *The War in the Soil*:

"The war in the soil is the result of a conflict between the birthright of humanity—fresh food from fertile soil—and the profits of a section of Big Business in the shape of the manufacturers of artificial fertilizers and their satellite companies who produce poison sprays to protect crops from pests and who prepare the various remedies for the diseases of live stock and mankind" (Howard, 1946, quoted in Heckman, 2006, p. 145).

Other leading thinkers in the European organic movement at the time were also concerned about the role of synthetic fertilizer, including its disruption of plant metabolism and soil chemical balance ([Vogt, 2007](#); [Balfour, 1943](#)).

The 1930s-40s saw the emergence of highly polarized debates over the pros and cons of organic vs. conventional farming. Proponents of synthetic nitrogen, for example, argued that from the plant's perspective, artificial nitrogen was effectively the same as nitrogen derived from organic materials and claimed that the organic movement was spreading misinformation ([Heckman, 2006](#), p. 146). In the intervening century, however, interest in organic farming has only grown, especially as more information has emerged about the full range of ecological

costs associated with synthetic fertilizers, including not just the problems pointed out by its early critics, but also nitrogen pollution, greenhouse gas emissions, and energy use.

Early Critiques of Seed Hybridization

The development of the commercial seed industry had huge social and ecological consequences. The early seed industry in North America, for example, depended not only on access to plant germplasm but also on the knowledge of how to cultivate it. Settlers appropriated both resources from Indigenous peoples, along with their land. Maize cultivation was traditionally a female activity in North American Indigenous societies, who practiced a milpa system of cultivating maize with beans and squash. ([Pleasant et al., 2010](#)). The process of colonization shifted the activities of cultivation, along with seed selection and seed saving, from Indigenous women to white male settlers. As seeds increasingly became commercial products in the mid-late 1800s in the US, free government distribution of seeds to farmers played a role in encouraging further settlement to the west, further displacing Indigenous peoples from their lands and the installation of monoculture agriculture ([Clapp, 2025](#); [Kloppenborg, 2004](#)).

The advent of hybrid seeds from the 1920s onwards also had important consequences. Because hybrid seeds cannot be saved and deliver the same results, farmers were effectively locked into purchasing new seeds each season ([Fitzgerald, 1993](#); [Kloppenborg, 2004](#)). Because hybrid seeds were more expensive than traditional varieties, farmers who adopted them saw their expenses rise considerably, especially because they had to replenish them each year ([Fitzgerald, 1990](#), p. 189). Moreover, hybrid seeds worked best with increased applications of fertilizer, meaning farmers had to purchase both products. In this process, farmers lost their role in seed selection and breeding on the farm, leading to what many call a "deskilling" of farmers with respect to seed ([Fitzgerald, 1993](#); [Stone, 2007](#)).

There were also ecological costs associated with hybrids. As the adoption of hybrids rose in North America throughout the 1930s, there was growing concern among plant scientists that their spread could threaten plant genetic diversity, a crucial input to plant breeding. Some scientists warned that many diverse, older varieties of crops could become extinct if measures were not undertaken to protect them ([Harlan & Martini, 1936](#); [Landauer, 1945](#)). As historian Helen Curry notes, this was part of a longer trajectory of concern, as there was worry that

improved seed varieties could displace plant diversity as early as the 1890s ([Curry, 2017](#)).

The growing chorus of critique led to several efforts to protect plant genetic diversity so that it could continue to contribute to plant breeding in the future. From the early 1940s, for example, the Rockefeller Foundation undertook measures as part of the Green Revolution to collect open pollinated varieties of maize in Mexico ([Clark, 1954](#); [Curry, 2017](#)). Indeed, there was widespread concern about the potential loss of seed varieties that had undergone thousands of years of evolution and selection by farmers ([Clark, 1954](#), p. 78). As stated by Paul Mangelsdorf - Harvard University botanist and maize seed breeder who also served as a consultant to the Rockefeller Foundation - in a 1951 article published in *Scientific American*:

The almost universal use of hybrid corn in the U. S., and the prospective wide adoption of it in other parts of the world, is not without its dangers. Chief among these is that farmers as a rule are no longer growing the open-pollinated varieties. These varieties, from which all inbred strains are ultimately derived, may therefore become extinct (Mangelsdorf, 1951, p. 44).

These concerns prompted the United States government to form the Committee on Preservation of Indigenous Strains of Maize in 1951. J. Allen Clark, the chair of that committee, noted, "In view of the rapid increase in the growing of hybrid corns in the United States and of the apparent value of the Mexican collection for producing new hybrids, the importance of keeping these collections viable and of preserving the pioneer open-pollinated corns of the United States was obvious" ([Clark, 1954](#), p. 79). This committee collected some twelve thousand varieties of maize for preservation at regional seed centres, which were subsequently made available for future plant breeding programs ([Clark, 1956](#)).

Although there was widespread acknowledgment of the threat hybrid seeds posed to plant genetic diversity, there was no halt in that type of seed breeding. Hybridization at the time was widely viewed as a necessary technological pathway, provided it was combined with the responsibility of maintaining plant germplasm diversity to secure future breeding programs for crop improvement. Yet, in subsequent years, there has been growing awareness of the loss of agricultural biodiversity because of monoculture planting practices on industrial farms.

Early Critiques of Chemical Pesticides

The development of the global pesticides industry came with enormous costs. When commercial pesticides came onto the market in the mid-1800s, their health risks were widely recognized, particularly because those early chemicals were often acutely toxic and required repeated applications, thus posing risks to producers who used them ([Perkins, 1982](#)). When synthetic pesticides came along in the 1930s-40s, they were widely seen as an improvement over earlier chemical pesticides because many of the new chemicals – such as DDT – were not acutely toxic. Moreover, synthetic pesticides were not only less expensive but also persistent, meaning that they could be sprayed less often. But at the same time, there were early scientific indications of serious risks associated with DDT and other synthetic pesticides. Almost immediately after its introduction, for example, some scientists pointed out concerns about the safety of DDT, including risks to wildlife and the fact that pests almost immediately became resistant to it, as well as worries about its potential to cause cancer ([Lindquist & Wilson, 1948](#)). Sociologists Valerie Gunter and Craig Harris, analyzing news items about DDT in the New York Times in the early postwar years, found that from 1944 to 1949, approximately one in six articles on the topic raised safety concerns, and that by 1954, that ratio climbed to nearly one in three ([Gunter & Harris, 1998](#)).

There was early evidence that DDT affected wildlife such as mammals, birds, and fish ([Cottam & Higgins, 1946](#); Dunlap, 1978). Several studies also found that exposure to large amounts of it resulted in damage to the central nervous system. Other studies indicated that DDT could accumulate in human tissue and be passed on to offspring via breast milk. These findings prompted worry about the potential cumulative effects of consuming food items treated with DDT. By the early 1950s, DDT had been found in the fat cells of people who did not even have occupational exposure to it ([Dunlap, 1981](#), pp. 64–66). As scientific evidence mounted, the safety of DDT was debated in US congressional hearings in 1950 and 1951. There was widespread sentiment that the legislation governing acceptable residue levels of chemical pesticides was insufficient. Yet pesticide lobby groups, including the National Agricultural Chemical Association and the Manufacturing Chemists' Association, expressed deep opposition to more stringent regulations (Dunlap, 1981, pp. 71–74).

There were also social costs associated with the growing use of chemical pesticides. As farmers increasingly relied on synthetic chemicals to manage pests on their farms, their knowledge about natural forms of pest control was lost, and expertise on pest control was effectively transferred from farmers to chemical companies ([Vandeman, 1995](#)). As a result, farmers became much more dependent on large chemical companies for information – the very actors with a vested

interest in selling more products. Not surprisingly, those firms often presented their products as safe and effective while encouraging farmers to over-spray their fields. While DDT and other pesticides were typically less expensive than earlier pesticides based on botanical and mineral substances, the costs associated with pest control grew due to the increased array of products targeting specific pests. As a result, many farmers shifted practices from spraying their crops only when there were pest outbreaks to spraying pesticides on a regular basis to prevent such outbreaks ([Flint & Bosch, 1981](#), p. 70; Vandeman, 1995, p. 55).

But as pests became increasingly resistant to pesticides, they became more difficult to deal with because of the phenomenon of pest resurgence. In many cases, insecticides killed the pest being targeted, but because the pesticides were nonselective, they also killed the natural predators of the pest as well as other beneficial organisms, like honeybees ([MacIntyre, 1987](#), p. 22; Perkins, 1982, p. 11). With natural predators eliminated after spraying, any surviving pests could reestablish themselves ([Flint & Bosch, 1981](#), p. 74). In such a context, pesticide application often multiplied the very pest problems the chemicals sought to address, which ironically meant the application of additional types of pesticides to address them (Flint & Van den Bosch, 1981, p. 76; Perkins, 1982, p. 21). Policy analyst Angus MacIntyre likened this process to drug addiction: "Initial uses were followed by successively larger doses, then by troubled dependence, and eventually by some type of crisis" (MacIntyre, 1987, p. 552).

Despite early scientific recognition of various problems with pesticides, these chemicals have maintained their role as a key component of industrial agriculture. The lag between their use and their effects worked to shield firms that produced them from responsibility for the impact of bioaccumulation, which takes time to manifest and cause harm, making definitive proof of the harm of specific chemicals difficult. Moreover, the concept of bioaccumulation of chemicals and their association with elevated cancer risk was a somewhat novel concept in the early years of synthetic pesticides. As a result, the dominant firms were able to externalize those costs as they reaped huge profits in a booming industry.

Lessons for Current Debates on Sustainable Agriculture

What became of these early critiques of industrial agriculture, and in what ways do they remain relevant? First, it is important to note that World Wars I and II played a role in tamping down these critiques, even as they continued to be expressed by some critics throughout and after both wars. The wartime policy strategy of governments both in Europe and in North America pressed farmers to produce more food because of widespread hunger and starvation in Europe caused by the conflicts. For North America, it was about producing more food, not just

for home consumption, but also to ship it to food deprived allies during the war. And in Europe, where hunger stalked during the wars, and millions died from starvation, there was a major push to modernize and industrialize agriculture to bolster food production ([Maltz, 2015](#)). In this context, the adoption of farm machinery, pesticides, modern seeds, and fertilizers was all seen as a patriotic act what propelled industrial agriculture, and as such placed a shadow over the emerging critiques of industrial agricultural methods.

Still, the early critiques of industrial agriculture were important and offer lessons for current debates about how to make food systems more sustainable. While much has changed in terms of the specific technologies within the broad categories of inputs – such as the rise of digital agriculture, agricultural biotechnology, and genome editing – the underlying points of criticism remain highly pertinent to present debates. At the same time, some of the earlier concerns raised by critics have become less relevant, while new issues that were not anticipated by earlier critics, such as climate change, have moved centre stage in discussions on sustainability transformations for food systems. More broadly, looking back at historical opposition to industrial agriculture sheds light on several key challenges that are likely to endure.

To begin, the early critics across all four of the major farm inputs highlighted the role of corporate power and its toll on farmer autonomy. From the Granger movement's focus on the monopoly power of the farm machinery companies, to the critics of artificial fertilizers and pesticides, to seed hybridization, the critiques of industrial agriculture have pointed to the decline in farmer autonomy as a corollary to the rise in corporate dominance in the sector. With the rise of digital farming in the current era, today's critics are also pointing to corporate power and declining farmer autonomy, as just a handful of firms dominate digital platforms and there is concern over corporate control over farmers' data ([Bronson, 2022](#); [Carolan, 2020](#)). The dominant machinery firms have also put a lock on repairs, requiring farmers to use only authorized dealers to complete repairs, further constraining farmers' ability to choose ([Mirr, 2019](#); [Montello, 2020](#)). Corporate profiteering has also been a key theme in more recent years with respect to fertilizer, as farmers have accused the dominant firms of deliberately driving up prices to maximize profits ([Clapp & Howard, 2023](#)). Loss of farmer control has been highlighted by critics of genetically modified herbicide-resistant seeds, as the dominant firms forced farmers to sign agreements that they will not save their seeds for planting the next season ([Howard, 2016](#)).

At their root, these critiques in the current era, like in the past, are about farmers' autonomy and agency – their right to make choices and to shape their own relationship to farming. The enduring nature of this concern points to the deeply entwined nature of corporate power with industrial farming – one which critics have long resisted, but which has been difficult to overcome given the extensive

access the dominant firms have to different forms of power with which they can influence markets, technologies, and governance ([Clapp, 2021](#)).

Other ideas first put forward by early critics of industrial agriculture also continue to be relevant in current debates about sustainable food systems, although in new ways. In the 1930s, early critics warned that biodiversity loss would accompany the hybridization of seeds, a concern that has been borne out as the FAO reports that around 75% of agricultural biodiversity has been lost in the past century ([Elouafi, 2024](#)). Today, concern about biodiversity loss has been somewhat overshadowed by debates about agricultural biotechnology and genome editing. The concern with these new technologies has focused more on safety questions, not just regarding genetic modification of seeds, but also on how those seeds have been modified to make them resistant to the application of specific herbicides. Those herbicides, including glyphosate, dicamba, and other chemicals, have raised huge questions about human health and safety, especially because the growth in adoption of genetically altered seeds has led to a massive increase in herbicide use (Shattuck, 2021). There is growing evidence that these herbicides cause cancer and other health problems, in addition to the fact that they are damaging ecosystems ([Clapp, 2021](#)).

Other ecological concerns about pesticides, including their toxicity as well as the capacity of pests to quickly become resistant to them, have also remained pertinent in today's debates, but again in new ways. While early critics did not have an appreciation for the longer-term consequences of these chemicals and processes, such as bioaccumulation, today we have ample evidence of these effects. Yet at the same time, some of these chemicals have remained contested, in part because of corporate efforts to promote their safety in public debates as well as their lobbying efforts with governments to keep those chemicals registered for use. Some of the worst chemicals from the early days, like DDT and other toxic organochlorines, have since been banned in most countries. However, farmers today have become much more reliant on toxic herbicides, such as paraquat, that are banned in some countries, but not others (notably the US still allows use of this herbicide on farm fields) (Shattuck, 2021). There remains robust debate about the safety of herbicides in agriculture, which has prolonged debates about the future of agriculture, even in the face of extensive and longstanding scientific evidence of their harms.

Questions about land distribution and access also remain relevant today, including in new ways. While the big concern in the past was that mechanization was displacing people from the land and driving them into poverty in urban centres, today the debate is much more about land access for those who want to take up farming. There is broad concern today about the huge decline in the number of Black farmers in the US, for example, which dropped precipitously since the 1930s, exactly the time of a huge uptick in tractor uptake in that country ([Taylor,](#)

2018). Yet debates today do not typically note the historical role of mechanization in the problem of farmland consolidation and inequitable access for newcomers and marginalized farmers. This reticence on the role of mechanization may have to do with the fact that tractors and other machinery have become so ubiquitous on farms that it is difficult to imagine farming today without machines. While farm machinery itself was highly problematized in the past, the current focus is much more on structural inequities in landholdings ([Ferguson, 2021](#); [Wittman & James, 2022](#)) as the source of that inequity. In this way, these critiques mirror the approach of the Grangers in the 1870s, who railed against the monopoly power of the large firms, but not against the machines that they made.

Several of the early concerns surrounding the use of farm machinery, like soil compaction from tractor use and fracturing of soil and damage to life forms in the soil – while still important today – have been less prominent in contemporary debates. Because of the dominance of machinery on farms and the rise of synthetic fertilizers over the past century, there has been a wide assumption for the past 80 or so years that soil damage can simply be 'addressed' with additional fertilizer use. This assumption is now changing, as discussed below, but more because of the climate impact of agriculture than because of its damage to soils ([Erisman et al., 2011](#); [Stuart et al., 2014](#)). The fine tilling of the soil with disc harrows that gave rise to the 1930s dust bowl has also been reduced through new kinds of practices, such as increased fertilizer use, the use of herbicides (including no-till farming), and machinery improvements that have mitigated problems of wind erosion. However, these changes, especially the growth in no-till farming, have led to huge growth in herbicide use, which, as noted above, is highly contested ([Benbrook, 2016](#)).

The early critiques of industrial agriculture highlighted the poor labour conditions in fertilizer mining – both in the guano mines and phosphate mines. The depletion of guano reserves and the rise of fossil energy-powered machinery for mining have reduced the focus on these forms of labour in current debates on the future of farming. Much more concern today is focused on working conditions for migrant farm labour in food production. While there were certainly migrant farm workers in the early days, there was less concern about worker rights, and many farmers sought to replace those workers with machinery ([McCormick, 1931](#)). The continued need for human labour on farms, and the growth in migrant farmworkers – many of whom are undocumented – has fostered poor working and living conditions on many farms.

Some issues that have become dominant in today's debates about sustainable farming were not anticipated by those who expressed concern about industrial farming a century or more ago. The most prominent of these issues is climate change – including the fossil energy and greenhouse gases associated with industrial farming as well as the impact of the changing climate on agriculture

([Fanzo et al., 2018](#); [Vermeulen et al., 2012](#); [Zurek et al., 2022](#)). The early critics of industrial agriculture did not foresee the massive climate crisis that is currently upon us, despite some early recognition of fossil energy dependence.

The interconnections between the climate crisis and agriculture are complex, and space does not allow a full assessment here. However, it is worth noting that the rise of synthetic nitrogen is perhaps one of the biggest contributors to greenhouse gases on the farm, both from its production (which relies on natural gas) and its application (which emits nitrous oxide, a greenhouse gas up to 300 times more potent than carbon dioxide). Fossil energy and emissions are also associated with land clearing, mechanization, pesticide use, plastics on the farm (coated seeds, fertilizer, plastic mulches, etc.), and drying and storage of crops on farms. All told, current industrial food systems account for around 30% of greenhouse gas emissions and around 15 percent of fossil fuel use (GAFF, 2023). At the same time, industrial food production is profoundly challenged by the changing climate. Indeed, many see climate change as an existential crisis for our food systems, which demands fundamental transformative change to new production models. Critics of industrial agriculture, for example, widely promote agroecology as an alternative production model. Agroecology – which uses natural practices such as intercropping rather than toxic chemicals – sequesters carbon ([Blaix et al., 2026](#); [Wezel et al., 2025](#)). Yet, it is worth noting that even organic and agroecological farming makes use of farm machinery.

An important lesson from the comparison of past critiques and current debates is that many of the underlying concerns – farmer autonomy, corporate power, ecological disruption and degradation, labour, and land access – all remain relevant in today's debates, even if in new ways. Although earlier critiques could not halt the expansion of industrial agriculture, the work of those critics laid important groundwork that led to growing recognition of these key issues, even if some of them remain contested and unresolved today. The scientific work of the critics has contributed to growing acceptance that certain aspects of industrial agriculture pose risks that are not acceptable. For example, there was early progress on recognition that pesticides can cause harm, and some of those chemicals have since been banned. There was early recognition that there is a need to preserve biodiversity, as the numerous seed banks seeking to safeguard crop germplasm demonstrate, even if this approach is not the *in-situ* solution many critics would rather support ([Curry, 2022](#)). There was early recognition that there was a need to reduce the over-plowing of soil, and today, no-till farming has spread as a practice ([Lal et al., 2007](#)).

The fact that there is robust debate about certain aspects of industrial farming in this current moment is a testament to the fact that the critics have pressed these matters to the extent that the powerful transnational agribusiness firms have been forced to respond. But challenges remain. First, with problems such as climate

change, genome editing, the use of certain herbicides, loss of control over data ownership, and plastics on farms, there is a distancing of cause and effect, which opens the door to powerful actors and enables them to promote the industrial agricultural model as a solution to these problems. This process has continued since the early rise of industrial agriculture, and the power of dominant firms to craft and spread opposing narratives is likely to continue to serve as a recurring roadblock for critics ([Stone, 2022](#)).

Second, there is a much smaller proportion of the population in industrialized countries who are engaged in farming compared to a century ago – typically around 2-5 percent of the population compared to around 80 percent in the mid-1800s. This drop in the farming population presents challenges to critics of industrial agriculture, especially as the few farmers who remain on the land perceive those critiques to be against their way of life, rather than a call for reform that would benefit farmers as well as the broader public. While in many Global South countries, farmers make up a higher percentage of the population, those farmers' voices have been overpowered by the powerful channels of influence of the large agribusiness firms promoting industrial agriculture as essential to "feed the world" ([Chopra, 2015](#)). Alliances between critics and farmers in both the Global North and the Global South can help to strengthen the transformative agenda for food systems.

Finally, the lock-ins and path dependency of the industrial agricultural model – while not as recognized by the early critics – are a significant challenge because lock-ins make it all the more difficult for farmers to switch to new farming systems ([Vanloqueren & Baret, 2009](#)). Lock-ins also reinforced corporate power in debates about the future of farming and played a role in the industrial agricultural model being shipped out around the world in the form of the Green Revolution. These technological and behavioral lock-ins also contributed to institutional lock-ins whereby government policy has tended to favour the industrial agricultural model ([Clapp, 2025](#)). Focusing on the ways in which corporate power extends these lock-ins and taking measures to tackle that power through policy change can potentially open pathways to break those lock-ins. This remains an important area for further research.

Conclusion

In the context of today's debates on the future of agriculture in the context of the sustainability crisis, it is important to look to the past for insights on how the last transformation of agriculture – the shift to industrial farming, which is at the root of many of the problems facing food systems today – played out. As this paper has shown, the critiques of industrial agriculture have long roots. Almost from the time the new technologies that make up the pillars of industrial agriculture –

farm machinery, artificial fertilizers, hybrid seeds, and chemical pesticides – were introduced, they faced sharp public criticism from early analysts who warned of the social and ecological dangers of that model of farming. These early critics identified some of the core issues that remain relevant today, including the autonomy of farmers in the face of corporate power over those inputs and land distribution and access. They also identified ecological concerns, including soil fertility and structure loss, biodiversity loss, pest resistance, and health and safety issues associated with chemical pesticides. While these points of criticism have in some cases brought about changes to the model, in other cases those problems persist. At the same time, the early critics did not foresee some aspects of the social and ecological crisis associated with modern industrial agriculture, such as the contribution of the industrial farming model to climate change, as well as that model's vulnerability to a warming world. Today's critics of industrial agriculture can learn from the earlier history to identify areas of success and weakness in their campaigns to transform agriculture, focusing on documented scientific evidence, building alliances, and tackling corporate power, to break the lock-in of industrial agriculture and its widespread social and ecological costs.

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