Legibility and the Legacy of Racialized Dispossession in Digital Agriculture

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This paper examines the causes and consequences of legibility as an organizing principle in the design of digital agriculture (DA) systems in the United States. Legibility refers to systems of governance that use simplified understandings of a situation to control and direct action upon it. Legibility in digital agriculture systems occurs at the confluence of two traditions of legibility: the data-driven model common in the design of digital systems, and tactics for the control of nature and labor that have developed in the United States since the foundation of the colonies. Our argument draws from (1) a historical analysis of broader patterns of agricultural technology and racialized land dispossession in what is now the United States and (2) empirical fieldwork that examines the adoption and maintenance of digital agriculture systems in rural New York State. We describe the role that legibility historically has played in the development of agricultural systems in the US, and their consequences for who is able to farm and how. This history raises the questions: What is made legible to whom? In that process, what becomes illegible? While legibility promises transparent and environmentally beneficial control, in our fieldwork we find that the demands of legibility are also restructuring the physical landscape, creating additional invisible labor, producing systems that are brittle to real-world conditions on farms, and creating opaque systems that block people from adapting to their circumstances. In reading our fieldwork together with the historical case, we demonstrate the pressures that are shaping the stakes, subject, and objects of legibility in agricultural technology. As more data-driven systems are used for environmental contexts, the CSCW community needs to extend its ways to understand how data-driven systems impact land, labor, and resources.

CCS Concepts: • Human-centered computing → Collaborative and social computing → Empirical studies in collaborative and social computing

KEYWORDS: digital agriculture, rural computing, design of data-driven systems, race in agriculture

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1 INTRODUCTION

Increasingly, networked systems are designed, developed, and deployed in the agriculture industry to address social, economic, and environmental challenges in food production. Many of

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these systems are designed for on-farm applications to address issues like rising costs of farm labor and equipment, natural resource management, and weather fluctuations associated with climate change [50,54,59]. These systems include a broad suite of tools and infrastructures that use computing technologies throughout the agricultural process, such as planting, watering, weeding, and harvesting. This development follows a recent trend where networked and data-driven systems are developed for a wide variety of settings and activities [22]. In recent years, the CSCW and HCI community has raised concerns about how these systems could affect existing work and practices. This critical scholarship in computing questions the ethics of these systems by focusing on issues like increasing governance of labor, privacy concerns, and unchecked biases [22,40,44]. Our paper contributes to this literature by examining the issues emerging from the confluence of digital systems of control and the historical systems of control of land, living beings, and labor at work in agriculture in the United States.

Our core contention is that a vision of legibility underlies many digital and data-driven agriculture (DA) systems currently under development in the United States. By legibility, we mean methods of governance that couple simplified understandings of an environment or situation – often produced through quantification – to actions taken to control that system. Hopes that digital agriculture will increase the productivity of agriculture while reducing its environmental impact are grounded in faith in the capacity of automated digital systems to adequately sense, understand, and control land and the living beings dwelling on it. This faith draws strength from the paradigms of data-driven systems in digital design, as well as from longer-standing traditions of control of land, plants, animals, and labor within the history of agricultural technology and production since colonies were established on the continent.

In this paper, we analyze the historical legacy and present reality of digital agricultural technologies in the US in order to characterize what is at stake in using legibility as a core design frame for contemporary DA. While adoption of these systems is nascent, especially in our region of study in the northeast United States, our observations and analysis can inform current approaches to the development of digital agriculture systems. We ask: in the context of digital agriculture, what is made legible to whom? In that process, what becomes illegible?

We begin by situating our research in current dialogues in digital agriculture research, building on previous work in science and technology studies (STS) and anthropology. We define legibility as systems of governance that bring situations and environments under control by coupling processes of simplified understanding, such as through quantification and modeling, with action intended to optimize outcomes from that situation. We analyze the causes and consequences of legibility in digital agriculture through two case studies: (1) a historical analysis of broader patterns of agricultural technology and racialized land possession in the United States and (2) a field study analyzing the current adoption of digital agriculture technologies on farms in the northeastern United States. We look at the historical roots of legibility in agricultural technology by analyzing the rise of agricultural technology and governance in the US, with a focus on the ways in which agriculture in general and modernized agricultural technology in particular have functioned to create a racialized dispossession of land. While legibility can frame our understanding of how technologies may unfold in the field, our historical analysis undermines any notions of neutrality of the logics that drive legibility, such as extractive data logics and colonial settler logics. Legibility in digital agriculture promises increased, transparent control over productivity and the environmental impact of agriculture. We find in our fieldwork that the demands of legibility are simultaneously restructuring the environment, creating new forms of invisible labor of data collection and management, producing breakdowns in the face of farm variability, and generating opacity which hinders their users' ability to adapt devices to farm conditions. These issues raise questions of who legibility is for and what is rendered legible and illegible.

Our overall finding is that the data-driven paradigm of digital design reinforces and refracts with the systems for control of land and labor that have arisen through the history of US agricultural technology. This situation calls attention to the need for contextual analysis and historical understanding in the design of such data-driven systems. Our conclusion is the ethics and consequences of digital agriculture systems and other systems that measure and impact the land are not simply issues about or for design in a narrow sense; they require attention to the institutions, systems of governance, logics, and histories in which those systems are embedded.

2 BACKGROUND

2.1 Agriculture and CSCW

Agriculture and food systems have long been a focus of CSCW and HCI. As Steup et al. has surveyed [58], many of these efforts have been aimed towards small-scale farms, community gardens, and urban contexts. Much of this existing research focuses on the role of the farmer, grower, or consumer in the food system [31,33,39,43,48,58]. While these actors play important roles in food systems, we examine additional stakeholders, such as extension agents, federal institutions, and land-grant universities, to illuminate the broader politics of agricultural infrastructure. Rather than focus on small-scale growers, we provide an account of how networked and data-driven systems are used in industrial agriculture settings. Industrial, or conventional, agriculture typically refers to large-scale farming that relies on a combination of mechanization and chemical interventions, such as synthetic fertilizers, herbicides, and pesticides for monocultural row cropping and livestock production. While practices like small-scale organic farming have seen a steady rise in recent years, industrial agriculture continues to be the main form of agriculture in the United States, making up about 98% of farmland [67]. Given the dominance of this form of agriculture, many recent efforts towards digital agriculture systems are designed for industrial contexts.

Our work is situated in recent technological developments in agriculture that have prompted discussion among researchers, policymakers, and people in industry about whether these changes will usher in a new revolution in agriculture. This potential revolution, called "Agriculture 4.0" or "the fourth revolution," is imagined to be the consequence of data-driven techniques, such as networked technologies, artificial intelligence, and robotics, to radically transform farming [50]. Under this understanding, earlier agricultural revolutions were characterized by widespread and large-scale transitions in agricultural methods and practices. These revolutions include the prehistoric shift to agricultural settlements from hunting and gathering, the increase of mechanization in conjunction with the British Industrial Revolution, and most recently, the Green Revolution, which introduced cultivating and breeding technologies like fertilizers, pesticides, and high-yield crops in the mid 20^{th} century. Proponents of digital agriculture often cite pressing concerns like climate change and rising populations as the motivations for this current revolution [5].

Despite the revolutionary language of digital agriculture, the use of technologies within industrial agriculture is not new. The Green Revolution played a large role in disseminating technologies that bring high crop yields in efforts to increase global food production. Additionally, farmers have been using 'precision agriculture,' i.e., digital technologies that incorporate GPS and other satellite positioning technologies, for tasks such as tractor guidance, field mapping, and yield mapping since the 1990's [64]. While such technological development has increased the productivity and efficiency of industrial agriculture, players in the industry are aware of criticisms that the historical introduction of new technologies has exacerbated socioecological issues like biodiversity, fossil fuel consumption, land distribution, and contamination of soil and water [27,29]. New digital agriculture applications are often framed as a win-win means to address such criticisms because their extensive data collection and analysis could be used in efforts to improve sustainability, for example by reducing the indiscriminate use of pesticides, while simultaneously increasing crop yield.

In this paper, we specifically analyze the rise of digital agriculture within the context of racialized histories and institutions that are involved in U.S. agricultural production. Race has played a significant role in shaping contemporary agricultural landscapes. According to the 2017 US Census of Agriculture, more than 95% of farmers and farm owners in the United States are white [68]. As we will describe, this homogeneity is a result of specific policies and practices that affect factors like land ownership. We describe how these policies have been built into federal institutions that steward the development of scientific agriculture, and we explore the degree to which the aftermath of explicitly racial policies shapes digital agriculture in the US today.

2.2 Critical data studies, agriculture, and the environment

While discussions around digital agriculture are nascent in the CSCW community, scholars in other areas have called for examination of the impact of these technologies in agriculture and high-tech development. In critical data studies, Christopher Miles suggests that digital agriculture is not a revolution in industrial agriculture, but a continuation of it, "shorthand for efforts to reorganize conventional farming's epistemological and professional foundations around informatics, algorithmic principles" [29: 2]. Other social scientists have raised similar cautions regarding how digital agriculture may transform the industry, such as how these technologies can "re-script" workflows for farmers [50], redefine what best farming practices are [65], and change relationships between different actors on the farm [26]. The increasing use of automation can invoke tensions between farmers and farmworkers through increasing surveillance or automation of certain tasks [54]. These tensions echo concerns around how increasing use of technologies can strain relationships between workers and managers in other workplace environments [22,32]. Additionally, researchers have addressed how issues from critical data studies around privacy, ownership, and access will arise through the increasing use of Big Data in agriculture, exacerbating existing power differences, such as those between farmers and corporations [9,12].

Other scholars have connected these concerns to problems and dynamics in environmental sensing. Many digital agriculture systems incorporate extensive sensing and measurements to understand environmental conditions on the farm. For example, satellite or drone imagery is becoming a more common means to map field health. As critical data studies scholars have shown, data needs to be understood within social and cultural contexts. Rather than accepting satellite imagery or any other environmental data as showing an impartial "view from nowhere," the data collected is "endowed with different claims and qualities depending on who obtains it, how, and for what purpose" [3]. How the data is presented also plays a key role. For Brynsdottir et al., values and perspectives become embedded in the system that affects what data is collected or analyzed. As they show in the design of persuasive sustainable technologies, what counts as environmentally sustainable behavior is often left to the designer or researcher's judgement [10]. Pine and Liboiron discuss a similar story of decision-making in their historical case study on certain measures being excluded from water quality assessments. This exclusion leads to what they call "ignorance by design," where harms that have political and scientific consequences become obfuscated or omitted [45].

Digital agriculture systems thus exist at the confluence of two technological traditions: the development of large-scale data-driven systems on the one hand, and the development of technologies and related forms of control for agriculture and the environment on the other. Our goal in this work is to elucidate one way these two traditions become knitted together and reinforce each other: through creating systems of legibility. Next, we describe what we mean by legibility and its role in contemporary DA systems.

3 LEGIBILITY AS A FEATURE OF DIGITAL AGRICULTURE SYSTEMS

Legibility is not exclusive to data-driven systems. Our use of legibility draws crucially on anthropologist James C. Scott's analysis of forms of state control in *Seeing Like a State* [55]. Scott's overall argument revolves around how modern states have sought to use a combination of simplified modeling and top-down optimization of social organization in an attempt to improve their citizens' lives. He documents how this top-down focus has caused significant harm, particularly under authoritarian regimes where people are not able to resist these efforts. Legibility in this context refers to tactics of governance that reduce unruly situations to formal models which drive management action. This work has been influential in other recent work in HCI and CSCW, for example to describe how algorithmic systems incorporate bureaucratic tendencies which can lead to absurd outcomes [1].

A key example Scott uses is the rise of scientific forestry in 18^{th} century Prussia and Saxony as a means to manage resources for state revenue. This management was based on a simplified view of forests, where an "actual tree with its vast number of possible uses was replaced by an abstract tree representing a volume of lumber or firewood." [ibid: 12] Reflecting this abstract modeling, trees were planted equidistantly and in straight rows to allow for ease of management. This form of legibility narrowed the vision of what a forest is to a set of measures that can be quantified, controlled, and optimized. Everything that was not a tree that could be commoditized into lumber or firewood was rendered as an externality in the management scheme. This exclusion included not only flora and fauna, but also the "vast, complex, and negotiated social uses of the forest for hunting and gathering, pasturage, fishing, charcoal making, trapping, and collecting food and valuable minerals as well as the forest's significance for magic, worship, refuge, and so on." [ibid.: 13] While this tactic proved to be effective for the first crop of trees, leading to greatly increased forest productivity, it eventually led to widespread "forest death" because simplified forest management interrupted the necessary symbiotic relationships the trees needed to thrive. Through examples like these, Scott demonstrates a tendency of modern states to govern through actions shaped and selected through simplified models of the world, and the unexpected consequences of leaving other aspects of the world outside of focus.

Inspired by Scott, legibility as we are using it refers to systems of governance that use simplified understandings of a situation to control and direct management action upon it. Digital systems in agriculture have introduced their own forms of legibility, based on data-driven systems. For example, in the case of smart irrigation systems, a model is developed in order to determine optimal times and amounts of water to apply to a field [66]. These models are built using measurements through gathering data about a situation, which is represented in simplified form in the digital system. In the case of the irrigation system, this model can include data like historic weather patterns, soil moisture, and comparative data from other fields. This collection of measurements is seen to be what is needed to achieve optimal watering patterns for the plants. Based on these measurements, the model can respond dynamically, based on the assumption that the model is homologous to the outside world. Rather than setting a routine watering schedule, a smart irrigation system can use its model to predict when and how much a field needs to be watered. Through these measurements, the system can mirror the reality of the outside world. This translation of the world into model that drives action is a form of legibility that is a core attribute of many computational systems.

In digital agriculture, legibility is seen as a tool for creating responsive approaches to farming that will allow this farming to be sustainable and productive at scale. Rather than simply mechanically applying water, fertilizers, or other interventions, these systems have the potential to predict and respond to environmental conditions and needs that arise dynamically. The stakes of legibility are clear in how data-driven farming is promoted by companies in the area, as described by Steup et al.[58]: their advertising and websites project a "vigilant farmer" who is in control of their farm thanks to actionable insights generated through data collection; an "efficient farmer" who uses data to minimize their resource use and maximize profitability, and who automates and streamlines farmworkers' labor; an "enlightened farmer" who uses data sensing to understand and respond to what nature is doing; and an "empowered farmer" who has access to and can share their data for profit. These visions highlight the imagined role of sensed data as providing reliable insight into labor, resources, land, plants, and animals, which in turn allow for them to be managed and controlled by the farmer.

In this paper, we explore what is at stake in the centrality of legibility as a design frame shaping digital agriculture systems. We start by examining the historical legacy of pre-digital agriculture management in the US context, with a focus on its racialized dimensions. We argue that legibility is a key organizing principle drawn on in this history, and that the racialized forms of dispossession that characterize this history raise urgent questions around who or what is made legible to whom. Then, drawing on fieldwork examining the adoption of digital agriculture technologies in the northeastern US, we examine the unexpected consequences for land and labor that arise from the contemporary emphasis on legibility in digital agriculture. We use these analyses to reflect on the stakes of legibility, and to suggest design sensibilities that better reflect the complicated historical legacies of these systems.

4 LEGIBILITY IN US AGRICULTURAL HISTORY

In this section of the paper, we examine the role of legibility within the history of agricultural management in the US. Following a recent trend in CSCW to understand computing systems as part of longer historical trajectories [2,28], we illuminate reasons why legibility in digital systems resonates within the agricultural context, and suggest historical issues with legibility that contemporary digital agriculture systems may inadvertently reproduce. Our examination also reveals the broader constellation of institutions that affect the development of digital agriculture technology beyond its designers. Rather than seeing legibility as a neutral, inevitable consequence of data-driven farming systems, our analysis shows that legibility is socially and politically situated within regimes of racialized control.

4.1 Legibility in systematic racialized dispossession

Legibility has been a feature of agricultural management in North America since the establishment of the colonies. Our historical analysis starts with a recognition of the broader context of Indigenous conflict with the colonies and later United States, beginning with the occupation of Indigenous lands by European settlers. Native Americans created the first food systems on the land that is now known as the United States [19]. European settlers used the Doctrine of Discovery, which posits that non-Christians are nonhumans, as their justification to claim land and commit genocide. The land was considered “terra nullius,” or nobody’s land, informed by a European ethic that land should be owned and controlled by those best able to put it to good use [16]. The concept of “terra nullius” justified erasing existing ecologies and people to form an artificial blank canvas for cultivation. This mass clearing of landscapes was necessary to support settler methods of farming and food production [19,53]. In this context, legibility refers to simplification in terms of stripping land of existing claims and humans, plants, and animals living on it, in order to be able to impose new regimes of control.

In tandem with Indigenous genocide and land dispossession, the United States was built on the labor of Black slaves, who were enslaved and brought to the United States primarily to provide labor for agriculture. The ability for the agricultural industry to produce surplus, and thus generate a profit, was dependent on the use of slave labor for commodities like cotton. The large-scale plantations that produced these commodities through forced labor required the development of new management techniques. Management systems were developed to meticulously collect data on slave labor and output as a means of extracting profit. For example, cotton planters on plantations in the antebellum American South developed methods to track labor in the form of keeping detailed accounts for individual slaves, such as clothing allotments and the amount of cotton they picked day to day [52]. Here, managing a simplified landscape required a complex management system to track the precarious balance between inputs and outputs. Legibility here meant collecting data from a recalcitrant workforce in order to better control their labor and outputs.

The forms of agricultural legibility described so far are clearly racialized, leading to the nullification and genocide of Indigenous peoples and asserting violent management control over Black persons. In this context, legibility was for white people and aligned with their modes of control. The end of the Civil War, and with it the institution of slavery, heralded a moment when this understanding could potentially shift. Right before the end of the American Civil War, Union general William Tecumseh Sherman issued Special Field Orders No. 15 to seize lands from the Confederacy in the South and redistribute them to recently emancipated Black people. This order included "40 acres and a mule," a reference to the offer of land parcels and means to support agricultural work, which has now become a symbolic phrase to reference the continued failure of economic justice for Black Americans [18]. After the Civil War, the United States entered an uneasy period of Reconstruction, where the government sought to address racial inequity after the abolishment of slavery. This included incorporating ideals of settler colonialism via land distribution, where it was "believed that only through such [land] ownership could real economic and political independence be achieved" [36]. However, racial discrimination and rising white supremacy created hostile conditions for Black Americans to purchase and maintain land. Despite these conditions, Black land ownership rose significantly at the end of the 19th century and into the 20th century. At the height of this era, Black Americans accounted of full or partial ownership of 925,000 farms in 1920 [17]. Over the course of the next 50 years, this number dropped to 45,594, a 93% decrease. Farm consolidation and industrialization due to the Green Revolution accounted for a general decline of farms overall, regardless of race. However, during this period, white farm ownership only dropped by 58%. In the 2017 USDA agriculture census, Black farmers accounted for 35,407 farm owners out of the over 2 million farms in the United States, or less than 2% [69].

What caused this decrease in the number of Black farmers? There were many factors, such as discriminatory property laws [46]. But a major factor related to legibility was the development of state-supported scientific agriculture, deployed within the context of federal agencies and legislators who discriminated against Black farmers and farmworkers, as we will examine next.

4.2 Legibility and race in the development of scientific agriculture

Since the 19th century and the development of the industrial revolution, agriculture has undergone a transformation, leveraging new forms of mechanized legibility to continue increasing productivity, efficiency, and control, with the push towards industrial agriculture underwritten by both private industry and the state [21]. During this time, there was a focus on new manufacturing processes across several industries, including agriculture, with the goal of using mechanized processes to increase efficiency and productivity. Within agriculture, these mechanized processes included using tractors, harvesters, and other machinery that replaced manual labor done by humans and nonhuman animals. The goal was to use science and technology to make farming more productive and less laborious. Early agriculture scientists include George Washington Carver, who developed methods like organic agriculture to help Black farmers in the South achieve economic autonomy [61]. While scientific agriculture had a positive impact in developing new experimental methods to growing food, this approach became systemized when it was adopted by federal institutions. It is here that we begin to see that "the logic of scientific agriculture is... one of adapting the environment as much as possible to its centralizing and standardizing formulas" [55].

Processes of industrialization generate new forms of legibility. In "Do Artifacts Have Politics?," Langdon Winner describes the ongoing development of a mechanical tomato harvester by researchers at the University of California [63]. To make sure that the tomatoes can endure this rougher form of harvesting over handpicking, the tomatoes that are suited for this process are bred by scientists to be "hardier, sturdier, and less tasty." [ibid.: 126] The machine is efficient, with, at the time, the "newest model sorting the tomatoes electronically into large plastic gondolas that hold up to twenty-five tons of produce headed for canning" [ibid.: 126]. To ease this process of harvesting, the tomato was bred to fit the mechanization process. In other words, it was made legible to the machine. Other examples include the hybridization of corn and wheat to be made more easily harvestable by certain machinery or be able to be fertilized using chemicals that they could withstand [21]. Under industrial, scientific forms of agriculture, then, agriculture is managed by simplifying land and the living beings that grow on it to make them amenable, or legible to, automated machinery.

Who could be a manager of such mechanized legibility? A simple answer is 'fewer people.' At the start of the 20th century, the United States Department of Agriculture (USDA) and Black land ownership were growing in tandem. However, Pete Daniel has argued that "the increase in programs and the USDA's swelling bureaucracy had an inverse relationship to the number of farmers: the larger the department, the more programs it generated, and the more money it spent, the fewer farmers that survived" [17]. This rise of agricultural experts, which included economists, farm managers, employees of agricultural colleges, and extension agents, "dreamed of large mechanized operations run on scientific principles by efficient managers who would replace small and less businesslike farmers tied to almanacs and labor-intensive work." For historian Deborah Fitzgerald, these experts created an industrial vision of agriculture, which "functioned as a matrix of ideas, practices, and relationships that persuaded farmers to change the way they did things. This set of practices and relationships was explicitly modeled on factory and business practices that were familiar to this leadership" [21].

The embedding of scientific agriculture within these growing federal agencies in particular was fraught, given explicit racial discrimination within those agencies. For example, in the Pigford v. Glickman (1999) lawsuit, 400 Black farmers filed a class-action lawsuit against then Secretary of Agriculture, Dan Glickman, over accounts of the USDA distributing and delaying farm loans and assistance to Black farmers. In farming, delayed loans can mean delaying the start of the growing season. This can lead to later issues of decreased yield, which can make it difficult to repay the loans after harvest. While this case resulted in the largest civil rights settlement with a $1 billion payout for the plaintiffs, numerous cases of discrimination persist [51].

This centralization and institutionalization of scientific agriculture within discriminatory governance structures led to a racialization of who could be a scientific farmer. Historian Carmen Harris shows how Black Americans were seen as inferior in learning and disseminating scientific agriculture, an attitude that was reflected in the distribution of funding for extension services at the federal level [25]. While race was not explicitly discussed in these policies, white Southern legislators systematically withheld funding and support for improving agricultural conditions for Black farmers over white farmers. As a result, legislation pushed for investment and development of agricultural technology, rather than investing in and providing material support for Black farmers. For example, sociologist Monica White describes a case in Sunflower County, Mississippi, in 1967 where James Eastland, a white cotton grower and U.S. senator, received a $167,000 subsidy check from the USDA to improve mechanization while letting the fields lay fallow [61]. As one of the largest landowners in the county, Eastland's decision led to the unemployment of Black farm workers, tenants, and farm managers. As farms in the county and surrounding areas continued to focus more on mechanization, the population of Black residents dropped, and many moved to more urban areas for employment.

4.3 The legacy of legibility in agricultural technology

To review, legibility refers to systems of governance that aim to control otherwise unruly situations. This is done by making those situations 'legible' to would-be managers, i.e., understandable enough to allow for the imposition of systems of control. This is done through processes of simplification, often accomplished through quantification and subsequent optimization. Legibility involves both ways of knowing or seeing in a limited sense, and acts of control and management that derive their logic from these ways of knowing. This historical analysis suggests that when considering legibility in agricultural technology, we should be asking: who or what is being made legible to whom? What is rendered illegible, or external to the system?

Legibility emerges in various ways under the regimes we have described. Under colonial conditions, the land was literally cleared of the claims of human and nonhuman actors in order to enable its control. In plantation systems, recalcitrant labor was tracked through ledger systems, while new forms of organization of labor were imposed in order to increase the system's profit. Mechanization, industrialization, and the breeding of plants to meet industrialized needs created automated, repetitive forms of action, and transformed the landscape to allow those forms of action to be effective despite their inability to be responsive to that landscape.

Legibility in agricultural systems in the US has historically been undergirded by logics, i.e. ways of reasoning that justify actions and decisions. One set of logics is settler colonial logics, a notion developed by geographer Sarah Rotz to understand how racialized narratives continue to shape how white farmers and institutions interact with marginalized groups in Canada [53]. These logics are rooted in an idea of personal freedom through permanent family-based ownership and control of dispossessed land, and through management of the labor of a dispossessed working force. Over time, this logic bred centralized private control of large farms and an orientation of extraction rather than care towards the land. These logics shape racial formations in agricultural through the elimination of Indigenous people and exploitation of workers of color. Settler colonial logics ultimately produces a justification for maintaining control of land and property by white farmers in North America. Legibility provides one mechanism for enacting these forms of control.

A related logic that underwrites legibility in agricultural system is extractive logic, which underwrites the process of removal and disconnection of resources, land, and labor for the purposes of capital accumulation. Lourdes Vera et al. describe extractive logic as "the logic of pulling relations out from bodies and lands" in order to use them for other purposes [60]. This logic transforms certain entities, such as minerals and coal, into commodities awaiting extraction. Extractive logics occlude the context in order to narrow the focus on the target of extraction. For example, in industrial agriculture, certain monocropping practices are designed to extract the nutrients in soil in order to maximize crop yield. Eventually this can lead to soil exhaustion, since the soil ecosystem is unable to keep up with the rate of extraction [47]. Legibility, through creating simplified understandings of situations, sharpens certain entities into focus to ready them for extraction.

Rather than seeing digital agriculture technologies as apart from this history and these logics, we see a need to consider how and to what degree digital agriculture continues these legacies. Data systems of modeling and control that couple sensing, modeling, and actuation allow for more differentiated, responsive forms of action than purely mechanical forms of legibility. Nevertheless, they are still based on simplified models and aim to eliminate human action and natural variability as sources of unpredictability in the management of land and labor.

Legibility in digital systems may further develop the logics inherent in agricultural history. In discussing environmental data collection, Lourdes Vera et al. describe an extractive data logic that "ignores the situatedness of data, regarding it as a resource to be pulled out for free, without relations or responsibilities." [60] They point out that harm-centered data collection can perpetuate forms of violence against marginalized communities. While environmental data collection is often done through good intentions to document environmental violence, when it is pursued in an extractive mode, the data's situatedness within a particular community and their concerns and needs can be lost, further marginalizing them.

The issue of extractive data logics underscores the necessity of understanding how historical legacies of marginalization can be inadvertently reproduced through design logics in contemporary digital systems. In the next section of the paper, we explore some of the consequences of legibility as a defining characteristic of contemporary DA systems. Through fieldwork with farms and the extension agents working with them in the northeastern United States, we will examine how the pressures of legibility within these systems are reshaping farm practices and natural environments.

5 METHODOLOGY

Our empirical research is drawn from fieldwork conducted over 2019 in the upstate New York region of the northeastern United States. The upstate region typically refers to areas of the state outside of metropolitan New York City. Based on the 2017 USDA Census of Agriculture, New York State has over 33,438 farms in the region that span almost 7 million acres [70]. While the dairy industry makes up the largest portion of the state's agricultural income, this region is also known for other crops and commodities like apples, onions, and grapes.

This research included interviews with agricultural stakeholders, primarily farm managers and extension agents, and participant-observation at farms. Over the course of our study, we interviewed 15 participants. Our interview protocol addressed digital technology and sensors used in agriculture, including challenges with adoption, use, and maintenance. Since digital agriculture systems are currently not in widespread use in this region, we expanded our interview protocol to address tools beyond data-driven systems. The research also included visits to 9 farms in the upstate New York region and attending farm events associated with local farming organizations. These farms were centered around the production of agricultural commodities, such as fruit, grains, and vegetables (as opposed to livestock). We employed a thematic analysis on our interview and field notes data, in addition to creating memos as a strategy to elaborate on emerging themes.

By including extension agents in our study, we see them as one link between research institutions and the agriculture industry. As discussed in our historical analysis, U.S. federal institutions have been invested in scientific agriculture since the 19th century. Extension agents are part of this investment as employees of cooperative extensions, agencies associated with land-grant universities in the United States. These institutions, funded by the sales of federal land taken from Indigenous peoples via the Morrill Acts of 1862 and 1890, were aimed at advancing curriculums centered on agriculture, engineering, and science. Additionally, in 1914, the Smith-Lever Act was passed that created the cooperative extension services, programs that were attached to these land-grant universities to serve as outreach for institutional research. For example, extension agents would host demonstrations that would showcase new agricultural techniques, a practice that continues to this day. In incorporating the role of extension agents, we see them having a key role in connecting institutional knowledge to farm operators and managers.

Our research design was shaped by our original intention to understand factors that influence technology adoption. This lens led us to focus in data collection on farm owners and managers who were making technology decisions, as well as the extension agents who were actively working to promote new technologies in practice, as opposed to farmworkers or other stakeholders. But our perspective changed in response to experiences in the field through subsequent memoing and reflection. The stakeholders we spoke with were overwhelmingly white. The lead author, who executed the fieldwork, is not. This led to awkward moments in the fieldwork that highlighted the racial identities of both the researcher and the participants. For example, interviewees appeared uncomfortable in discussing issues around migrant labor, often offering extra reassurance that they were okay with certain forms of immigration. The lead author's racial identity placed them as an outsider in a predominantly white rural landscape. In one case, when they had the wrong address for a meeting, this led to a moment of fear of personal safety. These moments sensitized us to the unspoken role of race in agriculture.

Indeed, while the northeast region of the US does not share the same history of plantation systems as the American South (while slavery was legal in New York State until 1827, the number of enslaved persons was small), its agricultural system nevertheless is shaped by legacies of settler colonialism and racism in agriculture. Our study takes place on the lands of the Haudenosaunee Confederacy, a territorial alliance among the Mohawk, Oneida, Onondaga, Cayuga, Seneca, and Tuscarora nations. In 1779, as part of American Revolutionary War efforts, George Washington ordered Generals Sullivan and Clinton to systematically destroy Haudenosaunee villages and farmlands in the region because of a Haudenosaunee alliance with the British. The result was the decimation of the Indigenous population, with many of those surviving the genocide either fleeing north to the then British-controlled Canada or west to regions that were eventually incorporated into the United States. European-American settlers quickly moved in to claim the forcibly cleared land, breaking the former Confederacy into pockets of isolated settlements. As part of their legal strategy to justify occupation, white settlers continued to use claims of Indigenous inferiority to make land claims in forming what is currently upstate New York [41].

The dominance of white landownership continues, especially in the agricultural sector, where 99% of farmers are white and also own 99% of available farmland [70]. In examining the state's agricultural workforce more broadly, we see a racially stratified industry. While demographics of farmworkers can be difficult to collect due to the often temporary and precarious status of farmworkers, several studies point to the majority of these workers identifying as people of color, with varying levels of citizenship statuses [23,42]. For example, migrant farmworkers include those on H-2A visas, a temporary visa for seasonal labor, or undocumented workers. Despite increasing requests of H-2A positions in the agriculture industry, undocumented farmworkers are estimated to make up at least half of farmworkers in New York state [20]. This percentage can be attributed to the often bureaucratic and time intensive nature of the visa application for both farmer and farmworker, in addition to restrictions such as the limitation on seasonal work.

These legacies of dispossession and displaced labor form the often silent backdrop for contemporary farm practices. In what follows, we trace the impact of legibility on farmers' use of digital tools. In the next section, we see how the consequences of legibility are experienced from contemporary farmers' perspectives and, where possible, trace where issues related to racial dispossession can be seen to emerge. In the discussion section, we will juxtapose these perspectives with those from our historical analysis, to develop a more wholistic perspective on how colonialism, racialized dispossession, and digital agriculture intertwine.

6 FINDINGS: LEGIBLE YIELDS, LEGIBLE FIELDS

In the following sections, we analyze consequences of legibility on farm practices, landscape, and labor. Our understanding draws on Scott's argument that forms of legibility are often based on narrow views and on our historical analysis that examines how consequences of these systems draw attention to what's out of view. Our empirical study shows the aftermath of racialized policies and institutions that privileged practices and practitioners legible to scientific agriculture. Together, these cases will demonstrate how legibility in data-driven systems restructures the landscapes, creates new and more work, creates systems that are brittle in the face of the variable conditions that exist on farms, and creates opacity in systems that limit people's ability to tinker with and adjust them.

6.1 Restructuring the Fields

The first consequence of legibility we identified in our fieldwork is a need to simplify the landscape itself in order to render it legible to digital systems. Visions of farmland can evoke images of fields with evenly spaced rows that stretch into the distance. In the rugged terrain of upstate NY, these parallel rows seem to undulate in tandem with the uneven topography. Row spacing is largely dependent upon the equipment that is available to a farm operator. Prior to agricultural mechanization, row spacing was often determined based on the width of the horse or other draft animal used to work the field [37]. As more farmers adopted tractors, this width became less fixed. Narrowing the rows means that more plants can fit into a field, which leads to a higher yield and potential profit increase. In the case of corn, in the mid 20th century, when mass mechanization was adopted across many farms in the United States, row spacing shifted from an average of 40 inches to 30 inches. While mechanized equipment can allow for this decrease in row spacing, the evenness of the rows is still dependent on the skill of the tractor operator. In recent years, laser-guided and GPS-systems have been incorporated into the planting process to ensure uniform rows.

The decision around initial row spacing directs what tools are used, since these tools now need to be able to fit beween the rows without disturbing them. At a farm that grows organic vegetables at industrial levels of production, the operators rely on row-crop cultivators to remove weeds. These cultivators trail behind the tractor with a span that is about twice the width of the tractor. Jutting out perpendicular from this frame are shanks, pieces of metal that are shaped to stir the soil in order to pick up and remove unwanted vegetation growing between the rows. Without proper spacing or placement of the tractor, the tines would lift and pull up the plants, rather than the weeds.

We see the importance of straight rows trickling down to how DA tools are used in the field. For example, one type of sensor that is currently incorporated into these systems are cameras that calculate Normalized Difference Vegetation Index (NDVI) for vegetation health. NDVI can be recorded in several ways, such as on the ground through a sensor that is carried or attached to a tractor, or through remote sensing, where the sensor is mounted on an aerial device, like a drone. These sensors measure the difference between near-infrared light, which vegetation strongly reflects, and red light, which vegetation absorbs. This difference results in a score between 0, meaning unhealthy or dead, and 1, meaning optimal plant health. The number can then be placed on a map with GPS coordinates to create a choropleth map, a visualization where certain sections are colored to represent a statistical measurement. This map can then be used by the farm operator or grower to see the overall crop health of their fields.

This plant health information is also factored into the variable rate application (VRA) process. VRA is the automated application of certain materials such as fertilizers or pesticides. While NDVI sensors and GPS systems have been around since the 1970's and are used for agricultural applications, the integrated use of the tools in the form of VRA is relatively new. VRA relies on a host of computers and networked systems to process this information and control the application rate for mechanization. This application controls the amount of chemical that is applied based on the crop health and GPS location. For example, areas of a field that are closer to the score of 1 are automatically sprayed with less fertilizer. For areas that are closer to 0, more fertilizer might be applied to these low-scoring areas. This method is considered to be cost-effective and a benefit for the environment because of the reduced use of costly fertilizers or pesticides.

By using automation, VRA enforces the need to make the crops legible through uniformity. In the case of using on the ground NDVI sensors, crops generally need to be grown in straighter rows to ensure a consistent reading. This works for crops that are replanted every year with the aid of GPS units or laser guidance systems. However, this might be more difficult for orchards or vineyards that are not replanted annually. In the case of vineyards in some parts of the state, some of these vineyards' rows were established over a century ago by horse and plow. While to the human eye the rows look straight, there is sufficient variation to make it difficult to receive fluctuation by the sensor. When the farmer drives through the inconsistent vineyard rows with the NDVI sensor mounted on the tractor, the tapering or widening of the rows can complicate the use of future VRA methods.

The legibility of the fields determines how easily equipment and tools can be used. In the case of row cropping and other planting methods at scale, this spacing allows for tools like tractors and other equipment to go through processes like seeding, weeding, and harvesting. Digital agriculture systems inherit and build on these existing practices of agricultural mechanization as a prerequisite for proper data collection. As these systems are developed, how will they embody established practices of industrial agriculture?

6.2 The Labor of Legibility

The second consequence of legibility that we identified is the production of new forms of labor. While digital agriculture systems are often designed and marketed as reducing the amount of manager and workforce labor required to run a farm [58], in practice we found that the demands of legibility also created new forms of labor for those working on farms, including growers and planters, as well as those who provide services for farms, such as extension agents and consultants.

One situation arises because of the ways in which equipment is supplied to farms. There is often reluctance to invest in a new technology if it will not be frequently used:

> *"We just planted a new vineyard this year and we hired out somebody to come in with this laser planter which is a way that plants the grapevines in perfectly straight rows and we paid for that service and we got a really nice, we got the vines planted really well and there's no way it would have made any sense for us to invest in that piece of equipment. So I think there's one thing that's interesting to note about agriculture technology, if it's an irrigation system that's stuck on the farm that can never leave, that's slightly different than something that has value that can be moved around."* [P4, farm manager]

This model for renting or loaning out equipment is not uncommon in rural agricultural communities for larger or more specialized equipment [62]. This loaning model is being adapted for networked sensors and technologies. One extension agency piloted a sensor loaner program that allowed farmers to borrow cameras and soil health sensors as a means to make the technologies more accessible for the farmers. This is a strategic step in encouraging the adoption and use of DA tools.

However, this process may not be as seamless as simply providing the physical sensor. In speaking to a specialist on the project, this process entails several steps to get from data collection to information that can be of use to the farm manager or grower. In the following, we recount how the process of how the NDVI sensor is used in the program:

1. First the farmer needs to receive the sensor by scheduling an appointment with the office. While the program has multiple sensors out for use, there still maybe a wait time for a sensor to become available.
2. The sensor then needs to be installed on a tractor and driven through the field to collect data.
3. The sensor is then returned to the office where the data is retrieved on a memory card and given to another specialist.
4. The specialist will then overlay the sensor data on an existing field block map of the farm. If the farm doesn't already have a map, there is a precursor step here where the initial map needs to be made.
5. The agent then prints out and brings a map of the map to the farm
6. Based on the printout, the farm manager can make a decision on how to adjust their practice. For some growers, this map can validate things that they are already aware of, such as a spot on the field that has poor drainage, which translates into red spot indicating poor plant health. For others, this can reveal potential points that need more attention.

This type of work has been described as "articulation work," i.e. work (often in the background) that is required in order to fit the formally anticipated work (sensing and mapping a field) to the variable and particular aspects of a situation [57]. This invisible work [57] is a significant basis for making the system function. In the pursuit of more efficient ways of knowing what happens in the field through digital agriculture, new forms of work are required to make this data collection possible. However, the need to collect information on the workflow entails yet more work to be performed, and those who perform this work are becoming increasingly skeptical of its benefit:

> *"It really makes sense to have one person, maybe two people manage [the tracking software] and so that is the downside, it's that it's more keeping track of things and you know this time of year, we're really busy, we're like, we haven't entered a ton of stuff so at some point we have to sit down and enter it all but yeah, so that's probably the downside, it's that it's more work, hopefully you get something out of that that's worth it, but it's definitely more work keeping track of it."* [P4, farm manager]

Digital systems not only produce labor; they also provide new means to control labor. In one instance, we witnessed a white tractor operator reporting to a farm manager their observations that migrant farmworkers were taking a longer break than was scheduled. Such racialized and hierarchal monitoring can become embedded through increased data collection. As Fox et al. note in their work on understanding hygiene infrastructures, this kind of networked technology is likely to privilege managerial oversight at the expense of the workers [22].

Furthermore, infrastructural challenges, such as the connectivity issues which are common in rural areas [11], further complicate the visions of labor-free data collection which animate the designers of digital agriculture systems:

> *"With a lot of these systems, they need to have a way to take that data out of the field, pull it back and get it to whatever device you want so you can see it in real time. And of ten times the current system is that you're out in the field and you can't get your data connectivity, you come back at lunchtime and you upload it or then you can look at it and do some analyses on it, but this would be more of a real time process, so you're seeing it in real time, you're able to transmit that information, but yeah, connectivity is a big issue and other farms are taking other practices."* [P1, extension agent]

Creating legibility requires a significant amount of labor to track and manage data. Mateescu and Elish describe how integrating AI technologies into farm contexts requires physical reconfigurations that elide any notion of a smooth adoption [34]. Rather than "real-time" sensing, getting data into a form that is useful for decision-making is a multi-step process that can span days. Processing the data is not merely isolated at the field; it is spread across rural agricultural communities, where issues such as rural connectivity present issues for access. This increase of labor points to a contradiction in framings of digital agriculture as addressing economic issues such as labor shortages, usually framed around lack of farmworkers to perform tasks such as planting or harvesting. As noted earlier, farmers in this region are finding workers, though temporary and in vulnerable undocumented positions. The caveat here is that increased labor is also needed at the managerial level.

6.3 The limits of legibility

A third consequence of legibility is that digital systems can easily break due to a myriad of factors on a working farm that are outside the scope considered in digital systems design. As one extension agent recalled, a sensor that needs to be attached to the tractor was known to fall off in the field due to vibrations of the tractor loosening the screw that held the sensor to the vehicle. Many external factors such as the weather can cause a digital tool to fail:

> *"They [companies] don't really know, they don't even know how long it will last. That's one of the issues. Even if they want to be honest, with farms, they cannot. Because some of these technologies has not been under farm environments for long enough to be able to document and guarantee that it will remain functional for a certain period of time. And there is farm to farm variation. I mean the environmental conditions in NY state with swings in temperatures are so extreme and then you go to California or any other part of the country with very different climates and technology may last a year longer there than here in NY. There's a lot of moving parts."* [P2, extension agent]

In our conversations, participants frequently compared agriculture in New York to other regions of the United States, such as California or eastern Washington. These areas tend to have larger farms on average, in addition to drier climates. If certain models are designed for conditions for a specific geographical region, they may not translate to other regions:

> *"So you basically, when you start tweaking things, like changing the amount of water or something of a small amount [in California], you can get noticeable differences, predictable differences. So move that model over to New York. Well, the weather is different everywhere, the soils are highly variable. So you can't really control anything. You can put irrigation in, and try to control the amount of water that the plants get, but the reality is that in NY, probably almost every year we get too much water."* [P3, extension agent]

This variability undermines the simplified models that often underly digital agriculture systems. While these systems may work under ideal conditions or ones similar to their testing, this is no guarantee that they will work in all environments. As discussed earlier, the development of industrial and scientific agriculture points to a standardizing effect, where farms can seem interchangeable in order to accomplish production goals. The focus on productivity is tied to settler colonial logics that ranks who and what practices are acceptable on occupied land. However, these logics can lead to oversight of other variable factors that result in environmental degradation we see today in agriculture, such as soil exhaustion and erosion. When digital agriculture incorporates these tenets of agriculture, we see similar values of control, and subsequent breakdown, emerge in practice.

6.4 The opacity of legibility

A fourth consequence of legibility is that, as systems become more legible to machines, those machines can become more opaque (illegible) to the people who use the systems. Opacity here refers to the "black-boxed" nature of certain computational systems, where the reason for particular outputs may be unexplainable because of the complexity of the systems [14,58]. In other words, opacity refers to the inability to understand why something went wrong, or why things go right and function as desired. This affects both hardware and software aspects of digital agriculture systems, which in turn affects the ability to perform repair and maintenance on the tools to assure they are working as expected – a situation which is particularly crucial given the just-described challenges of getting narrowly designed systems to actually function in the farm context.

At one of the farms we visited, a farm operator showed us his tool bag that he keeps in his tractor cabin in case he needs to do minor repairs or adjustments while out in the field. When asked why he carried two versions of the same tools, he responded that one set was metric, while the other was Standard American units. The tractor that he drove was built by an American company, while cultivator that was currently attached was from a German company. Having both sets of tools allowed him to be prepared to address any minor issues that come up.

These ad-hoc repairs are part of everyday practice in farm contexts [30]. However, the ability to repair and maintain farm equipment with digital components is a point of contention between farmers and corporations. John Deere's repair policy makes it illegal for farmers or farmworkers to service their own computerized tractors, a policy that right to repair activists contest [56]. As equipment becomes more specialized, as we see with digital agriculture tools, these tensions likely will increase. In conversations, farmers, farm managers, and extension agents described how the increase of sensors and other digital equipment can make repair work more complex. A few noted how it is easier to throw away broken sensors rather than repair them. On top of proprietary concerns, they need to balance whether the skills and time necessary to repair a tool outweigh the initial cost.

The increase of digital tools suggests a changing skill set that is needed for people working on farms, aggravating the labor issues discussed in the last section. For example, it might be necessary for a person to also have basic programming and hardware skills to maintain and troubleshoot these tools on a farm. This increase in digital skills has farm managers concerned that this demand for targeted skills can make farmworkers unaffordable for full time hire, especially in small to mid-scale farms:

> *"I guess you would really have to have incredible knowledge to get into the computer on any tractor or car or anything. You really need to be very well trained... If somebody is that well trained, then you can't afford them because you don't want them all the time because they're too expensive."* [P1, extension agent]

In making work legible for digital tools, black boxes create situations where a human is unable to understand what is happening. These situations can lead to fewer points of human intervention if (or more accurately when) something goes wrong. With digitization of mechanization, part of the workflow takes place in digital tools and systems that have become increasingly opaque to the people who use these systems in the field. Opacity may seem to run counter to legibility given the lack of transparency. However, this opacity points to a prioritization in the design of DA systems that places trust in the system, in addition to those who are facilitating the decision making in the first place. Those involved include not only the farm operators or managers, but agricultural experts and technologists who instill understandings of how farming should operate via products and practices. As DA systems are developed, it is necessary to examine not only the agendas of government institutions and agribusiness corporations, but also expand to include the tech corporations that are becoming increasingly involved.

6.5 Summary

Legibility in the case of digital agriculture systems involves using data to create simplified models of farms, which are then used to inform management decision-making. Optimizations based on these simplified models enable farm managers to boost the efficiency and productivity of their farms. Scott warned about the unintended effects of top-down governance based on such simplifications [55]. In this section, we identified four clear side effects of this legibility. First, it reshapes and simplifies the landscape in order to enable these systems to work. Second, while it is intended to reduce labor, it also creates new forms of invisible labor to articulate farm practices and situations in the forms required by the system and enables new forms of surveillance of its vulnerable workforce. Third, the simplifications needed in order to make the systems work create brittleness in the face of variability and other material resistances provided by the natural environment and farm equipment. Finally, systems that make farms legible are themselves often opaque to the people using them, making it difficult for them to adapt and repair them in the face of their brittleness in the farm context. In the next section, we will juxtapose the results of this fieldwork with our historical analysis to lay out the stakes involved in legibility in digital agriculture.

7 DISCUSSION

In this paper, we have developed the concept of legibility and showed how it refigures practices and spaces in farms through digital agriculture systems. Our work was guided by questions about how legibility becomes realized in the context of digital agriculture systems and why certain practices are more susceptible to legibility. We demonstrated how legibility is not neutral, linking the history of agricultural technology development to a legacy of racialized dispossession of land and labor. Our fieldwork examined four consequences of legibility, demonstrating how the demands of legibility are reshaping the landscape, creating new forms of labor and new surveillance of existing labor, producing brittleness in the face of farm variability, and rendering systems opaque to tinkering and repair.

In this section, we consider what these findings and relations, taken together, mean for our understanding of legibility in digital agriculture systems. If legibility is not neutral, we need to examine power dynamics at play. Here we examine three key questions that result from this understanding: who gets to decide what becomes legible, what is made legible, and what becomes illegible in the process.

7.1 Who sets the agenda for legibility?

Identifying who determines what is made legible in digital agriculture systems is a complex question relating to power dynamics in agriculture. Farmers play an important, but often overstated, role in food production. As our fieldwork shows, the deployment and adoption of digital agriculture systems relies upon other actors and institutions outside of the individual farmer. Our fieldwork highlights the efforts of extension agents who dedicate time and resources to bring these technologies to local farming communities. This fact is in line with the original goals of cooperative extensions and their respective land-grant universities in supporting rural and agricultural communities through developing and disseminating advancements in science and technology.

As we saw in our historical analysis, the establishment of these institutions was also tied to settler colonial logics, which empowered the United States government to occupy Indigenous lands and underwrote an orientation to control the land and a dispossessed workforce. Subsequently, the research agendas of these institutions has been tied to imaginations of who is capable of being a scientific farmer and funding policies set by institutions that have actively undermined Black agricultural and rural communities since the Reconstruction period. Tracing this work has shown how scientific agriculture has come at the expense of Black farmers, contributing to the predominantly white agricultural landscape that we see today. In our present-day fieldwork in New York, we see a landscape where predominantly white farmers manage farmworkers in precarious positions. These racialized and exploitative relationships still exist, albeit in different forms.

In addition to the factors this history identified, agribusiness, and more recently, tech corporations also have invested in the development of digital agriculture systems. This investment includes partnerships with universities and federal agencies, where these private companies play a significant role in shaping digital agriculture [9]. Understanding who sets the agenda for legibility leads to mapping out a web of other actors involved in agriculture. In line with recent calls to articulate rural infrastructures in HCI [24], our research develops a more complex understanding of the institutions, actors, and historical underpinnings of the agricultural industry in the United States. While we see certain practices play out on the farm, these practices are shaped by broader institutional and governance histories that shape rural technologies, practices, landscapes, and actors. Our research suggests that focus on agriculture work in CHI and CSCW need to expand beyond attention at the level of individual farms and farmers to ask how institutions are shaping what technologies are available, what practices are possible, and who is able to farm.

7.2 What is made legible?

While the question of who is at the helm of legibility has a complicated answer, the question of what is being made legible is more straightforward. Landscapes must be altered radically to be made legible. As we saw in our fieldwork, orientation and spacing of crops plays a crucial role in how these fields are read by digital agriculture systems. This precise placement of the crops makes it easier to manage farms at scale, such as applying fertilizers or determining plant health via sensing. We place legibility within a history of "terra nullius," the settler colonial justification for seeing Indigenous land as prime for occupation and available for clearing and control. This concept was foundational to the beginnings of North American states like the United States and Canada and has lasting resonances in contemporary agriculture [53]. Through land grabs, the United States government acquired land on a large scale and distributed the land via homesteading acts to white settlers. In order for land to become farmland, the landscape usually required clear cutting and razing of the existing ecology in order to be split and shaped as different fields. With these lands cleared, the land became a blank canvas upon which structure could be imposed, such as the rows of monocrops that we see in industrial forms of farming. While developments in scientific agriculture sought to develop best practices for food production, maximizing yield and productivity in order to ensure food security, it simultaneously played a role in maintaining land ownership for white farmers.

The spatial configuration of farms and farmland in the United States is not neutral. These spaces exist because of specific ways of thinking about the environment and how the world should be oriented [15]. In the case of industrial agriculture in the United States, this is inseparable from Indigenous land dispossession and the subsequent expropriation of Black-owned farmland. Our fieldwork was conducted in a landscape long altered by the consequences of these processes, where the distorted demographics of farms has become seemingly normalized. The tools and technologies that are developed to support these practices continue to maintain the underlying colonial logics, however subtly. We see this through line between digital agriculture and terra nullius through the lens of legibility. Much like how scholars are revealing how racialized values become embedded in digital systems, such as search engines and recidivism risk algorithms [7,38], a critical eye needs to be cast upon the values embedded in technologies that envision legibility as an outcome, such as digital agriculture systems.

We are not claiming that legibility is inherently a racist or colonial tactic when used in digital systems. Rather, we are calling for a more nuanced understanding of how digital systems transform the environment. Given growing concerns to mitigate and adapt to the impact of climate change, an increasing number of technological systems are being developed to address these concerns, including in agriculture [6,49]. Often, the design of these systems is framed as extracting more data in order to lead to better insights [8]. As we see the development of these tools that address environmental concerns, we need to understand how they may reproduce historical harms as a result of the limited ways these may frame the environment, how human relationships to it are envisioned as 'controllers' or 'managers,' and who is licensed to be in control.

7.3 What is left/made illegible?

To make something measurable requires simplifying a situation to make it amenable to supervision and management. Within the design of digital systems, this is accomplished through a process of measurement and quantification across a defined, limited set of variables. Inevitably through this process, other aspects are left out of scope; they become illegible within digital agriculture systems. In our fieldwork, we saw two forms of such illegibility.

The first form of illegibility related to how the narrow view of digital systems made it difficult for them to function effectively across the true variability of material farm landscapes. Models that are developed to automate decision-making may not fit local conditions. While the landscape is being standardized to fit the requirements of digital agriculture systems, factors such as weather and regional conditions are not amenable to the same forms of control and vary enough to make it hard to create generalizable models. The challenges to these systems are exacerbated by the unevenness of rural infrastructure, since the design of these systems often rest on assumptions of available power and connectivity which reflect urban, rather than rural, realities.

The second form of illegibility has to do with the question of to whom or what the farming situation is being made legible. While the landscape is becoming more legible to digital systems, the functioning of the systems themselves and the reasons behind their decision-making are becoming less legible to the people who operate them. This makes it difficult for those in the field to repair, tinker with, or adapt the systems to work with local conditions that were outside of scope of the systems' design, a difficulty exacerbated by new property regimes embodied in warranties and proprietary contracts. The opacity of these system to those who best understand the local circumstances aggravate the challenges of breakdown caused by the first form of illegibility.

These insights suggest direct design implications, including a need for more transparent interfaces and modular, repairable hardware designs. It also suggests a need for participatory design efforts aimed towards those who are marginalized or left out of the design of these systems. But understanding this problem in its historical and institutional context suggests this issue extends beyond the sociotechnical requirements of a particular system. Efforts to move to more mechanized and automated forms of farming have been done intentionally at the expense of workers under the banner of making larger-scale, white-owned farms technologically advanced. With the systematic erasure of Black farmers over the course of more than a century and the systemic elimination of Native American farmers, methods such as those from participatory design may not be sufficient in addressing or repairing these issues, since the relevant stakeholders are no longer on the land. These skewed demographics point to the need to discuss and include factors of race in digital agriculture research, especially in North American contexts.

Certainly, the inclusion of marginalized farmers in the design of DA systems is valuable and could address some inequities. But the framing of legibility in DA systems, where a limited frame of measurements is used to optimize a system for the purposes of its owner/manager, is still based on a settler colonial logic of land as property. Given the trajectory of technologies that increasingly put workers and marginalized communities at risk for harm [7,13], it is important to reflect on the logics that are being built into digital agriculture systems, to identify places where systems built on those logics perpetuate harm, and to develop design orientations for these systems based on alternative logics.

CONCLUSION

While recent data-driven systems in agriculture may seem new, the logics built into these systems are not. Our work uses legibility to understand underlying logics of digital agriculture by pairing historical case analysis with contemporary fieldwork. Legibility as instantiated in digital agriculture builds on a longer tradition in scientific agriculture which is implicated in the racialized legacies which have shaped the history of agricultural production in the U.S. These histories are embedded in the ways contemporary technologies are being developed; our fieldwork demonstrates the ongoing consequences of a reliance on legibility as a frame for agricultural technology. Without closer examination, we will continue to build systems that reproduce these ways of thinking. This will ultimately run counter to the goals that digital agriculture has in addressing social, economic, or environmental issues in agriculture. These issues cannot be thought of as separate points that can be addressed in isolation.

Digital agriculture has been framed in the literature as a revolution. Undoubtedly, it is generating new agricultural practices, fostering new business models, and putting pressure on farms that resist technological adoption. But through its reliance on legibility as a design frame, digital agriculture is simultaneously continuing a racialized legacy of industrial farming and scientific agriculture. Legibility is not merely a design trope for digital agriculture systems, it is also part of a longer trajectory of settler colonialism. Historical analysis sensitizes us to the way that scientific developments in agriculture have been intimately tied to questions of land access and who has the standing and access to be a scientific farmer. When building on these traditions in agriculture, digital developments for industrial farming extend the legacies of settler colonial occupation. Ultimately, we offer in this paper is a way of examining how digital systems can inadvertently uphold legacies of oppression. As work in CSCW begins to work towards liberatory practices [4] in the work to move beyond structural legacies of oppression, we must chart out new pathways for technology based on a sharpened understanding of how these systems came to be.

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