New but for whom? Discourses of innovation in precision agriculture

Emily Duncan[1] · Alesandros Glaros[1] · Dennis Z. Ross[1] · Eric Nost[1]

Abstract

We describe how the set of tools, practices, and social relations known as "precision agriculture" is defined, promoted, and debated. To do so, we perform a critical discourse analysis of popular and trade press websites. Promoters of precision agriculture champion how big data analytics, automated equipment, and decision-support software will optimize yields in the face of narrow margins and public concern about farming's environmental impacts. At its core, however, the idea of farmers leveraging digital infrastructure in their operations is not new, as agronomic research in this vein has existed for over 30 years. Contemporary discourse in precision ag tends to favour emerging digital technologies themselves over their embeddedness in longstanding precision management approaches. Following several strands of science and technology studies (STS) research, we explore what rhetorical emphasis on technical innovation achieves, and argue that this discourse of novelty is a reinvention of precision agriculture in the context of the growing "smart" agricultural economy. We overview six tensions that remain unresolved in this promotional rhetoric, concerning the definitions, history, goals, adoption, uses, and impacts of precision agriculture. We then synthesize these in a discussion of the extent to which digital tools are believed to displace farmer decision-making and whether digital agriculture addresses the biophysical heterogeneity of farm landscapes or land itself has become an "experimental technology"—a way to advance the general development of artificial intelligence. This discussion ultimately helps us name a larger dilemma: that the smart agricultural economy is perhaps less about supporting land and its stewards than promising future tech and profits.

Keywords Precision agriculture · Digital agriculture · Discourse · Innovation

Abbreviations

PA	Precision agriculture
STS	Science and technology studies
DSS	Decision support system
AI	Artificial intelligence

✉ Emily Duncan
edunca01@uoguelph.ca

Alesandros Glaros
aglaros@uoguelph.ca

Dennis Z. Ross
zoeyross@live.ca

Eric Nost
enost@uoguelph.ca

[1] Department of Geography, Environment and Geomatics, University of Guelph, 50 Stone Road East, Guelph, ON N1G2W1, Canada

Introduction

> Improving yield is an age-old challenge for farms and always will be. However, for the first time in a generation, digital technologies enable farmers to achieve a quantum leap forward in their performance.[1]

Precision agriculture is a rapidly developing sector at the intersection of ag and tech industries and is seen as a "revolutionary" opportunity to feed more people, confront environmental crises, and create new markets. Precision agriculture (PA) involves a range of technologies, from sophisticated spatially-aware sensors that harvest massive amounts of data via automated tractors and drones, to algorithms that clean and make sense of this data in ways that help farmers and their advisors make decisions that improve yields, conserve inputs, and increase their bottom line (Bronson and Knezevic 2016; Wolfert et al. 2017; Klerkx et al. 2019). Here, we review how these set of tools—and their

---

[1] https://www.accenture.com/_acnmedia/accenture/conversion-assets/dotcom/documents/global/pdf/digital_3/accenture-digital-agriculture-point-of-view.pdf.

Fig. 1 Accenture's vision of "new growth potential" for the farmer overwhelmed by data. Source: https://web.archive.org/web/20200309230626/https://www.accenture.com/us-en/insight-accenture-digital-agriculture-solutions
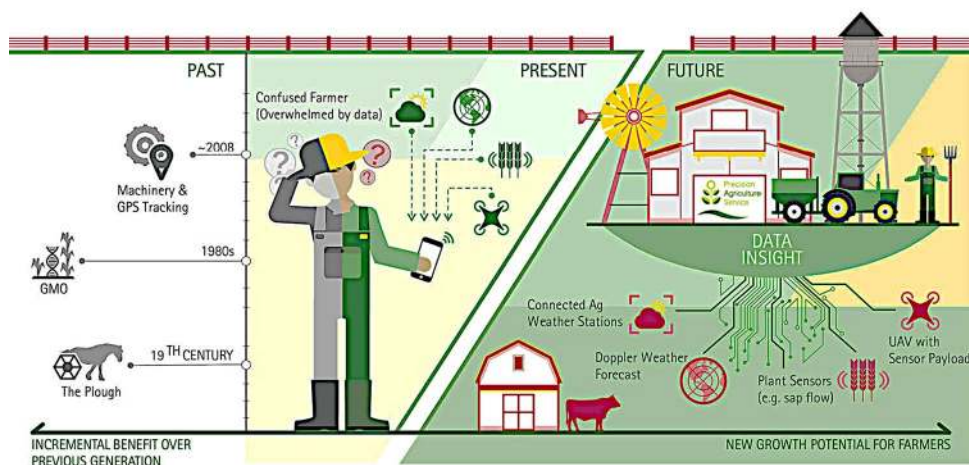
associated practices and social relations—are being defined, promoted, and debated. We do so through an analysis of popular and trade press websites.

Recent growth in the ag tech market is notable and predictions for its future rosy. According to the Environment Defense Fund, in 2017, startups in the sector raised $670 million, which was more money than the past two years put together.[2] By 2025, farm management platforms alone are expected to be a $1.5 billion market in the US.[3] Looking even further out, investment bank Goldman Sachs (2016) predicted that by 2050, a $240 billion farm tech global market that would increase crop yields 70%, would "[add] to agriculture's long history of holding off a Malthusian crisis." Though exact estimates of its size vary, there is clearly optimism about the potential of a "smart" farm economy.

These kinds of economic forecasts make speculative future economic value present. Other representational mechanisms also sustain precision and digital agriculture's promises. Just as emerging data technologies in general are believed to be deeply transformative, PA promoters emphasize it as "having one of the most pronounced impacts on ag production since the industrial revolution."[4] The epigram from IT services firm Accenture, and the image appearing alongside it in a promotional brochure (Fig. 1), echo this characterization of PA's ambitions.

In doing so, they remind us that it is important to understand not just the technical dimensions of innovations, but what kinds of imaginaries they express (Jasanoff 2015; Bain et al. 2019). Accenture's "confused farmer"—whose challenge has always been and always *will* be *yield* rather than sustainability or even profit—is overwhelmed by data. The problem is that massive farm datasets are poorly integrated, allowing new and emerging data analytics to be presented as "first in a generation" solutions. Technologies like decision support systems (DSS) promise to rectify the situation by storing, analyzing, and presenting data in useful ways (Higgins 2007; Lindblom et al. 2017; Rose et al. 2018). Thus, both the challenge *of* and the solution *for* modern agriculture is framed as technical, rather than social or political.

In our review of contemporary discourse around PA, we found that representing it in this way—as a new set of tools—is common. Popular and trade press websites, focused on the European and North American industrial farming context, promote these tools as novel, rather than as an extension of farm management strategies that have existed for decades. In other words, PA is defined by the tools used by farmers, rather than the decisions farmers make with them. We develop this point, guided by Bronson and Knezevic (2016, p. 1)'s insight that "the nature of the distinction between historic farm monitoring and Big Data" is an "open question." They prompt us to ask the following: does contemporary precision agriculture actually represent something new? Our approach focuses on how its promoters make distinctions between its past, present, and future, and what, in turn, these distinctions *do*. What does the discourse of novelty—newly connected ag weather stations, plant sensors, and other technologies—reveal and obscure about smart farm economies?

Our argument is that while some precision ag technologies may be novel, they are nonetheless embedded in a management philosophy that is not. We extend this to claim that the promotion of newness itself works to fetishize the technical components of PA, promising that technologies like plant sensors or connected ag weather stations will provide value not just to "traditional" agri-food stakeholders

like farmers and retailers, but beyond the agri-food sector to sectors like finance and tech. This value-promise comes at the expense of addressing broader questions around food production reform, including data justice for producers, defined as "fairness in the way people are made visible, represented, and treated as a result of their production of digital data" (Taylor 2017, p. 1; Fraser 2018; Bronson 2019; Lioutas and Charatsari 2020). To some extent, ours is a re-articulation of the claim critical social scientists have already made about PA: that it is a way for the agri-food regime to legitimate itself vis-a-vis environmental concerns. Early scholarship on this subject (see Wolf and Buttel 1996 and Wolf and Wood 1997) argued that PA confronts spatial and temporal heterogeneity in farming landscapes, but in a way that legitimizes and re-entrenches the industrialization of farming (Miles 2019). Our discourse analysis of current PA framings in the public realm builds on this finding. However, we articulate our argument within Science and Technology Studies (STS) concepts of experimental technology (Ensmenger 2012), promissory value (Rajan 2006), and sociotechnical imaginaries (Jasanoff 2015), to further understand what work envisioning farm futures performs. We build from emerging research that empirically examines the discourses at the heart of PA—what is it and who is it for (Fleming et al. 2018)?

In the next section, we present our framework for understanding how PA is promoted and why we focus on what its depiction as new does. We then elaborate on our methods for accessing and evaluating PA discourse. In the results section that follows, we overview six unresolved tensions in the way that PA is discussed in news stories, trade reports, and other web-based promotional material. These tensions represent differing ways in which farmers, agronomists, tech companies, input companies, and the media define PA, describe its definitions, discuss its history (or lack thereof), determine its goals, reflect on its adoption, envision its use, and navigate its impacts. We attempt to make sense of these tensions in the discussion, highlighting how they suggest PA may serve the interests of finance and tech sectors more than farm actors or institutions per se.

Theoretical background

In recent years, there has been an increased focus amongst social scientists on issues related to digital technologies in agriculture. This is sometimes described as "digital agriculture" and it overlaps with similar terms such as "smart farming" as well as precision agriculture. We summarize Klerkx et al. (2019)'s timely review of this research, which describes five major thematic clusters.

Most of the academic literature revolves around the adoption, uses, and adaptation of digital technologies on the farm (Klerkx et al. 2019), and as we show below, discussion of these issues is also clear in popular discourse. There have been many studies that approach ag tech adoption and use from perspectives grounded in economics, sociology, and innovation studies (Tey and Brindal 2012; Barnes et al. 2019; Erickson and Lowenberg-DeBoer 2020; Mitchell et al. 2018), though there have been fewer that use STS as a conceptual framework (but see, for instance, Schewe and Stuart 2015, Higgins et al. 2017, and Carolan 2020, who all draw on STS concepts). The second and third thematic clusters identified by Klerkx et al. (2019) are the effects of digitalization on farmer identity, farmer skills, and farm work (Lioutas et al. 2019; Vik et al. 2019; Rotz et al. 2019b), as well as on agricultural knowledge and innovation systems (Fielke et al. 2019; Eastwood et al. 2019). In our analysis of PA discourse, we group these themes together under the category of "impact" and explore how new digitized knowledge systems are seen to supplement or supplant farmer knowledge and decision-making.

The fourth thematic cluster of research emphasizes power, ownership, privacy, and ethics in digital agricultural production systems and value chains and has been developed by authors such as Wiseman et al. (2019), Jakku et al. (2019), Rotz et al. (2019a), Shepherd et al. (2018) and Regan (2019). In this stream, scholars see promise in efforts like open-platform farm tech because such efforts draw on notions of responsible innovation: innovation that engages all actors behind tech development in reflection about the values underpinning it (Bronson 2018, 2019; Rose and Chilvers 2018; Carolan 2016). A rich body of literature is emerging that attends to more inclusive governance processes in ag tech innovation, including attention to risks/unknowns and justice (who has access to technologies). The fifth and final thematic cluster identified by Klerkx et al. (2019) refers to the economics and management of digitalized agricultural production systems and value chains, supported by research from Phillips et al. (2019), Weersink et al. (2018), Leonard et al. (2017), and Rojo-Gimeno et al. (2019). The research we present in this paper falls somewhere in between these last two categories as our findings suggest that PA is an "experimental technology" for the tech and finance industries, which has both power and economic implications.

As human geographers with an interest in advancing STS theories, we draw on the concept of experimental technologies to understand how the framing of ag tech resonates beyond the domain of agriculture. As Ensmenger (2012) showed, experimental technologies are those that scientists have arranged such that they can translate insights from one domain into another. For instance, scientists have used *drosophila* flies to inform their basic understanding of genetics in more complex organisms. But choosing these flies as "models" shaped the kinds of knowledge they produced about genomics. Likewise, the choice of chess as an experimental

technology for the development of artificial intelligence (AI) was consequential for the ebb, flow, and nature of research in that field. The established popular culture of chess, the availability of guidebooks, and the game's existing set of rules were all resources to researchers who thought developing an AI that could play chess would then help them craft more generally applicable algorithms.[5] We suggest that farm data is seen by tech firms as grounds for further developing basic science around AI. In this case, farmland is framed as a "model" because of its heterogeneity, variability, and ability to generate actual big data,[6] which is "grabbed" for the insights it might provide for AI research, not just agronomics (Fraser 2018). Such experimentation affords developers a wealth of data and technical troubleshooting, but fails to adequately compensate—in time, money, or value—the users who generate these critical resources and then get sold 'new' products they helped to develop.

To develop this point, we analyze popular and trade media framings of PA. These often expect PA to be "innovative" and "revolutionary" and see it as a novel and necessary solution to solve agricultural challenges such as the need for sustainable intensification (Miles 2019; Carolan 2020; Fairbairn and Guthman 2020).[7] Rather than debunk the rhetoric that frames PA as new and emergent, we prioritize asking what does this framing *achieve*? Analyzing expectations affords us a deeper understanding of technological change. Borup et al. (2006), for instance, describe a "sociology of expectations" in which "imaginings, expectations, and visions" are "generative" rather than simply a result of the ways research and design is socially organized. More specifically, as STS scholars have long shown, visions of future developments in science and technology make "promises", often around their ability to realize monetary value. The growing subfield of "valuation studies" looks in part at the role of financial forecasts—like Goldman Sachs's (2016) "Profiles in Innovation—Precision Farming: Cheating Malthus with Digital Agriculture"—to demonstrate their importance in eliciting hype and investment (Fourcade 2011; Helgesson and Muniesa 2013; Birch 2017; Fairbairn and Guthman 2020). In an example from the medical field, Rajan (2006) showed

how "personalized" or precision genomic technologies prefigured "patients-in-waiting"—the expected users of such technologies—as well as "consumers-in-waiting"—the kinds of patients expected to be willing and able to pay for their personalized treatments. The construction of the "consumer-in-waiting" demonstrated to potential investors the value of funding genomic research. As we suggest below through our discourse analysis, such "consumers-in-waiting"—"farmers-in-waiting"—are imagined within PA discourse to constitute the coming smart farm economy.

Beyond garnering attention and promoting investment, such sociotechnical imaginaries "legitimate" proposed lines of research, produce shared understandings of what possibilities are likely, and coordinate scientists and funders alike (Bain et al. 2019). Kinsley (2010, p. 2772) analyzed promotional videos from Microsoft that envision how future technologies will be used and which "frame a citizen/subject whose world is effortless." These sorts of envisioning texts are abundant across the tech world, and now the ag tech world as well: from Accenture's sketch of the data-connected farm and confused farmer (Fig. 1) to John Deere's (2019) Farm Forward videos, which offer "a vision of how technology could drive the increased productivity necessary to feed a growing population." For Kinsley, these visions of the future have a tenuous relationship with present realities; the technologies they represent—like fully-autonomous tractors—do not presently exist, but "performatively" prototype what could and should exist. STS scholars, such as Jasanoff (2015) and Jepsen (2017), go on to show that the imaginaries framework affords scholars the opportunity to scrutinize power relations within science and technology. As Jasanoff (2015, p. 33) notes, imaginaries co-produce the social and technical and, in doing so, allow us to: "tackle head-on, and more symmetrically, the complex topographies of power and morality as they intersect with the forces of science and technology." As we describe below, PA imaginaries emphasize it as a set of new tools with value to tech developers and financial elites, perhaps at the expense of farmers.

Methods

Some of our previous research explored trends in North American farmers' adoption of PA and farmers' and PA retailers' perspectives on these trends (Duncan 2018). This interested us in more broadly understanding the discourse surrounding PA. The STS framework described above spells out the value in researching how people think about PA, not just how many have adopted it (but see Erickson and Lowenberg-DeBoer 2020; Mitchell et al. 2018) or even how individual farmers or crop advisers tinker with and otherwise practice PA tech (Higgins 2007; Higgins et al. 2017).

---

[5] As Ensmenger notes, in reality, it led researchers towards fine-tuning very specific kinds of algorithms rather than more general ones.

[6] "Big Data" has been used as a buzzword in the media in discussions around digital technological advancements. Big data has been defined by the volume, velocity, and variety of data points generated, but also a turn towards greater computing power to aggregate, analyze, and acquire information from datasets (Ali et al. 2016; Coble et al. 2018). Accessing big data is a requirement for creating and testing new forms of artificial intelligence and machine learning.

[7] cf. Fanfani et al. 1993, who argued that biotech discourse in the 1980s singularly focused on biology-oriented technical innovations rather than the full scope of economic, institutional, and scientific changes that would be required for GMO-based agri-food systems.
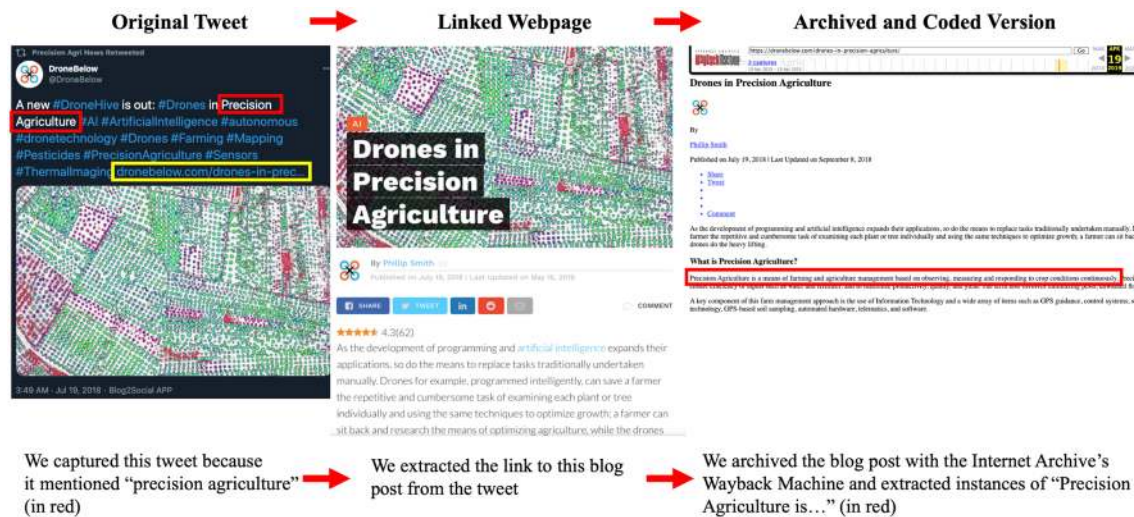
Fig. 2 Process for extracting links from tweets, and archiving and analyzing them. Source: Authors. Example is from: https://twitter.com/spect roag/status/1021419729590915088

In previous research and in preliminary investigations involving a passive collection and review of publicly-available materials (blogs, industry press, observation at industry conferences), we sensed that the rhetoric around PA focused on its newness. To substantiate this claim, we performed a critical discourse analysis. Discourse analysis is commonly referred to as "the study of language in use" (Gee and Handford 2012). We understand discourse analysis as a systematic approach to analyzing texts, which can be any object or process with social symbolism, such as a map or a dance performance, but it is often literally text or speech (Dixon 2010). This approach to the meaning of text seeks to understand the structures of thought around a topic by coding who says what, to whom, when and where. It is separate from, though sometimes built upon, content analysis, which is more strictly limited to counting the frequency of key terms in a text in order to make claims about their prevalence in social discourse (Cope 2010). Instead, discourse analysis situates the audience and purveyors of texts, as well as their content *and* their absences, in order to characterize the elements of structures of thought. *Critical* discourse analysis specifically looks at normative and explanatory critiques, and is therefore often used to understand social elements, such as power relations, of various phenomena (Fairclough 2012).

Many analysts have sought to comment on trends and directions in PA (e.g. Wolfert et al. 2017; Weersink et al. 2018; Klerkx et al. 2019), but there have been relatively fewer studies that seek to understand structures of thought around it. In what they deemed the first study of big data in agriculture to take a discourse analysis approach, Fleming et al. (2018) interviewed Australian farm industry stakeholders. By paying close attention to the language used in interviews and the assumptions, values, and consequences that participants implicitly and explicitly raised, they sought to characterize what approaches to big data in ag were being normalized. They found two—the most dominant being the idea that big data is for big ag operations that can afford and benefit from it, and a counter perspective that asserts that big data is or at least should be for all farmers.

In our case, we wanted to look at how industry, farmers, and the broader public have discussed the promise and practice of PA. The social media site Twitter is a key place this dialogue occurs in oftentimes direct ways. We used precision agriculture-related tweets as a starting point for our analysis. We searched Twitter for mentions of "precision agriculture" and the related concept and set of tools known as "smart farming." Rather than coding tweets themselves (a research project of value in its own right—see Maye et al. 2021), we extracted links tweeters made to blog posts, news stories, and so on and coded these (see Fig. 2).

Boyd and Crawford (2012) note that many social scientists are using Twitter as a data source due to its publicly-accessible, large dataset, but caution against epistemological and ethical pitfalls. While there may be other social media venues where the promotion and discussion of PA happens, there are technical and conceptual reasons to prefer Twitter in contrast to, for instance, Facebook, which has more restrictive terms around accessing users' posts. However, there are limitations to employing any social media as a foundation for discourse analysis. To the extent that Twitter lends itself to self-promotion, we are by default more likely to encounter material couched in a rhetoric of newness. In addition, despite its ubiquity, there remain key digital divides in access to and use of social media. We hedge against this by coding websites linked to on Twitter, not the

tweets themselves, as websites may have a broader audience and be more representative of the conversation around PA. Given the interactive dynamics of Twitter—quoted tweets, subtweets, replies, and so on—we were able to observe more marginal elements of the discourse (e.g. "right to repair") or those "contra discourses" that go against the grain (Fleming et al. 2018). Dixon (2010) describes the need in critical discourse analysis to situate discourses within structures of who produces and consumes rhetoric. We did not attempt to systematically map specific perspectives back onto specific stakeholders—to say that a specific point of view is mostly held by farmers, for instance. However, we did categorize and count the source of each webpage; most were from trade associations or agricultural companies. The discourse around PA that we describe is a mix of perspectives from the variety of actors engaged in it. There is no singular way that it is talked about; much like Fleming et al. (2018), we aim to characterize tensions in it.

Using the Twitter basic search API (application programming interface) and the TAGS (Twitter Archiving Google Sheet) v 6.1.2, we collected approximately 80,000 tweets that mentioned "precision agriculture" and/or "smart farming" between April 2018 and 2019. We filtered this dataset to English language messages (n = 57,658) and extracted any outgoing links to news articles, other tweets, and so on that users had shared (n = 14,522). Because of our focus on English language tweets, our sample is skewed toward North American and European users linking to mostly North America- and Europe-based websites. We wrote a custom website-scraping script[8] and followed each outgoing link that was not a link to another tweet (n = 5136).[9] We archived each of these 5,136 pages at the Internet Archive's Wayback Machine (archive.org), created PDFs of each, and manually coded a randomized subset of them (n = 411) using the qualitative analysis software NVivo. We counted how many times each website was linked to in tweets, giving us a sense of the most prominent voices and texts in the sample. In addition, we made what Cope (2010) calls manifest or descriptive codes to label the source of each webpage (government, specific companies in the industry, trade associations, non-trade media, social media, other civil society organizations, or individuals) as well as the type of page (blog, press release, news story, or promotional piece.) Finally, we used our website-scraping script to determine whether phrases related to precision agriculture and smart farming were used on each of the 5,136 pages in the overall dataset. Specifically, we pulled out sentences that included definitional phrases—"precision agriculture is", "precision ag is", and "smart farming is"—and coded these. We wanted to target how these concepts have been defined in the public realm beyond scholarly research (cf. Bertoglio et al. 2021).

To exemplify our process: the blog post "Drones in Precision Agriculture" was shared 10 times during the study period.[10] As shown in Fig. 2, we saved a snapshot of this page to the Wayback Machine and then ran our website-scraping script on the snapshot to look for the key phrases.[11] For many pages that did not specifically mention "precision agriculture is…"—such as the news story, "Ohio State uses precision agriculture to create world's largest 'Script Ohio'"[12]—we still manually coded "latent", or implicit, themes apparent in the page's discussion of what PA entails, its benefits, and the challenges it faces (Cope 2010). In our inductive and iterative thematic coding of the randomized subset in NVivo, one author developed an initial set of codes which was then reviewed and discussed by all authors. As a result, new codes were added and some codes were refined before the rest of the pages were coded.

Results: six tensions in characterizing precision agriculture

Our coding of websites linked to on Twitter led us to six key tensions in the discourse around precision agriculture: Is PA defined as a set of tools or a management philosophy? Is there a history to PA, or is it a new innovation? Is the goal for productivity, environmental benefits, both, or neither? How has it been adopted or rejected by farmers? Even if farmers are adopting smart farming tools, how are they being used? Finally, what will be the impact of these new technologies—will they supplement or supplant farmers? While these are ultimately unresolved questions, in the section following this one we discuss how and why particular answers have come to dominate over others.

Definitions

The boundaries between definitions of precision agriculture and smart farming are not always clear, and this is reflected in the academic literature in agronomy as well as in broader

---

[8] A website scraping script is a method of extracting specific data from websites. Our script was written in the Python programming language and "scraped," or accessed, the text of each webpage automatically, saved it as a PDF for manual coding later, and searched for key terms and phrases (i.e. "precision agriculture is…").

[9] github.com/ericnost/EDGI.

[10] https://dronebelow.com/2018/07/19/drones-in-precision-agriculture/.

[11] https://web.archive.org/web/20190419050544/https://dronebelow.com/drones-in-precision-agriculture/.

[12] https://abc6onyoursiGlde.com/news/local/osu-uses-precision-agriculture-to-create-worlds-largest-script-ohio.

discourse. For example, Schönfeld, (2018, p. 110) define precision agriculture and smart farming separately:

> Precision Agriculture includes the implementation of automatically controlled agricultural machines, monitoring of the yields and various ways of seed drilling and fertilizer spreading....Smart Farming integrates agronomy, human resource management, personnel deployment, purchases, risk management, warehousing, logistics, maintenance, marketing and yield calculation into a single system.

In this definition, PA is seen more as a set of tools, and smart farming is viewed as a management approach. Wolfert et al. (2017) extends this definition: "While Precision Agriculture is just taking in-field variability into account, Smart Farming goes beyond that by basing management tasks not only on location but also on data, enhanced by context- and situation awareness, triggered by real-time events." However, others, like Levy (2017), fold smart farming into precision agriculture: "…precision agriculture definitions vary. While some use it only when referring to production [as in variable rate applications, see Schönfeld et al. 2018 and Wolfert et al. 2017 above], others maintain it is more about more holistic smart farming solutions, including ICTs such as sensors and drones."

Drawing on earlier literature around PA (Stafford 2000; Van den Heuval 1996; Nowak 1998), our own working definition of PA centers it as a farm management strategy in which farmers and farm advisors address field spatial and temporal variability. We find this definition particularly salient because it connects the social (farmers and their advisory network) and physical aspects (spatial and temporal variability) of the farm, while not relying on any particular tool to achieve this type of management strategy. While PA has a strong association with particular forms of geospatial tools and, more recently, smart IoT (Internet of Things) devices, we recognize that many activists, farmers, and others have begun to co-opt the term in utilizing diverse sources of information beyond the digital to address in-field heterogeneity. Thus, we hope to encapsulate the nuance of PA, by situating it as an approach to farm management that is embedded within a particular set of (digital) technologies and (uneven) social relations.

While our analysis and the literature show PA can have various definitions as tools or as a management philosophy and strategy, when we look at the *prevailing* discourse, we find that PA is seen as a set of tools. We found through our discourse analysis that definitions of PA in popular media, trade journals, and industry websites emphasize some components—tools, practices, and relations—more than others. PA is commonly articulated as a *new set of tools* associated with big data and AI that will digitize and/or automate the farm (see Table 1). It is defined less often as a management

philosophy that has evolved over the past three decades in relation to these technologies.

Even when PA is described as a site-specific management strategy, emphasis is still on the tools that enable this. It is notable that the discourse in news media and industry is more likely to define PA in terms of tools rather than management strategies, and even less so in terms of social relations involving farmers, their advisers, retailers, and input providers. By characterizing PA in this way, with a focus on technological objects emerging for use in the near future, it is easier to promote it.

History

Is PA reinventing itself, in response to new smart sensors and data tools? What about it has evolved over time, if anything? Without question, a variety of digital farm technologies have emerged over the past 30 years. But most of these could be characterized as extending general categories of tools, rather than as entirely new types. For instance, variable rate *seeding* is now possible, furthering farmers' ability to precisely target inputs other than fertilizer and pesticides. Likewise, sensors collecting data on soil moisture, crop health, and so on have proliferated and driven the development of farm management software tools (Wolfert et al. 2017). Yet yield monitors and displays have been on the market for over two decades (Tsouvalis et al. 2000). More importantly, the basic *mechanism* by which these technologies are supposed to achieve gains in yield and resilience has remained the same: optimized management of precise farm areas through use of field data. There is a breadth of academic literature from the beginning of the twenty-first century that discusses the drivers and development of PA (Van den Heuval 1996; Stafford 2000; Nowak 1998). Yet, the industry and popular press discourse situates digital ag technologies within the frame of "disruptive", "radical", and "game-changing" big data and AI (Lioutas and Charatsari 2020, p. 2), removing them from this longer history of site- and time-specific management approaches in agronomics.[13]

The apparent newness of the tech comes to stand in for a new approach, which some industry observers claim is "still relatively nascent at this point",[14] "a term we're hearing more and more",[15] and "a new approach to farming"

---

[13] Just as we might see in medicine how new big data technologies are discussed without a sense of their embeddedness in, for instance, the long history of rationalizing diagnosis and care (Berg 1997).

[14] https://www.cbinsights.com/research/precision-agriculture-acquisition-rumors-ulta-apple-nutrition/.

[15] https://www.kdlt.com/2018/06/21/school-zone-precision-agriculture-at-sdsu/.

Table 1 Definitions of precision agriculture from industry and trade websites

PA is…	Exemplary quotations—emphasis added	Webpage title	Source type	Source
A set of tools…	"There are several aspects of precision agriculture that can be applied to various types of farming operations, but they all share a commonality— the *use of technology* to enhance economic performance, better use of inputs and help to mitigate environmental damage"	Precision Agriculture Conference & Ag Tech Showcase	Conference website	https://www.farms.com/precision-agriculture/eastern-conference-2020/
	"Precision agriculture is *the use of technology like the Internet of Things (IoT), self-driving machinery, drones, and satellites* to operate farms in a more effective and efficient manner"	House passes precision agriculture connectivity act	Trade journal	http://bbpmag.com/wordpress2/2018/07/house-passes-precision-agriculture-connectivity-act/
	"While precision agriculture is *the brain of the farmer*, a drone can be the body of the farmer"	Drones in Precision Agriculture	Trade journal	https://dronebelow.com/drones-in-precision-agriculture/
	"Precision agriculture provides you *with the means to store, combine, and analyze a constant stream of data…*"	Precision Agriculture: Quality data for profitable management	Precision Agriculture Sales	https://droneservicescanadainc.com/services/precision-agriculture/
…that digitize and/or automate the farm	"Precision agriculture is planting with purpose, *recreating your farm digitally* to know it inside and out…"	What is Precision Agriculture? Introducing Dirt to Database	Precision Agriculture Sales	https://www.chetu.com/blogs/agriculture/precision-agriculture.php
	"The application of precision agriculture is simple, *take input, process it, automatically pick the best response.*"	Drones in Precision Agriculture	Trade journal	https://dronebelow.com/drones-in-precision-agriculture/
	"The job of a precise agriculturist is *to adopt the most suitable combination (package) of hardware and software technologies* to optimize farm operations and access to markets."	Scope of Precision Agriculture in Pakistan	Website	http://envjournalists.com/green_tech/scope-of-precision-agriculture-in-pakistan/

Table 1 (continued)

PA is…	Exemplary quotations—emphasis added	Webpage title	Source type	Source
A (site-specific) management strategy	"Agronomists and growers can *review information from precision ag technology* to determine the best course of action for individual fields"	What fertilizers and pesticides commonly go on ag fields and why?	Industry blog	https://sustainable-secure-food-blog.com/2018/05/22/what-fertilizers-and-pesticides-commonly-go-on-ag-fields-and-why/
	"Precision agriculture *is all about gathering timely geospatial information* on soil and plant requirement and prescribing site-specific medication to protect the environment while increasing agricultural yields."	GPS technology as an integral part of precision agriculture	Trade journal	http://www.farmmanagement.pro/gps-technology-as-an-integral-part-of-precision-agriculture/
	"Precision or smart farming is based on the optimized management of inputs in a field according to actual crop needs. *It involves data-based technologies, including satellite positioning systems like GPS, remote sensing, and the Internet,* to manage crops and reduce the use of fertilisers, pesticides and water"	Industry calls on EU member states to show clear commitment in smart farming	Research blog	http://chicproject.eu/2019/04/01/industry-calls-on-eu-member-states-to-show-clear-commitment-in-smart-farming/

that is "transforming agriculture."[16] Other commentators are more boastful, predicting that "technology advancements are stretching the bounds of production possibilities"[17] and that, despite its three decade history, PA is a "game changer".[18] PA is described as a "revolution"[19] that is "innovative and disruptive"[20] as well as "inevitable": "the value chain will become more digitized with data and intelligence …. This *will inevitably* enable new databased farm-management techniques in which agrochemicals are used differently than today."[21] PA will give farmers "unprecedented control over their growing operations"[22] and, ultimately, "in the next few years, the drone will join the mule and the tractor as an indispensable farming tool."[23]

ot everyone, however, sees the history of PA in this way. Some in the industry acknowledge that at the heart of big data- and AI-driven digital agriculture is a *decades old approach*: "while precision agriculture is not a new term to the farming industry, the software development and the gadgets are getting better every year."[24] Others even describe the promise of innovation as well-worn: "Seemingly every time a new technology disrupts, err, is introduced to the industry, precision ag professionals often act like it's the first time a new solution or product has ever been launched."[25] While PA is mostly seen as something new and revolutionary, the context of its development over the past thirty years is particularly relevant to understanding the goals and outcomes of these ag technologies.

Goals

A variety of overlapping goals—sometimes framed as actual outcomes—are stressed alongside definitions of PA. In Table 2, we list what we found through our coding to be some of the most commonly-stated ones. We did not count the number of times we employed each code—our primary goal was not to assess prevalence but to describe the structure of thought. Nevertheless, increasing yield appeared to be the most common goal of precision agriculture.

By analyzing the goals of PA, we also observed the *problems* it promises to solve: compliance with regulations,[26] unsustainable environmental impacts, climate variability, and information overload. The discourse around PA places the most stress on twin-threats of population and climate change, e.g.: "the future of agriculture will be directly impacted by two of humanity's biggest menaces on the horizon: population growth and climate change."[27] (see Fairbairn & Guthman 2020 for how COVID-19 now manifests in this part of the discourse) While PA is promoted as revolutionary, some industry representatives and observers acknowledge that there are challenges to implementing it and realizing its potential, including severe weather and market fluctuations. These, of course, are some of the very same barriers faced by "non-digital" farming operations, but there are also several barriers seen as unique to PA, including: equipment and infrastructural costs, cyber security, and tech incompatibility.[28] Not unexpectedly, PA is framed as costly—a "major restraining factor" in the development of a global digital ag market is the "high initial cost requirement for IoT integration in smart farming."[29] Cyber security is occasionally acknowledged as a weak point, as such measures: "have yet to evolve beyond a basic level."[30]

What is notable about this diversified set of goals, the problems they respond to, and potential barriers, is what is absent. The PA discourse tends to not be explicit about managing political changes or ensuring just food distribution, nor is it concerned with the types of foods that needed to be produced to ensure sustainable and nutritious diets. The current discussion continues to promote the narrative of sustainable intensification to meet growing demands for food in a changing climate (Garnett et al. 2013).

[16] https://www.edf.org/ecosystems/sustainable-agriculture/precision-agriculture.

[17] https://agribusinessintelligence.informa.com/resources/product-content/precision-agriculture-document-2018.

[18] https://www.capjournal.com/opinions/columnist/precision-ag-project-is-game-changer-for-ag/article_bea59f5a-3b9a-11e8-bc41-ab3b6893547c.html.

[19] http://agremso3il.eu/2019/03/21/responsible-innovation-key-to-smart-farming/.

[20] http://sparkle-project.eu/drones-for-precision-agriculture/.

[21] https://www.idtechex.com/en/research-article/monsanto-case-reaffirms-that-robotics-is-the-future-of-agrochemicals/15126?donotredirect=true; emphasis added.

[22] https://blog.bell.ca/how-bell-and-farmers-edge-are-creating-precision-agriculture-with-iot/; emphasis added.

[23] https://droneservicescanadainc.com/services/precision-agriculture/.

[24] http://modernagriculture.ca/integrating-high-tech-farm/.

[25] https://www.precisionag.com/service-providers/precision-ag-technology-act-like-youve-been-there-before/.

[26] As in Maryland, USA: https://www.baltimoresun.com/news/environment/bs-md-tech-farming-20150702-story.html.

[27] https://cleantechnica.com/2019/04/03/future-farms-agritech-innovations-to-feed-a-changing-planet/; It's not even increased demand that is presented as the challenge, it is simply the presence of nine billion people.

[28] On incompatibility: http://sparkle-project.eu/isobus-revolutionizing-agriculture/.

[29] http://news.rhodeislandchronicle.com/story/169717/iot-of-smart-farming-market-valued-approximately-usd-17-billion-in-2017-is-anticipated-to-grow-with-a-healthy-growth-rate-of-more-than-18-over-the-forecast-period-20182025.html.

[30] http://georgetownsecuritystudiesreview.org/2018/12/14/precision-agriculture-a-fruitful-target-for-cyber-adversaries/.

Table 2 The stated goals—and, sometimes, outcomes—of precision ag

	Summary	Exemplary Quotations—emphasis added	Webpage title	Source type	Source
Yield	PA will enable farmers to increase their yields first and foremost	"Continued development of precision ag will provide access to the most-modern technology and a wealth of data about the condition of crops, soil and air that will provide a blueprint into achieving optimum health and productivity. Using that information, farmers will *improve their yields* and at the same time reduce input costs"	Precision-ag project is a game changer for ag	News website	https://www.capjournal.com/opinions/columnist/precision-ag-project-is-game-changer-for-ag/article_bea59f5a-3b9a-11e8-bc41-ab3b6893547c.html
Income	Beyond yield, PA will result in greater farm income	"Precision agriculture is a continually evolving term where *technology advancements* are stretching the bounds of production possibilities leading to greater and greater farm income …."	White Paper: How Precision Agriculture is Changing the Game of Crop Farming	White Paper Press Release	https://agribusinessintelligence.informa.com/resources/product-content/precision-agriculture-document-2018
Knowledge	PA is about reconfiguring farm information flows	"Precision agriculture is planting with purpose, *recreating your farm digitally to know it inside and out,* and remaining environmentally conscious as a secondary benefit"	What is Precision Agriculture? Introducing Dirt to Database	Precision Agriculture Sales	https://www.chetu.com/blogs/agriculture/precision-agriculture.php
Environment	PA is about protecting the environment	"Precision agriculture is all about gathering timely geospatial information on soil and plant requirement and prescribing site-specific medication *to protect the environment* while increasing agricultural yields"	GPS technology as an integral part of precision agriculture	Trade journal	http://www.farmmanagement.pro/gps-technology-as-an-integral-part-of-precision-agriculture/
Labour/Health	PA is important to worker safety	"Precision ag, combined with mechanization and automation, is *the key to reduce labor use, make field workers safer,* and gives farmers the tools to cut use of chemicals, water, and other important resources"	WSU named top 25 in precision ag	Trade journal	http://www.washingtonagnetwork.com/2018/04/17/wsu-named-top-25-in-precision-ag/
Resilience	PA can enable climate resilience	"In short, precision ag initiatives can help farmers *boost their lands' resilience* in the face of climate change"	Making precision ag accessible	Research blog	https://www.earth.ac.cr/en/feature/making-precision-accessible/

Adoption

Over the next three sections, we characterize tensions related to adoption, use, and impact. PA rhetoric emphasizes that the adoption of new digital tools will increase farmers' yields. But are farmers adopting the technologies that are being promoted and promised? In positioning farmers as 'waiting in line' for new technologies, what does this discourse achieve?

Trajectories of innovation in PA rest uneasily alongside actual rates of adoption. Research has demonstrated that farmers adopt PA tech slowly and often adopt discrete technologies as opposed to complete PA 'bundles' (Miller et al. 2017, 2019). The development and deployment of PA over time has occurred in a top-down fashion (Gardezi and Bronson 2019; Rotz et al. 2019a). Ag tech promoters are now talking about technologies that are far away from being used in the field, such as 5G networks or mesh technology. This is the pattern we have already seen in precision ag: a presumption of innovation and market growth, without an articulation of *how* it will happen.

Some in the industry directly acknowledge the limited rate of adoption. One researcher featured on the blog of ag tech company Trimble suggested that "North America is 'just at the beginning'" but wondered "if more regulation would spur adoption."[31] This is quite a different refrain from the bold claims of disruption and inevitability presented above. Limited adoption rates are also sometimes understood as an inability to communicate the value of PA to farmers. As one industry observer lamented, "listening to grower panels at precision ag events has convinced me that most farmers still don't know what the ROI [return on investment] is for most ag data products on the market."[32] *Who* adopts is also an open question. Extension agents acknowledge that other farm actors—consultants, dealers, suppliers, and other advisors—"may be the more appropriate adopter category."[33] This assertion that those who are involved in providing custom work might be the more appropriate adopters of PA suggests that individual farmers are wary of the risk of investment in capital-intensive technology without a clear ROI. New tech is promoted as valuable in much of the PA discourse, but farmers themselves ask, "are these tools worth it to me?" Traditional public agricultural research and extension services have adopted more private and quasi-private forms, making the governance surrounding digital tools more complex over time (Fielke et al. 2020).

This governance landscape, composed of multiple and competing interests, shapes the power farmers have to decide if technologies are indeed worth it for them and is something relatively unaddressed in the discourse we analyzed.

If PA were for farmers, limited rates of farmer adoption should be at the forefront of concerns over the emerging industry. Yet, from our discourse analysis, this is not the case. We found the discourse to be highly optimistic and aspirational. By positioning limited adoption rates as a challenge to be overcome by turning to other types of users, or a function of farmers not understanding the benefits of PA, we question if these tools are really for farmers versus the developers and various stakeholders that promote them.

Uses

Are farmers positioned to use emerging digital tools as tech developers expect them to? Beyond adoption per se, there are tensions between what expectations promoters craft and the actual contexts in which tools are used (Rose et al. 2018). Following Rajan (2006), promoters' expectations are of "farmers-in-waiting"—farmers anticipated to use the tools in specific ways. For instance, as depicted in John Deere's Farm Forward 2.0 video, farmers are expected to be enabled by sensors and data dashboards to make clear decisions with all the necessary information at their fingertips.[34] They may worry about what tomorrow will bring, but they can rely on the technology. What is obscured by this expectation is that farmers are often constrained by multiple factors in their decision making, including debts, weather, and regulations (Higgins 2007; Higgins et al. 2017). This expectation also requires farmers to place significant trust into decision support systems, without accounting for how experiential knowledge, consultant advice, and other sources of information come into play (Rose et al. 2018).

We acknowledge that it is difficult to get at actual contexts of use by reading texts, as we do in this paper. We are not claiming that no farmer employs farm management software and other technologies exactly how they are imagined to by ag technology developers. Instead, we highlight cases where farmers and others are saying, "it doesn't actually work like that!" For instance, one consultant has written extensively on many of the challenges to employing satellite and drone imagery within farm management. He is associated with a firm that does such work, but he is critical of narratives that gloss over these challenges and calls for a "reality check."[35]

---

[31] https://ag.trimble.com/agadvance/true-precision-ag-economic-and-environmental-win-win.

[32] https://www.agriculture.com/content/finding-the-roi-in-your-ag-data.

[33] https://crops.extension.iastate.edu/perceived-risks-and-decisions-adopt-precision-farming-methods-introduction.

[34] https://www.youtube.com/watch?v=eVKG6kJ91Sg.

[35] https://www.precisionag.com/in-field-technologies/imagery/imagery-in-agriculture-time-for-a-reality-check/; https://www.precisionag.com/in-field-technologies/imagery/imagery-in-agriculture-time-for-a-reality-check-part-two/.

Speaking to Trimble, prominent manufacturer of ag data displays, one academic researcher explains that, "we have to face the fact that most yield monitor data simply doesn't get used…It's too difficult and farmers don't have the time or skills to do it."[36] Likewise, field management zones are at the heart of precision farming and therefore are a core component of how digital agriculture is envisioned to revolutionize farming. The creation of zones is presumed to be a relatively straightforward technical task but, as one farm organization reports, it is not, and management zones are often aggregated into larger units by producers.[37]

As data is collected from a variety of new kinds of sensors, the data needs to be in accessible and interoperable formats—otherwise, farmers will not be able to use it (Kamilaris et al. 2017). PA promoters confront the challenge of interoperability with standardization, imagining seamless use of data and digital equipment into the future: "standardization will allow more farmers to make use of inventions or upgrades, even if the company that made the tractor or combine isn't offering that technology yet."[38] The expectation is that if a farmer buys a certain brand of combine and then wants to add a sensor that another company has developed, data and hardware standardization will enable them to do this. But it belies the currently existing challenge many farmers face in accessing their equipment and getting different components to "speak" to each other—such as farmers who have had to "hack" into or "tinker" with their six-figure assets.[39]

In our discourse analysis, industry experts and developers are the actors defining proper technology use, not farmers. We suggest that in positioning farmers as using tools improperly or in unexpected ways, that the context of PA use is not actually about matching farmer needs. This is reinforced by positioning the challenge of PA use as a technical issue of data and equipment standardization to be sorted by manufacturers, rather than a legislative or governance issue to allow farmers to make their technologies work for them.

Impacts

Does farm management and decision-support software displace or supplement farmer knowledge? Is the smart farm of the future run by a farmer or by their tools? And what does the discursive framing of 'farmers versus robots' obscure in trying to understand the impacts of PA? We find a tension between whether there is a farmer-in-waiting or an algorithm-in-waiting, and note how other subject positions and social relations that define PA in practice—namely, crop advisors—are absent.

Most industry commentators and journalists frame the future of agriculture in terms of farmers, claiming that farmers will need to become "techpreneurs" or "agricultural technologists" by turning their operations into start-ups of a sort. As Microsoft imagines it, "AI will help farmers evolve into agricultural technologists, using data to optimize yields down to individual rows of plants."[40] The *farmer* themselves is at the center of this vision of digital agriculture's impacts, not crop advisors and/or agronomists; it is the farmer who has to acquire new skills and "evolve." This frames a 'farmer-in-waiting' who has mastered digital tools to optimize production, and frames the farming occupation as subject to disruption by technology.

While some industry observers predict that algorithmic analysis will displace these farmers' expertise (see e.g. in Miles 2019, p. 4), most see digital ag tech and decision support systems (DSS) as merely supplementing farmer decisions. A key refrain prevalent across journalistic as well as trade reporting on PA is that: "data, *coupled* with the farmer's knowledge and intuition about his or her farm, can help increase farm productivity, and also help reduce costs."[41] Data only adds to farmers' knowledge and intuition: "new methods *augment* local knowledge rather than replace it, providing cost-effective and highly accurate ways to predict and protect the growth of agricultural crops."[42] Digital tools, promoted as revolutionary, can actually only accomplish so much without human input: "a farm may have the latest digital gadgets and be fully mechanized, but hard work and precision by humans are a must for success."[43] Likewise, "smart farming is no substitute for farmers' experience, feel for their work and professional training."[44] Only certain tasks can be outsourced to algorithms and robots: "the repetitive motions of crop tending can be done more effectively and with more precision by autonomous vehicles, [but] the agronomy and all of the difficult decisions

---

[36] https://ag.trimble.com/agadvance/true-precision-ag-economic-and-environmental-win-win.

[37] http://ontariograinfarmer.ca/2017/01/01/where-do-management-zones-make-sense/.

[38] http://sparkle-project.eu/isobus-revolutionizing-agriculture/.

[39] https://www.cbc.ca/radio/asithappens/as-it-happens-monday-edition-1.4042503/updated-saskatchewan-farmer-hacks-his-smart-tractor-to-avoid-costly-dealer-fees-1.4042504.

[40] https://cloudblogs.microsoft.com/2018/11/29/feeding-the-world-with-ai-driven-agriculture-innovation/;

[41] https://www.microsoft.com/en-us/research/project/farmbeats-iot-agriculture/; emphasis added.

[42] http://www.cta.int/en/digitalisation/all/article/a-smart-farming-approach-to-agriculture-sid03a7e1e43-e341-4b5b-ac5b-c7f610d018c2; emphasis added.

[43] https://cropnuts.com/precision-agriculture/.

[44] https://houseofswitzerland.org/swissstories/economics/agriculture-40-swiss-smart-farming-revolution.

still need to be done by humans."[45] Ontario, Canada's Ministry of Agriculture, Food and Rural Affairs, summarizes this perspective: "[PA technology] simply provides new and powerful data tools to make soil management decisions." Digital and smart tools are seen to make farm life easier, more efficient, and effective by supporting farmer intuition.

What we see here is the drawing of a line between the disruptive power of innovative new tools and their support of farm-specific knowledge and farmers. PA is expected to be a revolution in how farms produce food, fiber, and fuel, but it will not go so far as to fundamentally upset farmers' command of their operations. Such a claim would prove quite unpopular (Miles 2019). In PA discourse, there is an underlying uncertainty around who or what will be responsible for decision making and an ambiguity about how to characterize this while also championing the smart farm economy revolution. So far, emphasis has been on supplementing farmers rather than displacing them or aiding other decision-makers.

Discussion: who is ag tech for?

In our results, we found that PA is pitched as such: new and emerging farm technologies will be the levers that help farmers solve challenges related to increasing yields and meeting growing global food demand. In this section, we discuss how and why this framing of PA has come to dominate over others and what dimensions, such as the role of finance, are conspicuously absent. If the rhetoric around PA focuses on tools over management, the new over the old, yield over farm stability, innovation over adoption, on expected uses rather than real contexts, and farmers evolving into "agricultural technologists", then who is ag tech for? To what extent is PA proposing and fulfilling diverse social and environmental goals? To us, the emphasis on PA as "new tools" in spite of its long history suggests how it is re-inventing itself in response to the opportunities and hype around digital data technologies. We posit that much of the current promotion of PA is geared towards two audiences that have become important agri-food governance actors—the financial and tech industries. We elaborate on this assertion in three parts below.

First, in our discourse analysis we observed that PA tends to be thought of as *new tools* for supplementing the decision-making processes of farmers. We asked what this framing as novel achieves, rather than assessing its merits per se. Following STS literature on the social work of promises and expectations, we see the hype-centered, win–win promotion of ag technologies as a way to shore up continued

investment. After all, the PA market—increasingly played by firms like Accenture, Microsoft, and a host of startups with minimal previous connections to agri-food—is expected to grow significantly over the next decade. In fact, digital ag tech applications are seen as pivotal to the tech sector more broadly, with some predicting that farms will account for over 80% of the commercial drone market.[46] Predictions like these bolster the legitimacy of ag tech and investments in it. They aim to position it as the 'next big thing' with a clear return for investors. Related, data-collecting precision tools themselves may facilitate a further financialization of agriculture (Clapp 2014); equipment companies or others collecting harvest data may use it to play international futures markets.[47] Generally, data and digital tech are seen to promise speculative value (Sadowski 2019). This explains why PA defined as 'new tools' is the dominant narrative rather than PA defined as a long-standing management strategy. Conspicuously, but conveniently, critical questions of finance are not addressed head on.

Second, we return to the emphasis we saw in PA discourse on supplementing and not displacing the decision-making of farmers. This focus on algorithmic aids to *farmer* decision-making misses the broader political economy of agronomic knowledge that farmer expertise is already situated within (Burton 2004; Eastwood et al. 2012; Rose et al. 2018). Commentators' framing of agriculture's future in terms of how digital tech might displace farmer expertise is somewhat misdirected. It overlooks the fact that farm decision-making power is already dispersed. It is not the case that farmers had full dominion over farm decisions until algorithmic, precision input prescriptions came along. That idea stems from a rural imaginary of small farms with male heads of household making decisions (see Bell et al. 2015 and Murray 2018 for further discussions of how the imaginary of farming is shifting with tech). In practice, there are many farm decision-makers other than farmers themselves. As Climate FieldView—a popular DSS—lets on in its disclaimer, farmers should "consult agronomists, commodities broker and other service professionals before making financial, risk management and farming decisions" with the tool.[48] Farmers have long been constrained in their decision-making related to inputs, because of various pesticide "treadmills" and cost-price squeezes (Weis 2007; Galt 2013). Debates about the impacts of rationalizing farm decision-making that center on farmer autonomy obscure this political economy.

---

[45] https://www.cbc.ca/news/technology/farming-technology-advances-1.4290569.

[46] https://droneservicescanadainc.com/services/precision-agriculture/.

[47] https://www.fcc-fac.ca/en/about-fcc/media-newsroom/news-releases/2019/producers-embrace-technology-but-want-control-over-their-data.html.

[48] Disclaimer at the bottom of its website: https://climatefieldview.ca/.

If digital tools are just supplementing decisions that farmers make, they may not be showing much that is new. If they are not, then who is benefitting from the sale of farm management software, the required data, and the analysis of it? The question can be explored through the pitch made by one ag tech promoter:

> There are some lower-cost entry points into precision agriculture for farmers who want to try it out, but don't want to make a big investment...If you simply manage one wet corner of a farm differently based on yield data or a simple satellite imagery map that showed a red spot all season, you've paid for your subscription already.[49]

A farmer may not need to purchase satellite imagery or acquire their yield data to "simply" manage a wet spot in their field. It is something many farmers would likely already recognize (see Tsouvalis et al. 2000). The imagery and field data provide the farmer an ostensibly more objective view, but also provide an extra revenue stream for a precision agriculture firm through the collection of crop data. Farmers pay a significant amount to use DSS, despite being the individuals who physically acquire field data and whose capital was used to generate it. Such data and its analysis are often packaged and re-sold to farmers as 'better' inputs.

Third, we synthesize what the two previous points illustrated: (1) the emphasis on novelty and tech is about soliciting and securing investment; (2) the focus on how PA supplements the decision-making processes of farmers obscures the political economy of agronomic expertise. Taken together, these two points prompt us to ask, who is precision ag for, "as data meets the land, and the land meets data" (Ghosh and Bronson 2019)? If PA is re-inventing itself to attract investment for new devices that promise revolutionary advances in farming, while overlooking how farmers are embedded in economic structures that already constrain their choices, then we should explore how PA aligns with financial and technological interests.

Following Ensmenger (2012), we suggest that one important role farm data may serve is as an "experimental technology" for AI development. Tech firms are increasingly amassing data from all sectors to build better AI (Zuboff 2018). Farm data is voluminous and heterogeneous—reflecting those very same qualities about the land itself—and for these same reasons as well, tech companies see farm data as having utility beyond farm gates. While many ag service providers, such as Climate Fieldview, justify their data collection by claiming it will enable them to develop improved and tailored hybrids and input prescriptions, other actors are interested in farm data in part because it provides a rich "training set" for the development of better algorithms that may or may not have actual application to improving yields or crop resilience (Fraser 2018).

Consider, for instance, Microsoft's AI for Earth program. AI for Earth draws on the firm's financial capacity and technical expertise to fund several conservation-related applications of artificial intelligence, a few of which center agriculture. As Microsoft acknowledges, it is not "an intuitive player in ag tech." Its involvement in developing data collection and analysis ag tech via AI for Earth is meant to establish the company as a "thought leader and innovator on key environmental issues."[50] As one observer of Microsoft's efforts explained, its value proposition is this: "agriculture needs technology, but likewise, the industry needs agriculture to help demonstrate technology's impact in a complex, data-rich environment."[51] In a keynote address for an ag tech conference, an AI for Earth representative further explained that farm data provides complexities that the company can learn from, not just demonstrate impact through.[52] This flips how we typically think of the rhetoric of innovation. Beyond noting their ability to solve problems in the domain of application (agricultural sustainability), Microsoft suggests internally-focused goals—to further develop AI tech in general through a "data-rich" domain. This echoes the company's earlier acquisition of job search platform LinkedIn and its substantial dataset (in Fraser 2018). It differs from a "data grab" (Fraser 2018), because while a firm like Climate Fieldview may be interested in land data for developing new farm services, Microsoft's ag tech development is also aimed at new data technologies in general. In this way, farm data serves as an experimental technology, or a means by which to develop insights about something else—in this case, AI. Instead of the chessboard early AI was thought through, we have the patchwork quilt of farmland. In this, farm DSS may solicit user data for ends apart from the purpose of the platforms themselves, without compensation or transparent agreements (Marquis 2020). Our analysis of how PA is defined, promoted, and debated on the web enables us to name a seeming paradox: a digitalized agriculture that is not necessarily about or for those we normally think of as agri-food governance actors.

Conclusions

In this study, we documented the framing of precision agriculture in response to Bronson and Knezevic's (2016) prompt: what distinguishes the era of agricultural big data from earlier, historic modes of farm management and monitoring? We found that, in part, the contemporary agri-food regime's claims to sustainability are shored up and promoted through the development, use, and promotion of digital and smart tools (Wolf and Buttel 1996; Miles 2019). Yet, the majority of websites we analyzed indicated the financial value of digital tech for farmers and investors alike before they described any environmental benefits, much less farmer justice concerns, or more fundamental forms of food system reform. Building upon STS analyses of PA, we found that an emphasis on novelty and innovation is relatively unchallenged as a way of securing investment by promising realizable value.

Highlighting six tensions in PA discourse—whether it is a set of tools or a management approach, whether it is new or old, whether the goal is yield or environmental sustainability, innovation versus adoption, expectations versus use, and whether it will displace or supplement farmers—we were able to tease out more of what precision agriculture is and is not, as well as its future. In conducting a discourse analysis of web content related to PA, we provided a unique contribution to the social science literature on power relations and political economy in digital agriculture. We sought to understand the current conjuncture of big data, AI, and PA, not to dismiss its novelty, but rather to question who benefits from it. In doing so, we highlight a significant paradox: that PA discourse prioritizes technical over social innovation in support of demonstrating value to financial and tech industry domains.

Every narrative has its contradictions or "contra discourse" (Fleming et al. 2018), but food systems would be well-served if the tensions within PA discourse were addressed head-on, rather than imagining tech will easily, completely positively, and equitably lead to "quantum leaps'' in agriculture. While scholars have long recognized that discussions of "precision" have reinforced hegemonic food regimes (Wolf and Buttel 1996; Miles 2019), there is no inherent association between precision and industrial food production. Researchers have explained many site-specific management practices that would justifiably count as "precision", such as the small-scale agroecological focus of the Practical Farmers of Iowa (Bell 2004). Indeed, there are emerging non-hegemonic digital agriculture technologies and "precision" uses of them, such as the "Slow Tools'' movement that (re)crafts tools to enable intimate yet efficient working of the land at relatively small-scales. While our discourse analysis picked up on such projects,

they were largely overshadowed. Future research is needed to further explore these counter-discourses and their material artefacts (e.g. open-platform tech, collaborative platform economies, etc.), and we see much fruitful discussion already occurring (Bronson 2019; Carolan 2016; Klerkx et al. 2019). As researchers describe PA discourse, it is critical to interrogate the uneven dynamics of its extension in practice.

References

Ali, A., J. Qadir, R. Rasool, A. ur Sathiaseelan, and A. Zwitter. 2016. Big data for development: Applications and techniques. *Big Data Analytics*. https://doi.org/10.1186/s41044-016-0002-4.

Bain, C., S. Lindberg, and T. Selfa. 2019. Emerging sociotechnical imaginaries for gene edited crops for foods in the United States: Implications for governance. *Agriculture and Human Values*. https://doi.org/10.1007/s10460-019-09980-9.

Barnes, A.P., I. Soto, V. Eory, B. Beck, A. Balafoutis, B. Sánchez, et al. 2019. Exploring the adoption of precision agricultural technologies : A cross regional study of EU farmers. *Land Use Policy* 80 (August 2018): 163–174. https://doi.org/10.1016/j.landusepol.2018.10.004.

Bell, M. 2004. *Farming for Us All: Practical Agriculture and the Cultivation of Sustainability*, 312. University Park: PSU Press.

Bell, S.E., A. Hullinger, and L. Brislen. 2015. Manipulated masculinities: Agribusiness, deskilling, and the rise of the businessman-farmer in the United States: Manipulated masculinities. *Rural Sociology* 80 (3): 285–313.

Berg, M. 1997. *Rationalizing Medical Work: Decision-support Techniques and Medical Practices*. Cambridge: MIT Press.

Bertoglio, R., C. Corbo, F. M. Renga, and M. Matteucci. 2021. The digital agricultural revolution: A bibliometric analysis literature review. http://arXiv.org/2103.12488 *[cs]*. http://arxiv.org/abs/2103.12488. Accessed 1 June 2021

Birch, K. 2017. Rethinking *value* in the bio-economy: Finance, assetization, and the management of value. *Science, Technology, & Human Values* 42 (3): 460–490.

Borup, M., N. Brown, K. Konrad, and H. Van Lente. 2006. The sociology of expectations in science and technology. *Technology Analysis & Strategic Management* 18 (3–4): 285–298.

Boyd, D., and K. Crawford. 2012. Critical questions for big data: Provocations for a cultural, technological, and scholarly phenomenon. *Information Communication and Society* 15 (5): 662–679. https://doi.org/10.1080/1369118X.2012.678878.

Bronson, K. 2018. Smart farming: including rights holders for responsible agricultural innovation. *Technology Innovation Management Review* 8 (2): 7–14. https://doi.org/10.22215/timreview/1135.

Bronson, K. 2019. Looking through a responsible innovation lens at uneven engagements with digital farming. *NJAS-Wageningen Journal of Life Sciences* 90: 100294.

Bronson, K., and I. Knezevic. 2016. Big data in food and agriculture. *Big Data & Society* 3 (1): 205395171664817.

Burton, R.J.F. 2004. Seeing through the "Good Farmer's" eyes: Towards developing an understanding of the social symbolic value of "productivist" behaviour. *Sociologia Ruralis* 44 (2): 195–215. https://doi.org/10.1111/j.1467-9523.2004.00270.x.

Carolan, M. 2016. Publicising food: Big data, precision agriculture, and co-experimental techniques of addition. *Sociologia Ruralis* 57 (2): 135–154.

Carolan, M. 2020. Acting like an algorithm: Digital farming platforms and the trajectories they (need not) lock-in. *Agriculture and Human Values* 37: 1041.

Clapp, J. 2014. Financialization, distance and global food politics. *The Journal of Peasant Studies* 41 (5): 797–814.

Coble, K.H., A.K. Mishra, S. Ferrell, and T. Griffin. 2018. Big data in agriculture: A challenge for the future. *Applied Economic Perspectives and Policy* 40 (1): 79–96. https://doi.org/10.1093/aepp/ppx056.

Cope, M. 2010. Coding Qualitative Data. In *Qualitative Research Methods in Human Geography*, ed. I. Hay. Oxford: Oxford University Press.

Dixon, D. 2010. Analyzing Meaning. In *Research Methods in Geography: A Critical Introduction*, ed. B. Gomez and J.P. Jones III. Hoboken: Wiley.

Duncan, E. 2018. An Exploration of How the Relationship between Farmers and Retailers Influences Precision Agriculture Adoption. MA Thesis. University of Guelph. http://hdl.handle.net/10214/13546

Eastwood, C.R., D.F. Chapman, and M.S. Paine. 2012. Networks of practice for co-construction of agricultural decision support systems: Case studies of precision dairy farms in Australia. *Agricultural Systems* 108: 10–18. https://doi.org/10.1016/j.agsy.2011.12.005.

Eastwood, C., L. Klerkx, M. Ayre, and B. Dela Rue. 2019. Managing socio-ethical challenges in the development of smart farming: From a fragmented to a comprehensive approach for responsible research and innovation. *Journal of Agricultural and Environmental Ethics* 32 (5–6): 741–768. https://doi.org/10.1007/s10806-017-9704-5.

Ensmenger, N. 2012. Is chess the drosophila of artificial intelligence? A social history of an algorithm. *Social Studies of Science* 42 (1): 5–30.

Erickson, B. and J. Lowenberg-DeBoer. 2020. 2020 Precision Agriculture Dealership Survey. https://ag.purdue.edu/digital-ag-resources/wp-content/uploads/2020/11/CropLife-Report-2020.pdf. Accessed 12 July 2021.

Fairbairn, M., and J. Guthman. 2020. Agri-food tech discovers silver linings in the pandemic. *Agriculture and Human Values*. https://doi.org/10.1007/s10460-020-10052-6.

Fairclough, N. 2012. Critical Discourse Analysis. In *The Routledge handbook of discourse analysis (Routledge handbooks in applied linguistics)*, ed. J. Gee and M. Handford, 9–20. Abingdon, Oxon: Routledge.

Fanfani, R., R.H. Green, and M.R. Zuñiga. 1993. Biotechnologies in the agro-food sector: A limited impact. *Agriculture and Human Values* 10 (2): 68–74.

Fielke, S.J., R. Garrard, E. Jakku, A. Fleming, L. Wiseman, and B.M. Taylor. 2019. Conceptualising the DAIS: Implications of the 'digitalisation of agricultural innovation systems' on technology and policy at multiple levels. *NJAS Wageningen Journal of Life Sciences* 90–91 (April): 100296. https://doi.org/10.1016/j.njas.2019.04.002.

Fielke, S., B. Taylor, and E. Jakku. 2020. Digitalisation of agricultural knowledge and advice networks: A state-of-the-art review. *Agricultural Systems* 180: 102763. https://doi.org/10.1016/j.agsy.2019.102763.

Fleming, A., E. Jakku, L. Lim-Camacho, B. Taylor, and P. Thorburn. 2018. Is big data for big farming or for everyone? Perceptions in the Australian grains industry. *Agronomy for Sustainable Development*. https://doi.org/10.1007/s13593-018-0501-y.

Fourcade, M. 2011. Cents and sensibility: Economic valuation and the nature of "nature." *American Journal of Sociology* 116 (6): 1721–1777.

Fraser, A. 2018. Land grab/data grab: Precision agriculture and its new horizons. *Journal of Peasant Studies* 00: 1–20. https://doi.org/10.1080/03066150.2017.1415887.

Galt, R.E. 2013. Placing food systems in first world political ecology: A review and research agenda. *Geography Compass* 7: 637–658. https://doi.org/10.1111/gec3.12070.

Gardezi, M., and K. Bronson. 2019. Examining the social and biophysical determinants of U.S. Midwestern corn farmers' adoption of precision agriculture. *Precision Agriculture*. https://doi.org/10.1007/s11119-019-09681-7.

Garnett, T., M.C. Appleby, A. Balmford, I.J. Bateman, T.G. Benton, P. Bloomer, et al. 2013. Sustainable intensification in agriculture: Premises and policies. *Science* 341 (July): 33–34. https://doi.org/10.1126/science.1234485.

Gee, J., and M. Handford. 2012. *The Routledge Handbook of Discourse Analysis (Routledge Handbooks in Applied Linguistics)*. Abingdon, Oxon: Routledge.

Ghosh, R., and K. Bronson. 2019. *Digital Innovations and the Future(s) of Agriculture*. New Orleans, LA, USA: Society for Social Studies of Science annual conference.

Goldman Sachs. 2016. *Profiles in Innovation—Precision Farming: Cheating Malthus with Digital Agriculture*, 43. New York: Goldman Sachs Global Investment Research.

Higgins, V. 2007. Performing users: The case of a computer-based dairy decision-support system. *Science, Technology, & Human Values* 32 (3): 263–286.

Higgins, V., M. Bryant, A. Howell, and J. Battersby. 2017. Ordering adoption: Materiality, knowledge and farmer engagement with precision agriculture technologies. *Journal of Rural Studies* 55: 193–202. https://doi.org/10.1016/j.jrurstud.2017.08.011.

Helgesson, C.F., and F. Muniesa. 2013. For what it's worth: An introduction to valuation studies. *Valuation Studies* 1 (1): 1–10.

Jakku, E., B. Taylor, A. Fleming, C. Mason, S. Fielke, C. Sounness, and P. Thorburn. 2019. "If they don't tell us what they do with it, why would we trust them?" Trust, transparency and benefit-sharing in Smart Farming. *NJAS Wageningen Journal of Life Sciences* 90: 100285. https://doi.org/10.1016/j.njas.2018.11.002.

Jasanoff, S. 2015. Future Imperfect: Science, Technology, and the Imaginations of Modernity. In *Dreamscapes of Modernity Sociotechnical Imaginaries and the Fabrication of Power*, ed. S. Jasanoff and S.-H. Kim. Oxford: University Press Scholarship Online.

Jepsen, K.S. 2017. Imaginaries of modernity: STS and topographies of power. *Science as Culture* 26 (1): 111–116. https://doi.org/10.1080/09505431.2016.1238887.

John Deere. 2019. Farm Forward with John Deere. https://www.youtube.be/watch?v=nKAz-g7MAxs. Accessed 27 June 2020

Kamilaris, A., A. Kartakoullis, and F.X. Prenafeta-Boldu. 2017. A review on the practice of big data analysis in agriculture. *Computers and Electronics in Agriculture* 143: 23–37. https://doi.org/10.1016/j.compag.2017.09.037.

Kinsley, S. 2010. Representing 'things to come': Feeling the visions of future technologies. *Environment and Planning a: Economy and Space* 42 (11): 2771–2790.

Klerkx, L., E. Jakku, and P. Labarthe. 2019. A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS - Wageningen Journal of Life Sciences* 90–91: 100315.

Leonard, E., R. Rainbow, J. Trindall, I. Baker, S. Barry, L. Darragh, R. Darnell, A. George, R. Heath, E. Jakku, A. Laurie, D. Lamb,

R. Llewellyn, E. Perrett, J. Sanderson, A. Skinner, T. Stollery, L. Wiseman, G. Wood, and A. Zhang. 2017. *Accelerating Precision Agriculture to Decision Agriculture: Enabling Digital Agriculture in Australia*. Cotton Research and Development Corporation.

Levy, W. 2017. A smart farming approach to agriculture. *Spore: A global perspective on agribusiness and agricultural development*. http://spore.cta.int/en/article/a-smart-farming-approach-to-agriculture.html. Accessed 29 Mar 2018

Lindblom, J., C. Lundstrom, M. Ljung, and A. Jonsson. 2017. Promoting sustainable intensification in precision agriculture: Review of decision support systems development and strategies. *Precision Agriculture* 18: 309–331. https://doi.org/10.1007/s11119-016-9491-4.

Lioutas, E.D., and C. Charatsari. 2020. Big data in agriculture: Does the new oil lead to sustainability? *Geoforum* 109: 1–3. https://doi.org/10.1016/j.geoforum.2019.12.019.

Lioutas, E.D., C. Charatsari, G. La Rocca, and M. De Rosa. 2019. Key questions on the use of big data in farming: An activity theory approach. *NJAS - Wageningen Journal of Life Sciences*. https://doi.org/10.1016/j.njas.2019.04.003.

Marquis, S. 2020. Datafication on the Farm: An Exploration of the Social Impacts of Agricultural Big Data on Canadian Crop Farms. MA Thesis. University of Guelph. https://hdl.handle.net/10214/21254

Maye, D., J. Fellenor, C. Potter, J. Urquhart, and J. Barnett. 2021. What's the beef?: Debating meat, matters of concern and the emergence of online issue publics. *Journal of Rural Studies* 84: 134–146. https://doi.org/10.1016/j.jrurstud.2021.03.008.

Miles, C. 2019. The combine will tell the truth: On precision agriculture and algorithmic rationality. *Big Data & Society* 6 (1): 205395171984944.

Miller, N., T. Griffin, J. Bergtold, I. Ciampitti, and A. Sharda. 2017. Farmers' adoption path of precision agriculture technology. *Advances in Animal Biosciences* 8: 708–712. https://doi.org/10.1017/S2040470017000528.

Miller, N.J., T.W. Griffin, I.A. Ciampitti, and A. Sharda. 2019. Farm adoption of embodied knowledge and information intensive precision agriculture technology bundles. *Precision Agriculture* 20 (2): 348–361.

Mitchell, S., A. Weersink, and B. Erickson. 2018. Adoption of precision agriculture technologies in Ontario crop production. *Canadian Journal of Plant Science* 98 (6): 1384–1388. https://doi.org/10.1139/cjps-2017-0342.

Murray, N. 2018. Agriculture Wars. *Viewpoint Magazine*. https://www.viewpointmag.com/2018/03/12/agriculture-wars/. Accessed 13 Mar 2018

Nowak, P. 1998. Agriculture and change: The promises and pitfalls of precision. *Communications in Soil Science and Plant Analysis* 29 (11–14): 1537–1541. https://doi.org/10.1080/00103629809370047.

Phillips, P.W.B., J.A. Relf-Eckstein, G. Jobe, and B. Wixted. 2019. Configuring the new digital landscape in western Canadian agriculture. *NJAS Wageningen Journal of Life Sciences* 90–91: 100295. https://doi.org/10.1016/j.njas.2019.04.001.

Rajan, K.S. 2006. *Biocapital: The Constitution of Postgenomic Life*. Durham: Duke University Press.

Regan, Á. 2019. 'Smart farming' in Ireland: A risk perception study with key governance actors. *NJAS Wageningen Journal of Life Sciences* 90–91: 100292. https://doi.org/10.1016/j.njas.2019.02.003.

Rojo-Gimeno, C., M. van der Voort, J.K. Niemi, L. Lauwers, A.R. Kristensen, and E. Wauters. 2019. Assessment of the value of information of precision livestock farming A conceptual framework. *NJAS-Wageningen Journal of Life Sciences* 90: 100311.

Rose, D.C., and J. Chilvers. 2018. Agriculture 4.0: Broadening responsible innovation in an era of smart farming. *Frontiers in Sustainable Food Systems* 2 (87): 1–7.

Rose, D.C., C. Morris, M. Lobley, M. Winter, W.J. Sutherland, and L.V. Dicks. 2018. Exploring the spatialities of technological and user re-scripting: The case of decision support tools in UK agriculture. *Geoforum* 89: 11–18. https://doi.org/10.1016/j.geoforum.2017.12.006.

Rotz, S., E. Duncan, M. Small, J. Botschner, R. Dara, I. Mosby, et al. 2019a. The politics of digital agricultural technologies: A preliminary review. *Sociologia Ruralis* 59 (2): 203–229. https://doi.org/10.1111/soru.12233.

Rotz, S., E. Gravely, I. Mosby, E. Duncan, E. Finnis, M. Horgan, et al. 2019b. Automated pastures and the digital divide: How agricultural technologies are shaping labour and rural communities. *Journal of Rural Studies* 68: 112–122. https://doi.org/10.1016/j.jrurstud.2019.01.023.

Sadowski, J. 2019. When data is capital: Datafication, accumulation, and extraction. *Big Data and Society* 6 (1): 1–12. https://doi.org/10.1177/2053951718820549.

Schewe, R.L., and D. Stuart. 2015. Diversity in agricultural technology adoption: How are automatic milking systems used and to what end? *Agriculture and Human Values* 32 (2): 199–213.

Schönfeld, M., and v., R. Heil, and L. Bittner. . 2018. Big Data on a Farm—Smart Farming. In *Big Data in Context*, ed. T. Hoeren and B. Kolany-Raiser, 109–120. Cham: Springer.

Shepherd, M., J.A. Turner, B. Small, and D. Wheeler. 2018. Priorities for science to overcome hurdles thwarting the full promise of the 'digital agriculture' revolution. *Journal of the Science of Food and Agriculture* 100 (14): 5083–5092.

Stafford, J.V. 2000. Implementing precision agriculture in the 21st century. *Journal of Agricultural Engineering Research* 76 (3): 267–275. https://doi.org/10.1006/jaer.2000.0577.

Taylor, L. 2017. What is data justice? The case for connecting digital rights and freedoms globally. *Big Data & Society* 4 (2): 1–14. https://doi.org/10.1177/2053951717736335.

Tey, Y.S., and M. Brindal. 2012. Factors influencing the adoption of precision agricultural technologies: A review for policy implications. *Precision Agriculture* 13 (6): 713–730. https://doi.org/10.1007/s11119-012-9273-6.

Tsouvalis, J., S. Seymour, and C. Watkins. 2000. Exploring knowledge-cultures: Precision farming, yield mapping, and the expert—farmer interface. *Environment and Planning A* 32 (5): 909–924.

Van den Heuval, R.M. 1996. The promise of precision agriculture. *Journal of Soil and Water Conservation* 51 (1): 38–40.

Vik, J., E.P. Stræte, B.G. Hansen, and T. Nærland. 2019. The political robot–The structural consequences of automated milking systems (AMS) in Norway. *NJAS-Wageningen Journal of Life Sciences* 90: 100305.

Weersink, A., E. Fraser, D. Pannell, E. Duncan, and S. Rotz. 2018. Opportunities and challenges for big data in agricultural and environmental analysis. *Annual Review of Resource Economics* 10 (1): 19–37.

Weis, T. 2007. *The Global Food Economy: The Battle for the Future of Farming*. London: Zed Books.

Wiseman, L., J. Sanderson, A. Zhang, and E. Jakku. 2019. Farmers and their data: An examination of farmers ' reluctance to share their data through the lens of the laws impacting smart farming. *NJAS Wageningen Journal of Life Sciences* 1: 100301. https://doi.org/10.1016/j.njas.2019.04.007.

Wolf, S.A., and F.H. Buttel. 1996. The political economy of precision farming. *American Journal of Agricultural Economics* 78 (5): 1269.

Wolf, S.A., and S.D. Wood. 1997. Precision farming: Environmental legitimation, commodification of information, and industrial coordination1. *Rural Sociology* 62 (2): 180–206.

Wolfert, S., L. Ge, C. Verdouw, and M.-J. Bogaardt. 2017. Big data in smart farming—A review. *Agricultural Systems* 153: 69–80.

Zuboff, S. 2018. *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power*. London: Profile Books.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Emily Duncan is a PhD Candidate in the Department of Geography, Environment and Geomatics at the University of Guelph. She is a researcher with the Canada First Research Excellent Fund's Food from Thought initiative and a Vanier Scholar. Her research interests include food security, technological transitions, and data governance.

Alesandros Glaros is PhD Candidate in the Department of Geography, Environment and Geomatics at the University of Guelph, and a Research Assistant with the Open Food Network-Canada. He studies novel foods, novel food technologies, and their outlooks for sustainable food system transformations.

Dennis Z. Ross is a Master's student in the Department of Geography, Environment and Geomatics at the University of Guelph.

Eric Nost is an Assistant Professor in the Department of Geography, Environment and Geomatics at the University of Guelph and a member of the Environmental Data and Governance Initiative. He is interested in how data technologies inform environmental governance and conservation.