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Restoring sense out of disorder? Farmers' changing social identities under big data and algorithms

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Abstract

Advances in precision agriculture (PA), driven by big data technologies and machine learning algorithms can transform agriculture by enhancing crop and livestock productivity and supporting faster and more accurate on and off-farm decision making. However, little is known about how PA can influence farmers' sense of self, their skills and competencies, and the meanings that farmers ascribe to farming. This study is animated by scholarly commitment to social identity research, and draws from socio-cyber-physical systems research, domestication theory, and activity theory. This conceptualization of PA within these theoretical perspectives helps to render visible how big agricultural data and machine learning algorithms can affect meaning, doing, and being for US farmers. Through analysis of data from six focus group discussions and follow-up surveys with stakeholders across the PA value chain, this paper shows that PA tools can necessitate farmers to learn and develop new competencies such as flying drones and interpreting yield maps. At the same time, PA can shape new meaning of farm work and new expectation about a 'good farmer', changing what it means to be a 'successful' farmer from someone who is not only a data observer or data gatherer but also validators of PA models by using their local knowledge of agronomic and environmental phenomenon. We conclude that PA can alter social expectations about farming by reorienting the role of farmers. Policymakers and agriculture extension and outreach programmers can develop more socially relevant PA knowledge and innovation if they can attend to both new and traditional 'good farmer' identities.

Keywords Precision agriculture · Farmer identity · Socio-cyber-physical system · Domestication · Activity theory

Abbreviations

AGRITECH	Agricultural technology firms
AI	Artificial intelligence
FGD	Focus group discussion
PA	Precision agriculture
P	Phosphorus
N	Nitrogen
NGO	Nonprofit organizations
UAV	Unmanned aerial vehicle
US	United States

Introduction

Precision agriculture (PA) technologies include a collection of hardware and software tools, such as unmanned aerial vehicles (UAVs), global positioning systems, sensors mounted on farming equipment, artificial intelligence (AI) and machine learning algorithms to enable agricultural technology (agritech) firms, university researchers, and governments to collect farm information, analyze large amounts of aggregated farm data, and provide site-specific solutions to farmers and agronomists about farming decisions, such as fertilizer recommendations, seeding plans, and grazing schedule plans (Coble et al. 2018; Klauser and Pauschinger 2021; Wolfert et al. 2017). Proponents of PA argue that through its expansive adoption on small and large-scale farms, globally, crop yield can increase by 15% by 2030 and greenhouse gas emissions from agricultural activities can be reduced by at least 10% (World Economic Forum 2019). While PA presents the potential to generate targeted on-farm and off-farm economic and environmental efficiencies, these technologies are radically changing the nature of farm work.

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PA is significantly changing farming from manual and experience-driven farm management to more reliance on data-driven recommendations about nutrient use, seeding, and harvesting decisions (Butler and Holloway 2016; Carolan 2020; Eastwood et al. 2017; Gardezi et al. 2022a). Future farmers may need to learn how to fly UAVs and interpret farm data, and some farmers may be able to operate their farm machinery from a remote office (Klerkx et al. 2019; Tsouvalis et al. 2000).

Recent social science literature on "smart farming", "precision agriculture", and "digital agriculture" emphasizes the importance of conceptualizing new technologies as part of a dynamic socio-material process in agricultural systems, that are characterized by dynamic relations between human actors and non-human nature (Darnhofer 2020; Driessen and Heutinck 2015; Finstad et al. 2021; Rijswijk et al. 2021). As part of socio-cyber-physical systems, PA is conceptualized as co-constituting an assemblage of human and non-human actors (Comi 2020; Darnhofer 2020; Higgins et al. 2017; Klerkx 2021). These coupled systems include social actors such as farmers, as well as those who do not directly make farming decisions such as extension agents, agronomist, policymakers, financial institutions, agricultural input providers, and environmental regulators. Non-human actors in this system constitute both living beings such as animals and plants, and non-living entities, such as analog technologies, and data, algorithms, and knowledge (Finstad et al. 2021; Higgins et al. 2017; Pigford et al. 2018). Human and non-human actors interact and influence each other and through this interaction generate agency, or the ability or capacity to act to address a specific problem (Lioutas et al. 2018, 2019; Wolfert et al. 2017). Although recent research has importantly highlighted the social and economic implications of digitalization in agriculture for farmers and farm workers (Lioutas et al. 2019; Rijswijk et al. 2021; Wolfert et al. 2017), limited theoretically informed research has explored how farmers' social identities help prepare them, or hinder their engagement with PA. Recent research has found positive linkages between farmer's social identity and their willingness to adopt soil and water conservation practices (Coughenour 2003; del Mármol et al. 2018; Roesch-McNally et al. 2018), but we know little about how farmers' social identities are co-constituted with the emergence and adoption of PA technologies (Klerkx et al. 2019).

This paper asks a question that is useful both for intellectual and practical purposes: *how does PA (big data and machine learning algorithms) entangle with farmers' competencies and social identity within a socio-cyber-physical system?* We use the term *entangle* as a way to describe the complicated and compromising relationships between new technologies and farmers' existing forms of knowing and doing agriculture. Exploring changes in farmers' social identities vis-à-vis the adoption of PA has important policy implications as it can influence whether or not farmers are able to use and derive socioeconomic benefits from PA (Prause 2021).

The remaining sections of this paper are organized as follows. We first present a literature review of social practices and social identity theories that inform the concept of "identity" in general, and "farmer identity" more specifically. We discuss properties of PA as part of a socio-cyber-physical system in order to highlight the relations between materials, skills and competencies, and social identities. Next, we detail the methods and results used in the study. This is followed by discussion of the findings and its significance for future social scientific research on PA as well as its broader implications for achieving important societal goals. The final section concludes the study.

Literature review

Social identity theory and the "farmer identity"

Scholarship on social identity reviewed in this paper has its roots in symbolic interactionism (Stryker 1980). Social identity is conceptualized as exploring how individuals think of themselves when they ask the question: "Who am I?" The conception of social identity entails a person's knowledge of belonging to a social category or group. Individuals use social identity to view themselves as members of the same social category. Social identity is made up of several meanings that sustain an individual (Burke and Stets 2009; Stryker and Burke 2000). People also actively participate in the construction of new social roles (Blumer 1969; Stryker and Serpe 1982). Social identities are therefore socially constructed, which result from social events, and are often symbolized as material and non-material culture (Burton 2004; Burton et al. 2008; Butler 1990; Korostelina 2007).

In agricultural research, the theory of social identity has been applied to study "farmer identity." The concept of farmer identity was developed to understand farmers' willingness to adopt or reject government initiatives in the United Kingdom (Burton 2004). Farmer identity symbolizes the subjective judgement of farmers regarding what they constitute as 'good' farming practices. These judgments are influenced by farmers' interactions with not only the social system, but also environmental phenomenon, such as weather, soil, and nutrients (Burton 2004; McGuire et al. 2015; Sulemana and James 2014). The concept of farmer identity within social sciences was advanced to explore how to better target conservation farming programs and policies that would be acceptable to farmers. Various typologies were introduced by this literature, such as "Productivist or

Agribusiness" farmers, whose primary focus was on increasing crop production, acquired more crop land, and seeking technologically efficient ways to manage farmlands to maximize profit (Burton and Wilson 2006). In the same vein, farmers who identified themselves as "diversifiers" were mostly interested in using their farms to create additional value products. "Conservationists" considered their land to be more than a resource for conventional food production, and instead as a means to perform environmental stewardship (Burton and Wilson 2006). Recently, studies such as (Gardezi and Arbuckle 2019; McGuire et al. 2015) have proposed other farmer identity categories, such as "Civic-Minded", "Naturalist", "Expert", and "Listeners". The exploration of farmer identity is a growing area of research, especially since it has been found to be effective for targeting soil and water conservation programs that are directly entangled with farmers sense of self.

Farmer identities are "complex, dynamic and often context specific" based on the prominent or activated identity within a place-based situation (McGuire et al. 2013). Farmers can hold multiple social identities, based on their belonging to social networks and roles that they perform in their specific community (Burke and Stets 2009). Introduction of new technology and knowledge often co-constitutes the birth of new relationships, knowledge systems, skills, and technologies. This process can reconstruct farmers conception of how they view the world and themselves in it. Several scholars describe the interrelation between the adoption of new agricultural technologies and practices with changes in farmers' identity formation (Coughenour 2003; del Mármol et al. 2018; Roesch-McNally et al. 2018). A study by (del Mármol et al. 2018) reveals that the identities of rural farming communities in Alt Urgell district of Spain, shifted from subsistent farming production model and livestock farming to an industrialized milk production economy and later to a tourism economy. The magnitude of transformation from traditional to industrialized production of milk through modernization of farming operations and everyday farming activities, transformed social practices into commodified business transactions, with corollary shifts in how farmers viewed themselves (del Mármol et al. 2018).

However, fewer studies have examined how farmers' social identities are changing in relation to PA. Existing research shows that PA is transforming farm work requirements from hands-on management to a more data-driven approach. For example, many farmers still apply fertilizers and pesticides on their entire farm, instead of applying to areas of the field that needed it most. A blanket application of chemical fertilizer is a key source of environmental pollution in water bodies that have affected both livelihood and marine life in lakes, rivers, and seas of the US and globally. Farmers can use PA to identify and address deficient field areas that require more nutrients and apply variable-rate inputs. This "management-by-the-foot" approach promises to improve crop productivity and helps reduce the agricultural impact on the environment (Clapp and Ruder 2020). Thus, PA offers an opportunity for farmers to achieve both: economic and environmental sustainability. By virtue of adopting these technologies, farmers may come to imagine themselves as crop producers that can *also* conserve and protect soil and water resources. In the same vein, it could be argued that farmers who do *not* use PA may be labelled as 'laggards' and held responsible for not protecting the natural environment. These labels can redefine what it means to be a 'good farmer' under PA's new logic of farming. This paper intends to understand how big data and machine learning algorithms—that constitute new technologies in PA—can change farmers social identities. Understanding the fundamental shift in social identities that are being co-constituted with the adoption of PA tools can allow policy makers to better plan research and education activities that are human-centered and inclusive. The next section theorizes how farmer identities are co-constituted with the development and use of new technologies, and creation of new skills and competencies.

Theorizing social identities as an element of social practices

Social practices are activities that are "routinized ways in which bodies are moved, objectives are handled, subjects are treated, things are described, and the world is understood" (Reckwitz 2002, p. 250). Social practice theory is situated within cultural theory. It explores the duality and interactions of social structures and individual agency by analyzing how certain practices are used and routinized by people vis-à-vis institutions (formal and informal rules and norms). Social practices are composed of three analytical categories: (a) materials, which are composed of technologies both hardware, software, and elements that form objects, (b) competencies which include new skills, knowledge, and techniques, and (c) social identities which are made of symbolic representation, ideas, norms, and social expectation (Shove et al. 2012). In addition to materials, artifacts and competencies, social practices are also constructed and redefined through changes to farmers' social identities (Fig. 1).

Earlier work in 'domestication theory' and 'activity theory' can be used to connect different social and material elements that are being explored in Fig. 1. Domestication theory suggests that the adoption of new technology can potentially 'trigger' three type of changes in user's behavior (Silverstone et al. 1989, 1992; Silverstone 1994; Finstad et al. 2021). First behavior change is 'practical domestication', which involves how innovation users incorporate

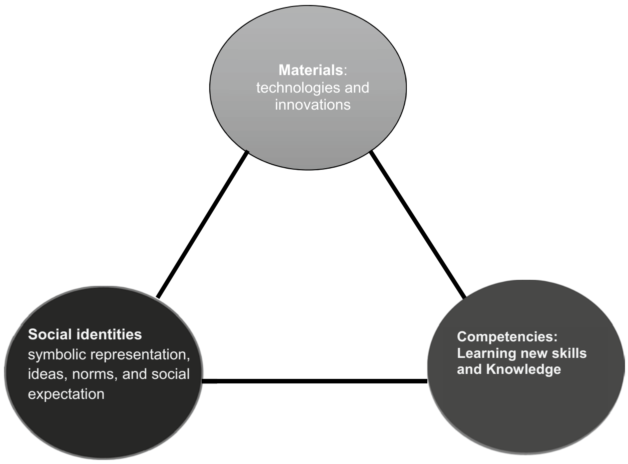

Fig. 1 Elements of social practices

new technologies into their daily routines, leading to the creation of new routines. Second type of behavior change is 'symbolic domestication' involves how innovation users ascribe meanings to these innovations, including how these technologies tend to alter their social identities. 'Cognitive domestication' is the third type of behavior change, which demonstrates how users learn from the technologies they embrace. This cognitive process demonstrates how technology is implemented and what changes occur in practices and ultimately changes behavior through new social learning (Finstad et al. 2021; Ingeborgrud and Ryghaug 2019; Søraa et al. 2021). The domestication theory provides a holistic understanding of the process by which farmers may integrate PA with their existing farming practices, learn new skills to operate and manage PA, and ascribe new meaning and social roles to their work.

While the domestication theory explains the *how*, or how do new technologies and knowledge influence social identities, it does not fully explain '*why'*. Therefore, we rely on the activity theory to explain why farmers may be redefining their identity in response to the introduction of PA. According to the 'activity theory', humans and non-humans collaborate and perform certain actions to complete specific activities that fulfill some social, economic, and ethical needs. These activities are carried out by people through interaction with objects of the world. It is through these performances that activities become generative forces, and transform not only the object, but also the subjects (Engeström 2001; Lioutas et al. 2019). This transformation is influenced not only by the activity, but also by external environment in which the activity takes place, such as the set of rules and norms that govern the relationship between the social and material elements (Engeström 2001; Lioutas et al. 2019; Nardi 1996). Recent research in PA has conceptualized these activities to be part of a broader "socio-cyber-physical system" (Rijswijk et al. 2021). The socio-cyber-physical systems research highlights how new technologies entangle with human actors, physical environment, and through this process create new environmental and social relationships (Griffor et al. 2017; Klerkx et al. 2019; Lioutas et al. 2019; Rijswijk et al. 2021). The network of human and human actors interacts and co-evolve, influencing each other, which changes relationships with the introduction of technology in the system (Finstad et al. 2021; Higgins et al. 2017; Pigford et al. 2018). We situate our study of farmers' social identities within a socio-cyber-physical system.

Methods

Study region

The locations chosen for this study are South Dakota and Vermont. These sites were selected to capture the diversity of biophysical and social conditions for farming in the US. Farmers in South Dakota predominantly produce export-based commodity crops, such as wheat, corn, and soybeans on large farms. In Vermont, most farmers engage in the production of specialty crops, such as fruits and vegetables. Dairy farming is also very popular in Vermont. Medium to large size farms in South Dakota mostly produce conventional monocropping practices, such as some type of rotation of corn and soybean. Many farms in Vermont are family-owned, organic, and growing multiple crops. The average farm size in South Dakota is 1459 acres while in Vermont is 176 acres (USDA 2020a, b). In 2020, Vermont had about 667 dairy farms and is one of the largest contributors to the local and national demand for milk and milk-based products. Differences in scale, cropping and farming systems between South Dakota and Vermont provide useful comparisons to understand how PA can influence social practices for farmers operating small and ecologically diverse farms, and medium and large-scale conventional farms (Kolady et al. 2021; Purdy 2016).

Population and sampling strategy

Based on our framing of PA as part of an assemblage of human and non-human actors, the target population recruited for this study were food system actors across the PA value chain. These include farmers, PA hardware and software developers, university and extension professionals, and representative from government agencies and non-profit organizations (NGOs). The recruitment of participants was conducted through purposeful and snowball sampling approaches. The purposeful sampling was used to identify stakeholders with experience and relevant knowledge about PA. These sampling strategies were helpful to draw from diverse perspectives and participants familiar with opportunities and concerns regarding PA. Through this process, fifty-two stakeholders in the US food systems were recruited across two study sites: South Dakota and Vermont. Participants' primary occupation was used for grouping them into FGDs. A total of six farmers were recruited, alongside 15 NGO personnel, 22 Academia/extension professionals, and 9 technology developers in South Dakota and Vermont. More than half of participants in the NGO and university extension categories considered farming to be a secondary occupation. Therefore, the overall representation of farmers in the sample was much greater than six. Participants were initially contacted through emails and a follow-up on the phone to ascertain their willingness to participate in the focus group discussions (more detail below).

Data collection

Data for this paper comes from focus group discussions (FGDs) held in South Dakota and Vermont between October and December 2019. A mixed-method approach was used to explore the research questions. In the first phase of data collection, we conducted six homogeneous FGDs, where participants deliberated on opportunities and concerns of PA technology for farmers and for themselves (if the participant was not a farmer). Participants were encouraged to expand their discussion on topics, such as how PA is changing their work and what it means for the wider community and the natural environment. Participants discussed how PA may or may not improve on-farm decision-making; what areas of crop production have PA helped to improve, and which PA tools may be needed to make farming more 'successful'. Therefore, questions pertaining to farmers' social practices across its three facets: artifacts, competencies, and social identities were central to the data collection effort. The FGD sessions were video and audio recorded and later transcribed. The confidentiality of participants was protected by using pseudonyms instead of their actual names.

The second stage of data collection included a follow-up survey that was completed by all FGD participants. The survey was aimed at triangulating the results of the FGDs by asking questions regarding the overall benefits and risks of PA to farmers in the present and included some questions about future of farm work. A series of questions on farmers' social identity were included in the survey to elicit who is considered to be a 'a good farmer'. Farmer identity was measured through a series of 17 questions related to the perception of 'a good farmer.' These questions were drawn from the literature on social identity theory in general and specifically from recent research that has examined the meaning of 'a good farmer' (Burton 2004; Burton and Wilson 2006; McGuire et al. 2013). Survey questions on farmer identity were modified from previous surveys designed by (Arbuckle 2013; McGuire et al. 2015).

Analytical approach and coding procedure

We used a qualitative interpretive method to analyze FGDs, allowing the emergence of concepts based on theoretical perspectives guiding this study (social practices and social identity theories) and the existing literature on PA. FGD transcripts were read several times to understand the narratives around changing social practices and social identities discussed by participants in South Dakota and Vermont. During the process of reading, re-reading, and getting familiar with the data, notes were made on the side of textual data that potentially answered this study's research question. To delve deeper into the transcripts, codes were applied to textual information that reflected the social implications of PA. Specifically, for instance, large texts such as "if you have fleets of drones and tools there could be some centralized place or can be stored on different people's land" or "We've had a ton of automation already, just like a continuation of the trend we have already seen in regard to, fewer manual labors, more machinery, those sorts of things" were coded into initial codes of *drone and data technologies* or *changing skill level* and *managing PA technologies.* These codes were further rearranged into axial codes such as PA automation, education, workforce development, and labor displacement. These codes were further refined and reorganized into broader themes such as "managers of data-based PA technologies" (see "Appendix 1" for more details on the themes).

Before coding all six transcripts, a codebook was developed from one of the coded FGD transcripts following the procedure outline by (MacQueen et al. 1998) and applied and refined for the remaining five FGD transcripts. The codebook was developed by generating codes, a short description of what the codes mean, and specifying inclusion criteria for codes (see "Appendix 2" for codebook). NVivo QSR 12 software was used to manage the entire coding process. In addition to analyzing qualitative data, survey data responses were coded into excel and imported into STATA software for further analysis. The study used both aggregated and disaggregated participants' responses to understand how PA is transforming the social identities of farmers and the perception of stakeholders on what it means to be a "good farmer." The main themes that emerged from FGD transcripts and survey data are interpreted and explained in the "Results" section.

Results

This section explores emerging themes emanating from the FGD transcripts and the coding process that helped us answer the research question: *how does PA (big data and machine learning algorithms) entangle with farmers' competencies and social identity within the socio-cyber-physical system?* Two distinct results emerged from the qualitative interpretive analysis. First, our results assert that PA is imagined by some stakeholders to augment work productivity and recreate social identities that will prepare farmers to successfully enter the 'digital age'. At the same time, however, many stakeholders across the food system value chain were concerned that this digital transition in agriculture can exaggerate anxieties among farmers related to their capacity to understand recommendations made by PA systems. Importantly, both results highlight some unique tensions between artifacts, competencies, and farmers' social identities.

The entanglements of PA tools, competencies, and 'good' farmer identity

Based on our framing of PA operating within a socio-cyber-physical system, activity systems, and its diffusion through domestication of technology in everyday farming practices in South Dakota and Vermont, we present our results through a visualization of the entanglements that exist between materials, competences, and social identities (Fig. 2).

FGD participants asserted that PA can allow farmers to achieve higher crop and livestock productivity and transition their farming operation toward greater environmental sustainability. A crop and livestock farmer in South Dakota expressed his ambitions about achieving both economic and environmental sustainability through PA: "When you really look at precision agriculture, it's profitable to be a good environmental steward. When you precisely apply the herbicide you need, and don't have overlap, you've saved money and done good things for the environment. When you properly manage your watershed, your expensive fertilizer does not end up in the stream; it stays in the field, where you need it." PA affords a certain balancing act to the farmer—maximizing economic *and* environmental performance—that also

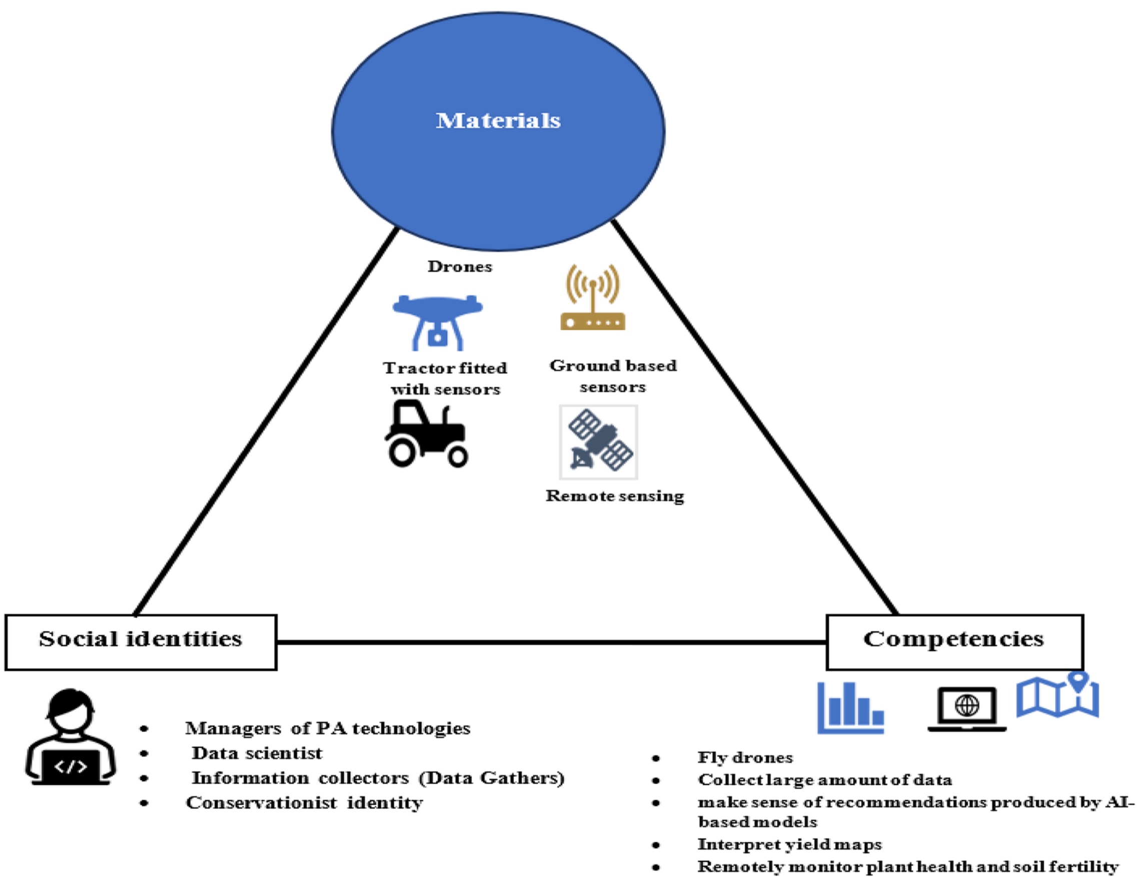

Fig. 2 Entanglement of PA with farmers in a "socio-cyber-physical system"

proves to garner supports for its development and use. Such narrative views PA to enable farmers to produce more food, fiber, and fuel on smaller acreage with only minimal disturbance to biotic and abiotic environments. This narrative can also influence farmers' social identities through activating the notion of a 'good farmer'. Indeed, survey responses show that all FGD participants (N = 52) perceived it to be important or very important for a "good farmer" to be one "who manages both for profitability and minimization of environmental impact." Through PA's approach to support economic *and* environmental sustainability, it becomes relatively easier for PA adopters to be considered by other farmers and social actors in the food system as a 'good farmer'.

The use of big data technologies and analytics involved in PA has necessitated some farmers and agronomists to gain new skills and competencies. There is more dependence on drones and ground-based sensors attached to farm equipment to collect big agricultural data to, for instance, draw soil fertility recommendations. An extension personnel from South Dakota asserted that PA tools allows remote monitoring of plant health and prescription of treatment where and when necessary: "now I can tell the health of the plant without physically scouting them." Some farmers are successfully using yield maps or disease maps to plan and make necessary improvements in agronomic decision-making, such as applying nutrients on farm fields. A farmer from Vermont asserted: "I see the robot system already having that database of seed or the hundred different [seed] varieties, and when you hit 'go', it asks, where am I going?" With the power of GPS technology and information produced by data-based PA models, farmers can precisely identify locations and then apply site-specific agronomic decisions, rather than only relying on intuition and labor-intensive data collection procedures (e.g., physically scouting land for pests and diseases).

The ability to read maps (*competencies*) produced from the combination of geospatial technology and big data (*materials*) also transforms farmers from a 'traditional' cultivator into a farm manager and collector or gatherer of data (*social identities*). New farming roles and decision-making capacities under PA are helping redefine a 'good farmer' as someone who is comfortable with using and managing big data. As conceptualized by (Burton et al.2021, p.131), the good farmer title is "bestowed on farmers worthy of being sought out by other for assistance such as knowledge, skills, or material assistance." When farmer offer such assistance within the farming communities, it creates social ties and bonds that are centered on farming norms and values. An extension personnel from Vermont highlighted this 'role model' farmer identity by saying: "the best farmers are observational data collectors, every single minute of every single day. They may not perceive themselves as data scientists, but [they are] information collectors." There is a chance that future farmers could become 'data gatherers' and engage in on-farm decision-making by collecting big data and the subsequent data-based agronomic recommendations. The discussion among participants showed that the manual approach to farming, such as physically visiting the farm at regular intervals to observe and monitor crop health will not simply disappear. In fact, PA tools will augment farmers and crop advisors' ability to bridge manual observations with dynamic or real-time information about the farm. This meant—as was also evident from the survey results—that farmers' physical presence in the field was still relevant in the 'good farmer' identity. All participants agreed or strongly agreed that it was still important for a "good farmer" to "scout before spraying for insect/weeds/disease." This result suggests that despite current PA technologies affording farmers to make on-farm decisions remotely, many participants still valued the importance of 'ground-truthing' results before moving forward with executing actions related to seeding, spraying, and harvesting.

Tensions between new required competencies and farmer identity under PA

Many farmers and agronomists still lack the 'necessary' skills to interpret, understand, and validate recommendations they receive from algorithmic systems that process big agricultural data. An extension personnel in South Dakota asserted about PA big data and algorithms as "there is little understanding of the agronomics; there is this black box." Farmers may be collecting a lot of farm data, but very few understand how these data-based models inform recommendations. An industry expert from South Dakota also recognized the challenge with knowledge and learning: "The biggest gap we have right now is in the interpretation of what the data is giving us to make agronomic recommendations." Yet, the challenge does not only reside with farmers' inability to interpret the results. Some farmers and agronomist mentioned how difficult it can be to *trust* the analysis or recommendations made by data-based systems. Some farmers lack the requisite knowledge to interpret agronomic recommendations made by AI-based models. A farmer in South Dakota asserted, "I made a decision not based on data, not based on information, I went with my gut. And instead of planting our typical 11 to 13 thousand seed population, I went to 18. And then, when it came time to put fertilizer on, I did not go by with the soil samples that my area should have for fertilizer for our targeted corn yield; I put on an extra 100 units [of fertilizer]. So, while all my neighbors are super excited because they have had the best corn harvest, they have ever had, 120 to 130, I did 190." Without a process that offers a transparent explanation of how data-based models are developed and how they can be validated, many farmers still rely on their lived experiences for agronomic decision-making and the knowledge of a closely trusted agronomist.

With potentially tens and hundreds of variables used in the development of data-based models, and the deep complexity commonly prevalent in physical-environmental systems, the entanglements of PA with farmers' lived experiences and local knowledge are important for social identity formation. A PA software developer from South Dakota, who was a part-time farmer, highlighted the importance of farmers' local knowledge in augmenting PA's performance: "Whenever we make farming decisions, we take limited information and use it to make decisions. We do not know the future either, the algorithm does not know future weather, we are still deciding [about planting, harvesting, and spraying, etc.] based on what we know and what we expect. Is there any way that PA can take that same information and improve the decision-making process?" In the farm field, many farmers and agronomists choose to validate information from PA models by conducting ground or field observations. This interaction presents new entanglements between farmer identities and new technologies. An extension personnel in South Dakota identified the need for keeping 'boots-on-the ground': There's still some ground-truthing that needs to be done, that I would assume that the data analysis and the AI is only as good as the data and the knowledge going in and so, I would suspect that continued agroeconomic research, leading into the precision agriculture tools will continue to be needed, as that ground-truthing." Ground-truthing could become a new and important role for some farmers and agronomist who use PA tools. Indeed, farmers are already seeing themselves or deriving meaning about their work through ground-truthing data and information that is collected by in-situ ground or aerial sensors. A farmer in South Dakota argued: "I want more sensors, I want more technology, but we need to fill in those knowledge gaps by having humans interact [on their land] to be able to ground truth." It is possible that the future role of a farmer or an agronomist in the US could be one who not only collects and analyzes data but validates that the information with the aim of expanding their decision-making capacities. New technologies can shape new meanings of farm work and new expectations about a 'good farmer', as someone who is not only "data observers or data gathers" but also "validators" of PA models by using their local knowledge of agronomic and environmental phenomenon.

Yet, some participants inquired whether farmers were 'prepared' to take on these new tasks and work roles. A technology developer in Vermont highlighted the changing nature of farmer identity under PA: "before tractors existed, farmers weren't mechanics, right? There's a certain cachet and identity of being a farmer. You don't think of yourself as a data scientist, and I think there's more of an identity barrier to making that transition than there is a technical barrier." The "identity barrier", as described by the aforementioned technology developer highlights that assisting farmers to make the transition to PA requires not only training them, but also programming training and education around new 'good farmer' identities.

Despite providing opportunities for training and education, not all farmers will be able to equally benefit from a digital revolution in agriculture. Specifically, farmers and farmworkers who are marginalized, those with less access to capital, low-skilled laborers, and farmers operating small farmland are the ones who can be left behind in this digital transformation. For instance, most PA technologies (software and hardware tools) are currently being designed for conventional farming systems that usually grow corn, soybean, and wheat—low-value commodity or export crops—on large acreage, and for farmers with a productivist orientation. Fewer PA tools are being developed to support other types of farming systems, such as growers of specialty crops, organic and agroecological farms, on small land parcels that can support conservationist farmer identities. There is a risk that future PA tools may be of limited usefulness to small scale and specialty crop producing farmers, as was highlighted by a PA hardware developer based in Vermont remarked: "Row crops [corn and soybean] are the first target for precision agriculture because you have a ton of land you can manage all with the same method, all have the same big data set, to learn about it. And the small producers or the diverse producers are left out because it's not an attractive economic target." To provide opportunities for the design and development of PA for small-sized farms and farmers growing non-conventional crops, it is pertinent to think about the impact of these technologies on supporting their 'good farmer' identities, and ways in which education and training can support the new meanings ascribed to farm work.

Discussion

Social practices in agriculture are rapidly changing in response to the development and use of big data technologies and machine learning algorithms (Klerkx et al. 2019; Klerkx and Rose 2020). Here, we discuss three important implications of our study findings. First, the socio-technical transition to PA technologies can influence and reconfigure farmers' social identities. During the FGDs, several participants explained how PA was changing what it means to be a 'good farmer'—along the spectrum from 'data gatherer' to 'information validator'. According to the domestication theory, 'symbolic domestication' occurs when new identities are drawn, activated, and internalized through interaction with new or different social practices. FGD participants highlighted that PA promises to enable farmers to achieve higher efficiency in productivity and environmental protection and conservation. The "win-win" narrative promoted by PA enthusiasts, may blur the traditional social identity lines between a 'productivist' and a 'conservationist' farmer. The narrative of PA allowing sustainable intensification can allow farmers to embody multiple, competing social identities. Over the last several decades, US farmers have redefined themselves from being producers of food for subsistence and domestic markets using analog technologies to feeding a food-insecure world through greater reliance on automation and data-based technologies (Brinkman 2017). 'Modern' humans have redefined their social identities to "…restore sense out of disorder. When the world one knows is in disarray, redefining identities is a way of putting things back into familiar places" (Jasanoff 2004, p. 40). Future research should examine how the emergence of new 'good farmer' identity is situated within the long durée of the Green Revolution, and more recently to data revolution in US food and agricultural systems (Carolan 2017; Fleming et al. 2018; Shepherd et al. 2020).

Second, our results show that despite overall optimism in the food system about PA, many farmers are skeptical about these tools. Some farmers and agronomists in the FGDs expressed distrust in AI-based decision-support systems. These participants were more confident in their 'gut feeling' and traditional or local ecological knowledge to make agronomic decisions. PA needs to be designed by ensuring that farmers' experiential knowledge remains relevant for their decision making (Carbonell 2016; Gardezi et al. 2022b; Ogunyiola et al. 2022; Van der Burg et al. 2019). Future research needs to examine the relationships between farmers' local knowledge and the 'expert' knowledge produced by machine learning and AI systems. Some questions that future research can inquire include: (a) How can AI-based systems augment farmers' knowledge for agronomic decision making? (b) How can new ways of developing PA tools also increase farmers' trust in these tools? Through a better understanding of these socio-material tensions and synergies, social and computer science researchers can collectively begin to chart a way forward for ethically transitioning rural agrarian communities toward digitalization. There are several ways of opening innovation to more reflexive and critical thought and inquiry: (a) democratizing the process of PA technology development by approaching innovation as a co-designed activity, and (b) influencing the direction of innovation from the top, by guiding agritech and agrobusiness firms toward responsible innovation, through more reflexive and transparent methods to extract and store farm data and design algorithms to conduct data analytics.

Third, the emergence of big data and machine learning algorithms is not only creating new work activities, but also new relations between various human and non-human elements of the socio-cyber-physical system. Automation and digitalization in agriculture is already shifting and replacing the traditional roles of farmers on large scale farms, for instance, by reducing the need to physically scout the field for making decisions about weeds and insects. Yet, PA may also be creating new forms of relation between farmers and the type of crops they grow. Our study highlights that PA is currently designed to favor monocropping and large-scale farms, which can often neglect other types of farms, such as the ones on which specialty crops are grown (Stock and Gardezi 2021). Currently, most agritech firms are producing PA tools for conventional farming systems that are growing commodity crops on large landholding. For example, by training algorithms on available genotype information that is skewed toward fewer commodity crops and by developing models that recommend nitrogen (N) and phosphorus (P) applications that require farmers to purchase expensive equipment, the digitalization of agriculture could make PA tools irrelevant and unaffordable for small and ecologically diverse farms. Within the social-cyber-physical system, it can be useful to highlight the importance of producing algorithms and farming recommendations that are relevant and useful for small scale and ecologically diverse farms.

This discussion identified that with greater advancements in PA technologies, new social practices will emerge, replace existing ways of knowing and doing agriculture, and continue to change what it means to be a good farmer within the socio-cyber-physical system. The development of PA must go hand-in-hand with ensuring that farmers are equipped with the necessary skills and competencies needed to use these tools effectively, and that data collection and interpretation can be simplified and made reliable for both large and small-scale farming systems. Future studies should examine the role of experiential knowledge of farmers and how it can be made useful for more effective utilization of PA tools for both small and large-scale farms and farmers. We observed that farmers social identities are changing from engagement in the data revolution. We see this as an opportunity for technology developers and policymakers to improve their understanding of farmers' social identities to center their programs and policies in ways that make farmers feel included in the process of technology design, development, and evaluation.

Conclusions

This paper answered the question: *how does PA (big data and machine learning algorithms) entangle with farmers' competencies and social identity within the socio-cyber-physical system?* We answer this question by situating PA within the broader context of socio-cyber-physical system, combining social practice and social identity theories through a qualitative interpretive approach to analyze FGDs and survey data from respondents in South Dakota and Vermont. We found that farmers' social identities and practices are constantly shifting and emerging with their adoption of PA technologies. The present data revolution in agriculture is leading to the emergence of new relations between farmers and other social actors, and between farmers and the natural environment. For instance, farmers are learning to engage with data-based agricultural technologies that are changing their relationship with their crop advisors and agronomists. Farmers are also learning new skills and competencies and performing agriculture differently. We show that farmers' engagement with PA depends greatly on how they adapt and change to newer 'good farmer' identities. Understanding how PA will influence farmer social identities is an important yet overlooked determinant of PA's social adoption.

Agricultural education and training programs should be targeted toward helping farmers achieve their 'good farmer' identities. One way to achieve that is by caring and respecting for farmers' traditional and local knowledge. When technologies and policies are designed solely by traditional experts (engineers, scientist), they may be considered universal and standardized in time and place, but impersonal and absent of context. Agriculture is place-specific, and farmers' knowledge is situated within specific cultural and ecological contexts. Our research in South Dakota and Vermont highlights that PA can be more inclusively designed if we are to embrace a diversity of farmers' knowledge and experiences or different ways of knowing and practicing agriculture. Incorporating farmers' experiential knowledge about the historical conditions and characteristics of their soil or water quality in the calculations made by AI models is challenging. A participatory approach for design and deployment of PA can allow for creating novel PA that integrates farmers' tacit, contextually specific information, and enables a powerful source of information to enrich AI models.

Appendix 1: Example of coding FGDs for changing social practices and social identities of farmers under the emergence of precision agriculture

Example text from FGD	Initial codes	Axial codes	Final codes
We've had a ton of automation already, just like a continuation of the trend we have already seen. In regard to, fewer manual labors, more machinery, those sorts of things	Digitalization, sensors, robotic milking	Precision agriculture, Automation	Automation of agriculture
There is little understanding of the agronomics back to the actual basic economics of saying we don't understand the agronomics, but of the black box	Lack of requisite skills, training of farmers, transition to new roles	Needed skills and capabilities	Knowledgeability and skills
Sensors and data processing that ultimately to make precision agriculture successful we're going to need the best possible way to gather data in the best possible ways to process it	Collection of farm data, data collection through sensors, processing data	Data gatherers	Data collectors

Example text from FGD	Initial codes	Axial codes	Final codes
In the last 6 months, there has been a National Geographic and the New Yorker special on the millions of dollars they have spent to replace workers in the strawberry fields, but what about the rest of the specialty crop area which gets nothing and falls into disuse and declines? That's what's happening with our agriculture, we're losing. That puts us at a competitive disadvantage with these specialty crops. If we could get climate change funded, we could learn a lot about how to grow them in a changing climate	Replacement of farmworkers	Labor	Labor displacement

Appendix 2: Codebook for changing social identities of farmers under the emergence of precision agriculture

Code	Brief definitions	Inclusion criteria	Examples
Emerging PA technologies	Various PA technologies that are used to replace old and manual practices of farming	When there is a mention of new PA technologies	Can install these soil sensors, or like sensors in the streams, and then use those to monitor the performance of these cropping practices that farmers are taking, or buffers, or other kinds of practices
Reliance on PA recommendation	Farmers now make farm management decisions based on aggregated data and information collected from site-specific farmlands	When statements refer to farmers' reliance on technologies for management decisions such as fertilizer application	A lot of precision ag businesses in South Dakota make recommendations on products that they sell, and it's like that doesn't quite compute with a lot of farmers that I work with; "Yes, this company gave you this recommendation, but they also sell this product, so you should review it, right?
Knowledgeability and skills	New forms of practices in the form of new knowledge	Farmers learn new ways of carrying out farming activities using technologies	A lot of education is needed for people to be trained into the implementation of those technologies
Managers of technologies	Farmers are becoming managers of a fleet of robots, sensors, and automated farming systems	Include when statement talks about farmers making use of PA technologies	If you have fleets of drones and tools there could be some centralized place or can be stored on different people's land

Code	Brief definitions	Inclusion criteria	Examples
Data collectors	Farmers now collect more enormous amount of data than previously known and available on site-specific farmlands	When statements make mention of data collected by farmers	On our farm, we collect a lot of data that never sees the light of day
Social expectations of farmers to PA	What farmers are expected to do in response to advancements in PA	Include when discussion mentions what is expected of farmers as a result of advancements in PA	I think the future of precision ag is coding

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