**Title: "How can we?" The need to direct research in digital agriculture towards capacities**

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***Abstract:***

Concerns about digital agriculture reinforcing industrialised models of agriculture and power inequalities have been widely articulated. This paper uses directionalities, which are characterised by dominant and durable directions or pathways, to conceptualise this envisaged entrenchment. It argues that we need to anticipate and collect the evidence on which to govern digital agriculture technologies before such directionalities set in. To support this anticipatory need, the paper draws on findings from a research prioritisation exercise with stakeholders in the UK. It identifies and critically analyses two interconnecting meta-themes, organisational capacity and human capacity, which emerged inductively in the analysis of selected themes and priority research questions. In doing this, the paper widens the scope of enquiry about digital agriculture, by introducing 'capacities' as a new theoretical lens to examine how institutional structures and processes shape the utilisation of digital data, technologies and their underlying directionalities. The paper concludes by outlining the implications of this new perspective on directionalities and capacities for digital agriculture research in the UK and internationally.

## 1. INTRODUCTION

Digitalisation in agriculture is seen to herald a transformation in agri-food systems bringing benefits to both food production and ecosystems services (Weersink et al., 2018). Innovations in precision agriculture, data-driven processes and smart technologies (Internet of Things, Cloud Computing, robotics and Artificial Intelligence) promise many opportunities for improved technological efficiencies and productivity and enhanced decision making for farmers, as well as ecological production (Kamilaris et al., 2017, Finger et al., 2019, Lowenberg-DeBoer and Erickson, 2019, Wolfert et al., 2017). This so called 'fourth agricultural revolution' is increasingly framed as part of a sustainable agriculture research and policy paradigm (Rose and Chilvers, 2018). Social science researchers, however, temper this technological optimism with 'social realities', by embedding digital agriculture in economic, political and social relations (Fleming et al., 2018). Taking the view that digitalisation is a socio-technical process of innovation, scholars have sought to understand the potential impact of digitalisation on social processes and practices using a range of empirical and theoretical analyses (Lioutas et al., 2019, Klerkx et al., 2019).

Through such enquiry many important social, political and ethical questions concerning big data and digital technologies and tools have been raised (Bronson and Knezevic, 2016; Wolfert et al., 2017). These cohere around the role of digital innovation and its impact on, or contribution to, societal or environmental ends and have particular resonance to rural settings (Klauser and Pauschinger, 2022, Carolan, 2020, Zscheischler et al., 2022, Brooks, 2021, Fraser, 2021). In particular, there is concern about how it will potentially reinforce industrialised models of agriculture, agrarian capitalism and the trend towards corporate concentration and power[1] inequalities (Lanzara, 2009, Rotz et al., 2019, Carbonell, 2016, Miles, 2019). This concern has prompted questions about the direction or pathway digital agriculture will take, given the way that such models and associated deterministic notions of technological progress become entrenched. As Stirling (2008 p2) notes, innovation includes the crucial but neglected normative property of direction, highlighting a need to understand how, in this case, "context, purpose and power" shape directionality in digital agriculture. This directionality is defined by sets of technologies, markets, institutional arrangements, and values (Kanger and Schot, 2019).

New forms of scientific governance, notably Responsible Research and Innovation (RRI), are relevant to such socio-ethical challenges (Owen et al., 2013, Stilgoe et al., 2013, Arnaldi et al., 2016). RRI recognises that the scientific and research community has a collective responsibility in anticipating consequences of their decisions, which impact the directions that agricultural system innovations take, and in turn to build capacity to respond to those consequences (Von Schomberg, 2011). Identifying where evidence is needed is a key part of this prospective approach (Grinbaum and Groves, 2013, Stilgoe et al., 2013).

[1] Here we understand power as a mode of action that 'structure[s] the possible field of action of others' (Foucault, 1982: 790).

This paper draws on findings from a research prioritisation exercise with stakeholders in the UK which identified key existing and emerging issues relevant to digitalisation in agricultural production[2] that would benefit from a stronger evidence/research base. The paper aims to critically analyse organisational and human capacity as two interconnecting meta-themes that emerged inductively in the analysis of the priority research questions. It builds on and contributes to the growing literature on digital agriculture in rural studies and related fields by introducing 'capacities' as a new theoretical lens for examining how institutional structures and processes shape the utilisation of digital data and technologies and their directionalities.

The article is structured as follows. First, we outline the rationale for the research by reviewing the concept of directionalities with respect to digital agriculture and demonstrating the need for evidence that supports and enables alternative pathways. Second, we describe the research prioritisation exercise conducted with stakeholders to identify priorities for such evidence. In the empirical part of the paper, we inductively analyse the priority research questions and characterise two meta-themes: organisational and human capacities. In discussing the results, we theorise connections between these capacities and directionalities. The paper concludes by outlining the implications for digital agriculture research which are relevant, not only to the UK, but to international contexts as well.

## 2. AGRICULTURE 4.0: DIRECTIONALITY AND THE NEED FOR EVIDENCE

### 2.1 Directionalities

The notion of agricultural digitalisation reinforcing industrialised models of agriculture and reproducing the institutions (practices, routines, norms, rules and policies) and balances of power governing agricultural systems is a central theme in social science analysis of digital agriculture (Prause et al., 2021, Carbonell, 2016, Phillips et al., 2019, Clapp and Moseley, 2020,

[2] Our focus is the farm level and we understand the term digital agriculture broadly as the application of big data and precision technology systems in agricultural production.

Miles, 2019). This has been explored from a number of perspectives. The dominance of corporate players is seen to underpin descriptions of lock-in, where technological, organisational and institutional processes become self-reinforcing and entrenched (Aubert et al., 2012, Robertson and Moore, 2018, Seyfang and Smith, 2007). In line with this, technodependency (Klauser and Pauschinger, 2022) and governance by algorithm (Carolan, 2020; Miles, 2019) can potentially lead to both technological and cultural hegemony of digital technologies (Gardezi and Stock, 2021).

This suggests that digitalisation may reinforce long-term path dependencies and the underlying socio-technical patterns of industrial societies. Directionalities, which are characterised by dominant and durable directions or pathways in socio-technical studies (Kanger and Schot, 2019), can be used to conceptualise this. The concept argues that socio-technical change has a direction, choices are made between directions and actors gradually "become blind to alternatives" (Stirling 2008, p1). These directionalities steer agriculture and food systems in terms of the set of technologies, markets, institutional arrangements, and values they embody and the transformative pathways and outcomes they envision (Kanger and Schot, 2019). Directionalities have been developed to conceptualise the multiple pathways towards sustainability in socio-technical transition theory (Grillitisch et al., 2019), and to articulate a societal or environmental contribution or direction for innovation (Klerkx and Begemann, 2020), but we apply the idea here to understand what direction digital agriculture technologies will follow.

With respect to the values and envisioned transformative pathways, digital agriculture is regarded as a way of solving agricultural problems and by improving economic and technological efficiencies (Kamilaris et al., 2017, Finger et al., 2019). Digital agriculture is thus considered a broadly positive force, changing agriculture for the better, although this is rarely critiqued and the values that underpin it are not made explicit. Such positive imaginings of applications of technology and hopes are key drivers of directionality in the broader innovation systems that support or do not support transformative change in future food systems (Lajoie-O'Malley et al., 2020, Klerkx and Begemann, 2020). Scholars argue that such frames are often about raising positive expectations and hype and display what has been called ‘agri-food tech solutionism’ (Fairbairn and Guthman, 2020, Duncan et al., 2021). This underpins and shapes the direction of policy and research as evidenced in policy statements, research strategies and large investments from national governments e.g. Innovate UK’s Agritech centres and research funding streams (Barrett and Rose, 2020), EU institutions (Poppe et al., 2015) and international bodies (Lajoie-O'Malley et al., 2020, World-Bank, 2016).

The significance of governance[3] and institutional arrangements and other elements in shaping directionalities and technology pathways has been explored from a number of perspectives (Wolf and Buttel, 1996, Wolfert et al., 2017, Pigford et al., 2018). Drawing on socio-technical systems, Stirling (2008, p1), for example, describes the concept of technological commitments which represent “discursive, institutional, economic, and infrastructural attachments to particular technological pathways”, and as such can lead to an intentionality in governance (Lash, 2001). These commitments, he argues, encompass a range of structures and processes for allocating resources (such as policy attention, research funding). This theme of intentionality is also picked up by Grillitsch et al. (2019), who regard directionality of a socio-technical regime as driven by actors pursing a specific interest and capable of mobilising resources around that interest. Others refer to underlying institutional intent, which is directional and akin to political will, and argue that technology is merely a magnifier of this intent (Toyama, 2011, Hernandez and Roberts, 2018, Agre, 2002). As Agre (2002, p315) observes, “people in a given institutional setting use a new technology to pursue the goals that the institution provides, using the strategies that the institution suggests, organized by the cognitive and associative forms that the institution instills”.

These differing perspectives raise important questions with respect to digital agriculture, such as: To what extent do institutional arrangements, structures and processes, and interacting actors, have the capacity to steer, respond to or change dominant and durable directions?

[3] We understand governance as the systems of institutional rules, policies, actors, structures and processes which can guide and shape technological configurations.

How can capacity be built to counter a directionality characterised by industrialised modes of agriculture? What evidence is needed to anticipate, understand, characterise and conceptualise this capacity and to support responsible governance of digital agriculture? Such questions provide the backdrop for the research reported here.

### 2.2 Evidence on which to govern technologies responsibly

Responsible Research and Innovation provides important insights with respect to directionalities (Genus and Iskandarova, 2018, Stilgoe et al., 2013), particularly in the context of digitalisation in agriculture (Rose and Chilvers, 2018, Eastwood et al., 2019b, Bronson, 2019). The concept coheres around the prospective notion of responsibility, aiming to anticipate possible consequences of innovations, and build capacity to respond to those consequences (Von Schomberg, 2011). Importantly, RRI addresses the limited evidence available on which to govern technologies. As Stilgoe et al. (2013, p1570) note, "[w]e face a dilemma of control (Collingridge, 1980), in that we lack the evidence on which to govern technologies before pathologies of path dependency (David, 2001), technological lock-in (Arthur, 1989), 'entrenchment' (Collingridge, 1980) and closure (Stirling, 2007) set in".

This paper presents a framework and method for identifying where such evidence is needed by identifying priority research questions concerning digital agriculture in the UK through consultation with a wide range of stakeholders across a number of agricultural sectors and disciplines. The rationale and logic are depicted in Figure 1, which shows how the method can identify research needs, particularly in the context of the dominant directionalities outlined above.

INSERT FIG 1

Figure 1. The research rationale and logic

## 3. METHODOLOGY - A PRIORITY RESEARCH QUESTIONS EXERCISE FOR DIGITAL AGRICULTURE

### 3.1 Prioritisation exercise

The prioritisation method (Sutherland et al., 2011, Sutherland et al., 2013) provides an established, effective and rigorous methodology for capturing and ordering a wide range of views about future research needs. The process involves identifying a large number of participants (50-100) and eliciting an initial long list of research questions which is reduced and refined in subsequent voting stages to select the top priorities by theme.

The exercise was organised in a series of steps. In Step 1 representatives from different stakeholder groups involved in digital agricultural production in the UK were purposely selected (see below). Stakeholders were invited to propose up to 10 priority questions for research on digital agriculture. The criteria for the questions was that they should be limited to key existing and emerging issues that would benefit specifically from a stronger evidence and research base; and that they could be addressed within a 3-5-year research project. The parameters for the study were primary production, using the definition "Digital Agriculture refers to farm management systems where decisions are taken using an increasing amount of digital information in order to increase productivity and sustainability"; however, there was some flexibility to allow for any overlap of questions with other parts of the agri-food system. A total of 40 respondents responded, providing 200 initial questions (Table 1).

INSERT TABLE 1

Table 1 Priority questions and capacity attributes

The priority research questions were clustered iteratively into seven themes by the lead researchers (see below). A subsequent online voting stage (Step 2) was then conducted, which ranked questions according to voting scores and identified the top 10 questions in each theme. All original contributors were invited to participate and out of 40, 28 responded. Questions remained unedited in Steps 1 and 2. In Step 3 an online interactive workshop was held with the same stakeholders invited (25 attended). This was an opportunity to further prioritise and refine the top five research questions for each theme questions. Working in break out groups, the participants used a qualitative scale of gold, silver or bronze, whereby gold questions are the highest priority, in terms of significance and being most in need of a stronger evidence and research base, with silver and bronze being of relatively lower priority.

### 3.1.1 Participant selection

In selecting the participants, the lead researchers drew up an initial list of relevant stakeholder groups using personal contacts, Google and Google Scholar searches to scope out participants' interests and expertise. Criteria for inclusion was firstly, to stakeholder areas of operation, namely: academia, agricultural research institutes, farmer representatives, agri-tech businesses, agricultural suppliers, NGOs, government bodies, consultants, and secondly, relevant experience or interest in digitalisation of agriculture with respect to evidence gathering, decision making and governance. Invitations were emailed to 148 potential participants (see Table 2) explaining the research and asking them to propose questions. They were also asked to suggest contacts or colleagues who could join the exercise in a snowballing approach. A link to the invitation was also circulated via the host institution's Twitter account (2462 followers) and website (2000 visit per month) which reaches a wide range of people in the agri-food and agri-environment community.

Numbers participating were deemed to be high given the relative novelty of digitalisation in UK farming systems. There was good representation across sectors and disciplines, as evidenced by wide-ranging nature of the questions. Participants who engaged were found to be representative of the expert continuum identified by (Regan, 2019), which distinguishes groupings of individuals based on their subjective, mandated and objective 'closeness' to the topic. They include respectively: practitioners (industry actors and farming representatives) who have direct experience of digital agriculture; policy makers and support agencies who have a professional responsibility; and the research community who explore digital farming from an objective and rigour driven perspective. In Steps 1 and 2 approximately half of respondents were from the research community (this included university departments and research institutes concerned with agriculture and technologies, data analytics, agri-food systems and humanities) and research funders; and half from a range of practitioner or commercial stakeholder groups. This balance was largely maintained through to Step 3. Furthermore, every effort was made in Step 3, the participatory workshop, to give equal voice to all participants in the group sessions. Overall a diverse and moderately large group, clear criteria, and a democratic process all helped reduce any bias distorting the outcomes.

INSERT TABLE 2

Table 2 Participants at each step of the prioritisation exercise

**3.2 Analysis: from thematic priorities to capacities**

The first step in the research prioritisation process generated 200 questions, refined to 195 after removal of unclear questions or statements. An inductive approach to analysis was employed. A coding framework was developed iteratively by a team of three researchers to allow clustering of the questions using NVivo 12 to organise the process. Data from the questions were initially analysed using open coding, followed by axial coding to seek out possible categories and relationships between open codes (Skjott Linneberg and Korsgaard, 2019). Seven main themes were identified, as follows: data governance; data management; enabling use of data and technologies; understanding benefits and uptake of data and technologies; optimising data and technologies for performance; impacts of digital agriculture; and new collaborative arrangements (Figure 2). Crosschecks were made between researchers when coding the questions to the themes to ensure a consistent and robust process was followed. The second element of analysis entailed qualitative analysis of the workshop discussion transcripts and summary notes and reports. A full description and analysis of all the themes is provided in xxx ({Ingram, 2022 #572} anon).

INSERT FIG 2

Figure 2. The seven themes identified in the prioritisation exercise with the overlapping meta-themes circled. Themes 1-2 and 7 emphasise organisational capacity and Theme 3, human capacity.

Recognising that there were also intersectional themes, a further analysis was undertaken after the workshop, which identified two meta-themes. This analysis involved a further round of selective coding using all the materials (top five ranked questions for each theme, the final gold, silver and bronze priority questions for selected themes (see Table 1 and the workshop materials). The analytical process was iterative, combining inductive and deductive analysis. Two groups of questions emerged asking: 1) how can we develop and enact organisational arrangements (social, political and institutional) to support digitalisation in agriculture, and 2) how can we enable farmers and other actors to analyse and effectively utilise these new forms of data and technology? These 'how can we?' questions were progressively unpacked and the significance of capacities, in terms of the ability to address them, became apparent (the 'we' referring to participants' organisations as well as public and private actors in general). Drawing on concepts of capacities from the literature, these groups of questions were characterised respectively as: organisational capacities and human capacities for digital agriculture. As described more fully below, we then progressively coded and assigned questions according to different capacity concepts and attributes (Table 1 outlines the start of the process). In this way, data was iteratively woven together with concepts from the digital agriculture and capacities literatures, and the capacities were refined and characterised as the analysis progressed (as shown in Figure 3).

INSERT FIG 3

Figure 3. The development of the main capacity constructs in the analysis for digital agriculture (DA).

## 4. RESULTS AND DISCUSSION

### 4.1 Two meta-themes

In total 27 priority research questions were identified: 15 gold, 7 silver and 5 bronze, across the 7 themes. The seven themes and constituent questions cover a plurality of ideas and topics and reflect a high level of uncertainty around what digitalisation means for the future of agriculture. They also indicate a range of evidence needs (see anon) (Figure 2). In this paper we focus on the two meta-themes that emerged from the further analysis of themes 1-3 and 7. These are connected by a common thread: the capacity to organise and to utilise digital agriculture effectively, equitably and collaboratively to enable a shift in directionality away from a reinforcing technological pathway. We refer specifically to the questions in these selected themes to illustrate how these capacities are understood by the participants and their perceived significance with respect to research priorities in digitalisation in agriculture. We then connect these two capacities back to the notion of directionality in terms of where research attention is most needed. Figure 4 provides a schematic diagram to show the connection between the different concepts discussed in the paper in relation to the questions and themes.

INSERT FIG 4

Figure 4. Making the link between capacities and directionalities

**4.2 Organisational capacity for digital agriculture**

The emphasis in a number of priority questions (in themes 1, 2, 7) was on how to create systems, whereby people feel confident in sharing data and working collaboratively, and in turn, can all benefit. They highlight the need to examine new governance processes and collaborative models to foster ownership and participation. They led to the formulation of the organisational capacities meta-theme which we characterise as comprising: the social, organisational and institutional structures and processes that shape practice, routine norms and values, as well as steer (and be steered by) governance.

Organisational capacity has been conceptualised from many different perspectives (see Table 3) and can be complex and multi-dimensional in nature (Hall, 2005; Walters, 2020). For example, from an organisation's or firm's perspective, capacity is defined in terms of the ability to perform effectively (e.g. as the set of resources, processes, management practices, or attributes that assist an organisation in fulfilling its mission) (Cox et al., 2018); and to build capacity, is to improve this function and performance (Brix, 2018, Ku and Yuen-Tsang, 2013). From an institutional perspective, concepts of innovation capacity and adaptive capacity (Hall, 2005, Turner et al., 2017, Edquist, 2010, Eakin et al., 2016) emphasise the capability[4] to identify opportunities, to adapt, to collaborate with others to mobilise knowledge, resources, to experiment with social, technical and institutional options and to reorganise through

[4] Capabilities are variously understood (innovation, adaptive, absorptive) and assessed at different analytical levels. They tend to be associated with individuals and human capacity (Brix., 2018). However capabilities are seen to configure innovation capacity (Turner et al. (2017) and to enable a systems' capacity, or potential, revealing a complex capability-capacity dynamic, which is explored further in section 4.4.

networks and institutions (Hall, 2005). The definitions in Table 3 show that multiple analytical levels (individuals, networks, etc.) are used to understand capacities.

Building on these concepts and the above characterisation, further elements of organisational capacity were revealed as the analysis unfolded, as follows. We refer here to example questions in Table 1 which lists the top five ranked questions and the final gold, silver and bronze priority questions for themes 1-3 and 7.

***The capacity to share data***

Firstly, the participants' questions prioritised issues of data sharing in the context of corporate control and power. For example: **"How can farmers and growers share data with confidence?"** and **"How can we encourage and support data sharing – with all the challenges of data ownership, security and protection- between commercial companies, for the good of agriculture?"** In asking this, the questions identified the need to create governance systems to take account of these power relations and associated ethical issues. The reference to 'for the good of agriculture' hints at a normative stance with respect to the benefits of digital agriculture, but also at a just and fair agriculture. The questions highlight too how the capacity to openly share data relies on institutional arrangements to govern access to, and use of, digital technologies and related data. Data governance issues have been widely considered in this context, particularly in relation to the dominance of private corporations in creating platforms to aggregate data, in enabling data exchange between systems, and offering decision support (Bronson and Knezevic, 2016, Carbonell, 2016, Capalbo et al., 2017, Rotz et al., 2019, Wiseman et al., 2019, Finger et al., 2019), but not in terms of insititutions' ability to address this dominance. Taking a simple understanding of governance as the capacity 'to get things done' (Czempiel and Rosenau, 1992), we can characterise such 'how can we?' questions as questions of building organisational capacity and having the ability to collaborate with others, to mobilise knowledge and to experiment with social, technical and institutional options (Hall, 2005), as a means of countering this corporate dominance. Key building blocks of this (trust, culture) are explored in the folllowing interconnected sections.

***The capacity to build trust***

Secondly, and related to the first point, the need to understand capacities for building trust to enable sharing was identified, for example, **"How can we generate an atmosphere of trust and collaboration to free-up the exchange of data?"** Participants also asked "**How to create the ecosystem / community that is needed to develop a transparent shared system of data which is attractive for farmers and commercial developers alike?"** Another priority was to understand how systems could be created to institute interoperability and regulatory powers necessary to ensure that the technology and data used can be trusted. Trust has been widely identified as underpinning barriers to farmers engaging in data exchange in digital agriculture (Jakku et al., 2019, Wiseman et al., 2019, Regan, 2021). In this respect, what constitutes "good" data-sharing has become a central topic of enquiry in digital transformation contexts (Hardjono et al., 2019). Experience has shown the importance of building trust over time and engendering this trust through mechanisms which balance public and private interests and control (Newton et al., 2021). The value of relationships of trust, over more instrumental relationships of accountability, in developing digital governance arrangements has also been identified (van der Burg et al., 2021). However, how to build the capacity for trustworthy structures and processes remains a point of discussion and controversy (Martens and Zscheischler, 2022).

These priority questions and discussions suggest that a shift in organisational culture is needed. Whilst cultural dimensions (collective beliefs, values, behaviours, attitudes, norms) of organisational capacity have been identified for public sector organisations (Cox et al., 2018), and distinct non-market traits are known to enable a firm's capacity in terms of creating and capturing value from innovation (Teece, 2017), our understanding of how to build capacities of trust and transparency in organisational processes for digital agriculture is still limited.

***The capacity to derive value***

Thirdly, the priority questions and related workshop discussions highlight different capacities to derive value. For example: **"How can the value proposition inherent in data sharing be underpinned by a governance system that gives people the confidence to enter into that proposition?".** Specifically, the questions ask, how farmers can build their organisational capacity to be able to obtain value from the data and the technologies, for example: **"How can farmers work together to benefit from the data that they provide (knowingly/ unknowingly) to the big global suppliers?"** Evidence is emerging of farmers starting to mobilise and organise themselves (e.g., in cooperatives, online communities) to create and share data, technologies and experiences, and big data understanding (Kamilaris et al., 2017, Carolan, 2018, Jouanjean et al., 2020), and the role of farmers as governance actors is increasingly being recognised (Newton, et al., 2020). Aligned to this, networks of social capital are known to provide new platforms for agricultural stakeholders to share knowledge and exploit key parts of their organisational and adaptive capacities (Lubell and McRoberts, 2018, Adger, 2003). However, not all farmer groups have the means, the equipment, networks or resources (Turner et al., 2017) to achieve this.

***The capacity to achieve collaboration***

Fourthly, understanding capacities to achieve collaboration in digital developments was identified as a priority. Questions and workshop discussions highlighted the need to understand the capacity to build new stakeholder and business collaborative models, and asked how to bring together farmers, academia, policymakers and the private sector together to develop effective digital technologies. For example, **"How can different actors with vested interests, competing goals and hidden agendas work more collaboratively together on digital agriculture projects?"** The workshop discussed what organisational and cultural changes are required to enable farmer-led innovation and user-centred design. This is about moving "towards a system where "there is [ …] good collaboration that benefits both farmers and other stakeholders", according to one participant. These questions highlight the power dynamics in play and the fact that user-centred approaches are not neutral (Kendall and Dearden, 2020). In this respect, understanding how to change the rules and routines and enable new institutional structures and processes for participative digital development (Heeks, 2016), needs a stronger research focus. Capacities for incorporating user-perspectives to address gaps between design and practice in digitalisation have been described as limited (Fountas et al., 2015, Van Es and Woodard, 2017, Newton et al., 2020), not least amongst wider stakeholders, technologists, data scientists, and others in terms of professional skills and norms (Eastwood et al., 2017). As McCampbell et al. (2022) point out, for participation to be meaningful, it has to be enacted in an informed way by capable stakeholders.

***Organisational capacity - where the evidence is needed***

We turn now to summarise what this means for future research. Overall the analysis suggests that a stronger evidence base is needed around organisational capacity for digital agriculture, not in terms of narrow performance or functional attributes that enable an organisation or system to achieve a defined goal or innovation, but in terms of social, organisational and institutional processes and structures. In particular, understanding actors' ability to coordinate and collaborate with others to mobilise new and existing knowledge, resources and capabilities is important, as observed in discussions of innovation and adaptive capacities (Hall, 2005, Adger, 2003, Hekkert et al., 2007). In addition, further investigation of organisational cultures of trust and transparency for sharing data, collaborating, and creating value for all is needed.

The need to provide stakeholders with the institutional, regulatory and technical capacities to deliver value, while maintaining trust in the use of digital technologies, has been highlighted by other studies (e.g. Jouanjean, 2020). This exercise, however, has identified where research should be prioritised, in particular in the face of dominant directionalities characterised by 'vested interests, competing goals and hidden agendas' and 'big global suppliers' who operate in a system that has limited open sharing, transparency and trust. In this respect, power dynamics is an underlying theme, with questions highlighting the need to understand how to strengthen capacities to counter the processes currently steering the direction of digital agriculture. The priority questions infer a limited or weak capacity for farmers to organise themselves and derive value from their own data. Conversely, they suggest a well-developed or strong organisational capacity amongst those who manage and control data, referring to “corporate control of and access to data”. The questions imply that, with superior technological and operational systems and competences, they have better access to the data’s value. The notion of strong and weak capacities, which has been advanced in Information and Communication Technology for development (ICT4D) is relevant here (Heeks, 2016), and raises new research questions about all actors having the capacity to derive value from digital agriculture implementation in a just, transparent and balanced way.

### 4.3 Human capacity for digital agriculture

Emphasis was placed in a number of priority research questions (especially in theme 3) on farmers and supporting actors’ competences, knowledge and skills and on how to enable them to analyse and effectively utilise and exploit new forms of data and technology. This focus led to the formulation of the human capacities meta-theme. We characterise human capacity as the ability (by which we mean the range of skills and competencies required) at the farm level to obtain, process, understand, evaluate and use data and digital technologies to make informed decisions. Human capacities have been conceptualised in a number of contexts according to technical, scientific and social dimensions. Researchers have described: farmers’ cognition and organisation capacities (Annosi et al., 2019), and capability requirements including adaptation, capability mapping and human capital in innovation systems (Hekkert, 2007; Eastwood et al., 2019a). Skills, competences and practices have been recognised as central to innovation capacity building (Brix, 2018), particularly with respect to the capabilities needed to put knowledge into productive use in response to challenges and opportunities (Hall, 2005; Edquist, 2010; Turner et al., 2017).

These concepts, together with the above characterisation, provided a starting point for the analysis and were elaborated as the iterative analysis of related priority questions progressed.

***The capacity to utilise data and digital technologies effectively***

The priority questions in this meta-theme centre around the overarching questions of: "**How can data be collated, combined, and analysed to be useful to and therefore valuable for farmers?"** and **"How can we move from data to information?".** More specifically, the first point is about farmers' and other actors' ability to use data and digital technologies effectively, as captured in this question: **"Do farmers feel resilient and digitally skilled and competent to capitalise on the changes in their sector?".** The questions emphasise the ability to interpret and use the data and to support this with tools and protocols. They confirm that more attention should be paid to on-farm capability to transform data into actionable knowledge at different decision points to achieve the potential of data and technologies (Evans et al., 2017, Ingram and Maye, 2020, Shepherd et al., 2018, Capalbo et al., 2017); and that farmers' and their supporters' differing capacities to adapt to digital technologies in terms of skills, knowledge, resources, need to be understood (Eastwood et al., 2019a, Rotz et al., 2019, Van der Burg et al., 2019, Schnebelin et al., 2021). This digital literacy, which covers critical reflections on the way algorithms and new skills can interpret quantitative and qualitative data (Zscheischler et al. (2022), extends to other literacy concepts of farmers' self-efficacy, beliefs about her/his potential to master the required skills and make an effective decision (Gray 2018).

***The capacity to discern the benefits of digitally informed decision and technologies***

Secondly, understanding the benefits of a dataset, and what really helps decision making, emerged as important, particularly given the increasing volume of data and automation of decisions. As participants reflected, "there is now a vast ocean of data which can be mined from multiple devices but care needs to be taken in choosing which data truly aids decision-making". At the workshop, farmers were described as having limited capacity for calculating or estimating the impact of using data or a technology on their gross margins, and evaluating value to the farm. The ability to understand the risks entailed in inappropriate interpretation and poor decision making was also identified as a necessary competence. These priority questions and comments distinguish awareness about the importance and value of digitalisation from the specialised and practice-oriented knowledge needed to exploit it. They reflect the fact that there has been little research attention on farmers' own understanding of how data can be valuable for farmers compared to their current decision-making practices (Sonka, 2015; Evans et al., 2017; Ingram and Maye, 2020). Commentators have observed that technologies require investment in terms of knowledge and an ability to economically assess these technologies and their risks (Zscheischler et al., 2022, Barnes et al., 2019).

Although researchers have made distinctions between farm managers' cognition capacities with regard to farm business technology investment and adoption decisions, and their organisational capacities, which are embedded in the managers' skills and routines in acquiring information (Annosi et al., 2019), the questions and susbsequent discussions suggest that several of these human capacity dimensions need further examination. Workshop participants agreed that these aspects are equally important for those in farmers' networks (other farm workers and producers, workers in the value chain, advisers, entrepreneurs, intermediaries) who are tasked with data analysis and interpretation and more strategic advice. The changing role of agricultural knowledge and service providers, and the need to improve their own competencies to exploit data and technologies, has been identified (Rijswijk et al., 2018; Ayre et al., 2019; Eastwood et al., 2019; Annosi et al., 2019; Fielke et al., 2021; Higgins and Bryant, 2017). These studies have shown that advisers are also having to adapt world views and organisational and professional identities, and need the capacity to understand the functions and processes behind the working of digital technologies and data processing practices (McCampbell et al. 2022).

***The capacity to compare and integrate digitally informed knowledge and tacit knowledge***

Thirdly, there were priority questions about understanding how farmers' experiential knowledge compares to data-driven decisions, in particular what is the value that farmers get out of using these data compared with existing datasets and intuitive forms of decision making. For example: **"How good are farm management decisions based upon (remote) digital data compared to traditional management decisions?"** The extent to which traditional forms of embodied knowledge are complemented or undermined by digital agriculture was probed in the workshop. Although there was agreement that digitalisation heralds a shift from tacit knowledge to digitally-informed knowledge, one participant commented: “We need to be wary, this data on its own doesn't necessarily provide the solution”. The participants suggested that research should investigate how to achieve successful data-driven agricultural systems through integrating all types of agricultural knowledge (e.g. from farmers, agronomists and plant scientists) with remote digital data. According to Sonka (2014) this enhances the ‘capacity to know’ over the normal data-driven focus on ‘what is known’. The risks of technologies and data undermining existing knowledge have been highlighted and the notion of deskilling suggests that capacities can be eroded as well as build (Brooks, 2021). Interestingly, participants did not refer to the possibilities or impacts of complete automation, farmer cyborgs who have lost all intuitive knowledge or algorithmic authority (Gardezi and Stock, 2021), and still envisaged an informed decision-making role for the farmer.

***The capacity to be digitally literate to enable equal access and uptake***

Fourthly, the question “**What action needs to be taken to ensure that digital divides do not deepen and to avoid a scenario where some farmers get ‘left behind’** (i.e. digital exclusion)?”. This was understood to be a particular issue for farmers lacking sufficient digital literacy capabilities to adapt to new technologies. This extends conversations about the first- and second-level digital divide, the former describing access to infrastructure and availability of hardware and (internet) connectivity, the latter referring to questions of digital literacy (in terms of the skills to operate hardware and software) as proposed by McCampbell et al. (2022). This so-called ‘differential capacity’ has been identified as a key issue in ICT4D studies, explaining unequal uptake (Toyoma, 2011). The literature supports this as a priority issue, noting that, if current trends of increasing inequality in the agricultural sector persist (Walter et al., 2017), some groups will be locked out of any opportunities in digitalisation (Van der Burg et al., 2019; Bronson, 2019).

***Human capacity - where the evidence is needed***

The priority questions for this meta-theme suggest then, in terms of summarising future research needs, that we need a stronger evidence base around farm level actors’ capacity to understand, and exploit, the value of data and technologies. As the priorities set by stakeholders make clear, this will involve researching elements of digital literacy, such as skills and competencies, in obtaining, processing, evaluating, and using data, as well as self-efficacy and self-determination in choosing what to analyse (Boughzala et al., 2020, Gray, 2018). Also, conceptually, the innovation capabilities needed to put knowledge into productive use in response to challenges and opportunities, are relevant (Hall, 2005; Edquist, 2010). The need to understand, not only skills, but also how professional roles are redefined when considering digital literacies and divides was also identified. This resonates with thinking emerging in business, where there is agreement that simply using technologies to drive the digital transformation process is not enough, and that digital capabilities, skill sets, culture, attitudes, and talent development are required and therefore need to be a foci for research (Morakanyane et al., 2017). Collectively these questions prioritise understanding the multi-dimensional aspects of human capacities with respect to digital agriculture at the farm level.

### 4.4 The relationship between organisational and human capacities

The intersection between organisational and human capacities is apparent both in this analysis and in the concepts described in the literature. For example, the ability to collate, combine and analyse data so that it is valuable for farmers relies on creating institutional processes and structures for trusted data sharing and collaboration, as well as building skill sets and competencies at all levels. Similarly, the need to invest in professional expertise and cultures throughout innovation support services depends on organisational capacity, as highlighted for individual, organisational and AKIS levels (Nettle et al., 2018, Barnes et al., 2019, Ingram and Maye, 2020). The relationship between organisational and human capacities is described for firms and organisations, where capacity is regarded as the potential of a system, and capabilities as enabling that potential. Brix et al. (2017), for example, distinguish organisational and individual levels of analysis, the former creating structures and processes to allow improvement of the latter, revealing a duality in the capacity building construct (Jensen and Krogstrup, 2017). Based on this, Turner et al. (2017) argues that innovation, adaptive and absorptive capabilities act to configure innovation capacity. Furthermore, capabilities operate at multiple levels and aggregations and extend to individuals, groups, networks and projects (Turner et al., 2017). In this respect, organisations themselves can develop specific knowledge and skills to cope with digitalisation (Rijswijk et al., 2019). This dynamic is also explored in work on literacies, where awareness and knowledge are an important starting point, and when combined with information-seeking and decision-making skills and self-efficacy for specific behaviours, such knowledge can inform collective action, community change and organisational capacity (Gray, 2018). Similarly, social and political capacities tie individual adaptive capacities to collective action and the potential for transformative institutional change (Eakin et al., 2016). These interdependent relationships between organisational and human capacities need to be disentangled in future socio-technical research agendas for digital agriculture.

### 4.5 Capacities and directionalities

The research questions for digital agriculture identify a common priority: how to build capacity to create systems that enable a directionality characterised by collaborative working, data sharing with confidence, value shared with all, and effective utilisation. They focus on how to strengthen capacities as a way to shift the hegemony or durable directions and power relations currently steering digital agriculture (Kanger and Schot, 2019). In doing this, they highlight areas where evidence is needed on which to build capacities before path dependencies set in (Stilgoe et al., 2013).

Although few scholars have examined the significance of capacities in the context of directionalities, Grillitsch et al. (2019) identified the need to develop capabilities in new forms of governance and new actors' competencies in the context of socio-technical regimes and directionality. Also, from an innovation systems perspective, Turner et al. (2017) argue that configuring capabilities and resources can build capacity and shape and steer path dependencies with respect to projects, and that understanding and analysing how capacity is built can help to break historic or negative dependencies. Furthermore, scholars working in ICT4D have also proposed that building capacity and intent, including individual and collective agency, organisational capacity and political direction, are necessary 'analogue components' that must precede digital development interventions (Hernandez and Roberts, 2018). These perspectives, together with the meta-themes identified above, provide some conceptual framing for linking directionality and capacity, and offer a new lens for social science inquiry in digital agriculture. Figure 4 shows how the capacities emerged as meta-themes and how they can contribute to prioritising where evidence is needed to address questions of directionality in digital agriculture.

## 5. CONCLUSION

This paper aimed to critically analyse the research questions identified by a prioritisation exercise with respect to digitalisation in agricultural production. The method allowed stakeholders to articulate a clear set of anticipatory questions, in line with RRI, identifying issues which require an evidence base to inform scientific and policy decision making. Due to the scope of the questions posed, this can only be an exploratory exercise, however, it sheds new light on emerging issues in rural studies literature on digital agriculture, through questions of capacity and directionality. The analysis found that organisational capacity and human capacity are interlinked priority areas for research that would benefit from a stronger research base. In particular, it reveals the need to pay more attention to the ability to govern and utilise digital agriculture effectively, equitably and collaboratively. The need to build capacity to break negative directionalities and to support responsible governance of digital agriculture was an underlying rationale of a number of the priorities. This new line of inquiry will be increasingly important as agricultural technologies rapidly develop and are implemented in rural areas and different combinations of public and private actors emerge, with different interests, forms of expertise, authority and complex power relations (Pauschinger and Klauser, 2021). This analysis applies equally to the UK and to other international research contexts, as evidenced by the supporting literature presented in the discussion. As well as offering new theoretical perspectives, the analysis allows us to identify where critical gaps in knowledge are about capacity, and potentially steer future research agendas, investment and policy decisions in agricultural innovation. This will be important, if digital agriculture is to achieve its potential of supporting more sustainable agricultural production responsibly.

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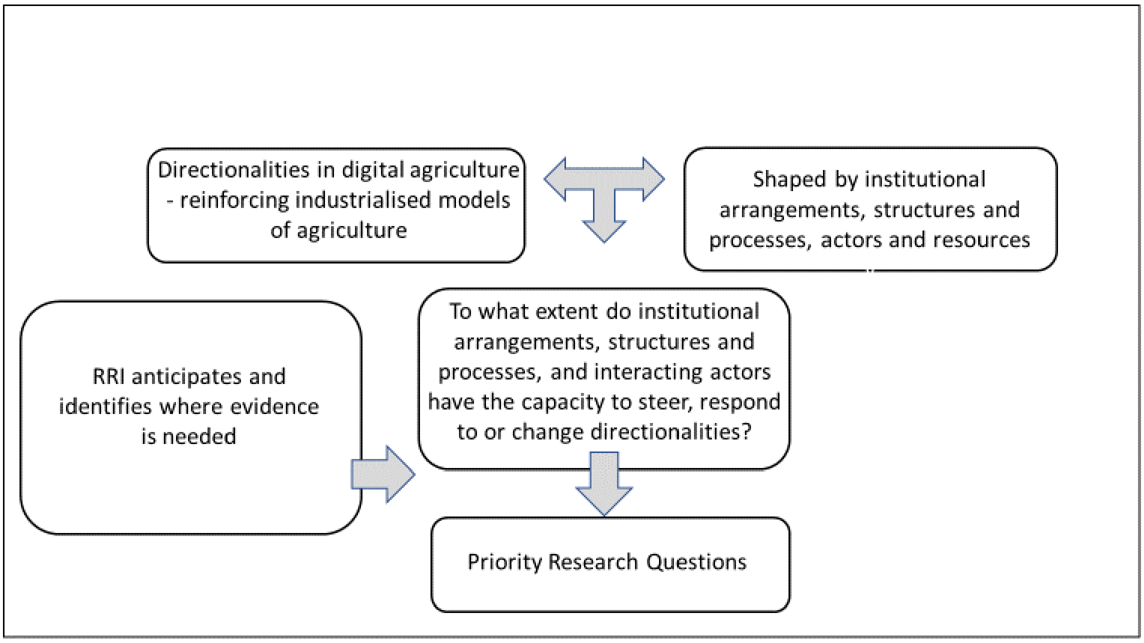

Directionalities in digital agriculture - reinforcing industrialised models of agriculture
Shaped by institutional arrangements, structures and processes, actors and resources
RRI anticipates and identifies where evidence is needed
To what extent do institutional arrangements, structures and processes, and interacting actors have the capacity to steer, respond to or change directionalities?
Priority Research Questions

Fig 1

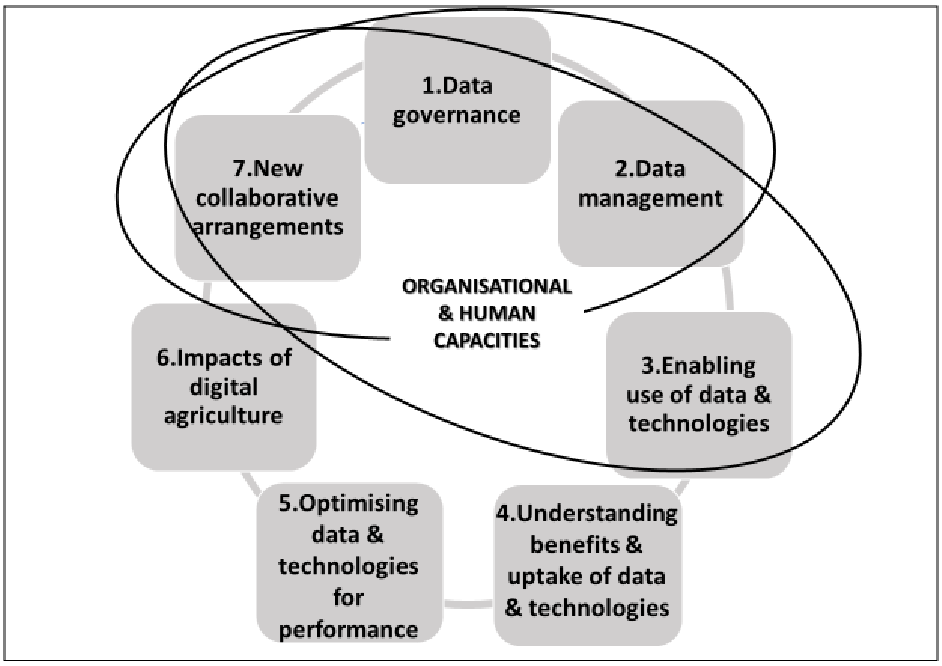
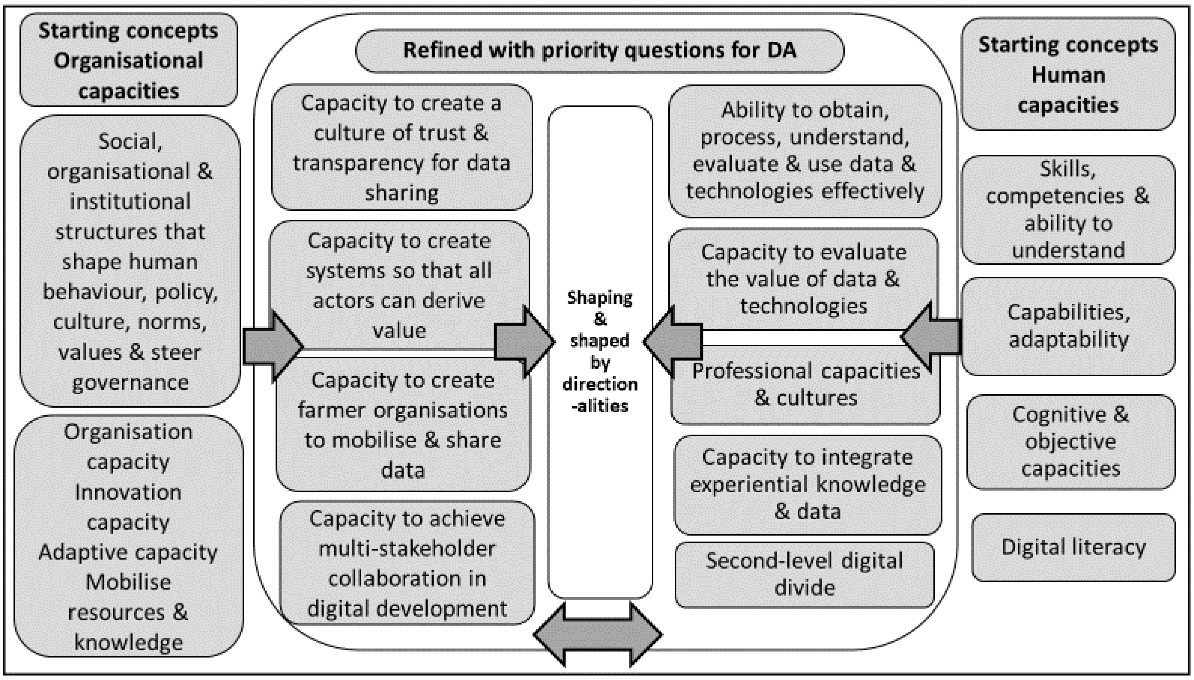
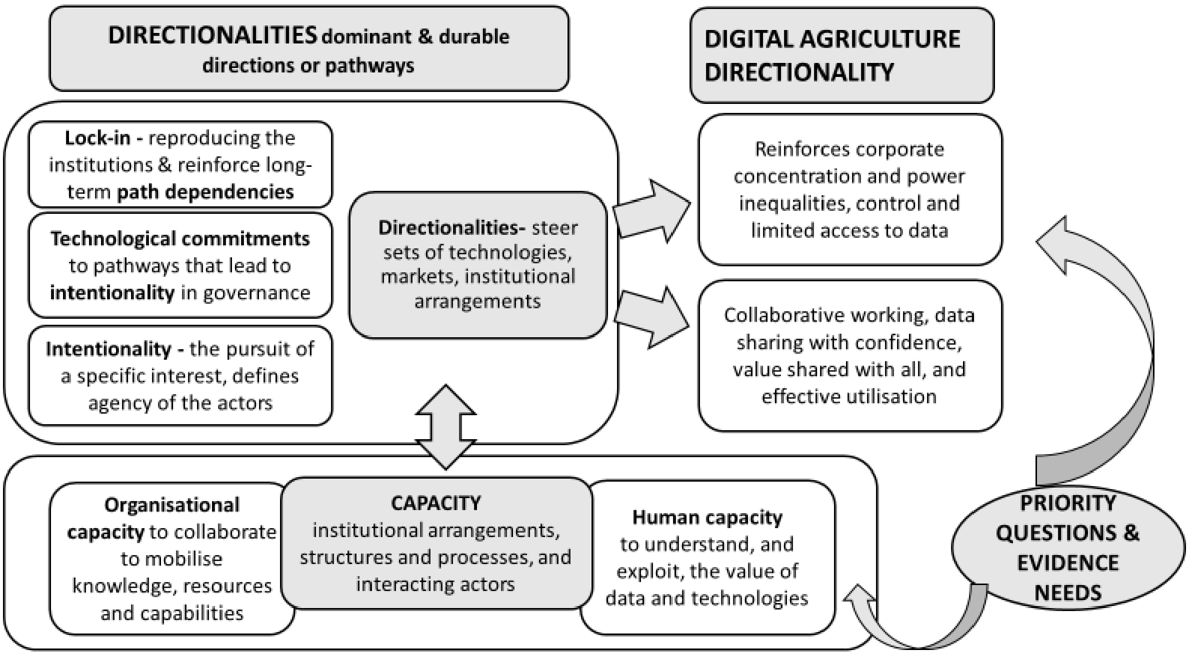

1.Data governance
2.Data management
3.Enabling use of data & technologies
4.Understanding benefits & uptake of data & technologies
5.Optimising data & technologies for performance
6.Impacts of digital agriculture
7.New collaborative arrangements
ORGANISATIONAL & HUMAN CAPACITIES

Fig 2



Starting concepts Organisational capacities
Social, organisational & institutional structures that shape human behaviour, policy, culture, norms, values & steer governance
Organisation capacity Innovation capacity Adaptive capacity Mobilise resources & knowledge
Refined with priority questions for DA
Capacity to create a culture of trust & transparency for data sharing
Capacity to create systems so that all actors can derive value
Capacity to create farmer organisations to mobilise & share data
Capacity to achieve multi-stakeholder collaboration in digital development
Shaping & shaped by direction -alities
Ability to obtain, process, understand, evaluate & use data & technologies effectively
Capacity to evaluate the value of data & technologies
Professional capacities & cultures
Capacity to integrate experiential knowledge & data
Second-level digital divide
Starting concepts Human capacities
Skills, competencies & ability to understand
Capabilities, adaptability
Cognitive & objective capacities
Digital literacy


Fig 3



DIRECTIONALITIES dominant & durable directions or pathways
Lock-in - reproducing the institutions & reinforce long-term path dependencies
Technological commitments to pathways that lead to intentionality in governance
Intentionality - the pursuit of a specific interest, defines agency of the actors
Directionalities- steer sets of technologies, markets, institutional arrangements
DIGITAL AGRICULTURE DIRECTIONALITY
Reinforces corporate concentration and power inequalities, control and limited access to data
Collaborative working, data sharing with confidence, value shared with all, and effective utilisation
Organisational capacity to collaborate to mobilise knowledge, resources and capabilities
CAPACITY institutional arrangements, structures and processes, and interacting actors
Human capacity to understand, and exploit, the value of data and technologies
PRIORITY QUESTIONS & EVIDENCE NEEDS


Fig 4

Table 1 Priority questions and capacity attributes

| RANKED TOP 5 QUESTIONS PER THEME | FINAL PRIORITY QUESTIONS | ORGANISATIONAL CAPACITY | HUMAN CAPACITY |
|---|---|---|---|
| **Theme 1: 23 voters** | | | |
| 1.How can we encourage and support data sharing – with all the challenges of data ownership, security and protection- between commercial companies for the good of agriculture? | GOLD: How can the value proposition inherent in data sharing be underpinned by a governance system that gives people the confidence to enter into that proposition? | Capacity to create structures and processes that support data sharing and create value for all | Farmer confidence |
| 2.What issues of data collection, management and use are raised by increased use of digital technology in agriculture? Particularly ethical issues about corporate control of and access to data. | GOLD: How can data sharing be underpinned by a governance system which takes account of ethical concerns? | Capacity to create structures, processes and cultures for trusted and ethical data sharing | |
| 3.How can farmers work together to benefit from the data that they provide (knowingly/ unknowingly) to the big global suppliers? | BRONZE: **How can farmers work together to benefit from the data that they provide** (knowingly/ unknowingly) to big global suppliers? | Capacity to create structures and processes for farmers to work together | Farmer digital skills and competence |
| 4.**How can farmers and growers share data with confidence** – is there a need for a common standard in data exchange both to ensure 'interoperability' and to maintain clarity on issues of data ownership and what permissions for its use have been given? | | Capacity to create structures and processes for sharing data with confidence | Farmer digital skills and competence |
| 5.A digital solution is a combination of various technologies, machinery and data collected by farmers and others. The integration of these capabilities is critical in digital agriculture. How can we generate an atmosphere of trust and collaboration to free-up the exchange of data? | SILVER: How to create the ecosystem / community that is needed to develop a transparent shared system of data which is **attractive for farmers** and commercial developers alike? | Capacity to integrate capabilities to combine data from different sources<br>Capacity to generate an atmosphere of trust and collaboration | Capacity to integrate capabilities and understand risks |
| **Theme 2: 12 voters** | | | |

| | | | |
|---|---|---|---|
| 1.Can a common standard be created to allow different datasets of farm metrics coming from different manufacturers and software packages to be used alongside anonymised data from other farmers for pre-competitive research into crop production, protection and environmental impacts? - | GOLD: How can we create data standards to allow data to effectively be interoperable between systems and solutions? | Capacity to create structures and processes for a common standard | |
| 2.What measures are UK farmers taking to mitigate cyber-security threats to connected farming technology? - | BRONZE: What measures is the industry taking to mitigate cyber-security threats connected to farming technology? | Capacity to create structures and processes to enable farmers to mitigate cyber-security | Capacity to understand risks |
| 3.With the increased reliance on farm management systems and the risk of cyber-attacks, should industry-wide information security standards be introduced? - | SILVER: How can the industry create systems for adopting common security standards? | Capacity to create structures and processes for industry-wide information security standards | Capacity to understand risks |
| 4.What are the regulatory powers necessary to ensure that the technology and data used can be trusted? - | BRONZE: What are the regulatory powers necessary to ensure that the technology and data used can be trusted? | Capacity to create regulatory powers necessary to ensure that the technology and data used can be trusted | |
| 5.Can a common standard be created to allow different datasets of farm metrics coming from different manufacturers and software packages to improve a farmer's ability to collate their own data? | | Capacity to create structures and processes for a common standard | Capacity to collect data |
| **Theme 3: 23 voters** | | | |
| 1.How can we move from data to information? Most farmers are drowning in data from machines, remote sensing and EO, market intelligence and environmental feeds, but unless we combine this into collated, accessible, mobile platforms containing management information most of this data will be unused | GOLD: How can data be collated, combined, and analysed to be useful to and therefore valuable for farmers? | Capacity to create structures and processes for collated, accessible, mobile platforms to ensure farmers can utilise data | Capacity to utilise data |

| | | | |
|---|---|---|---|
| 2.Do farmers feel resilient and digitally skilled and competent to capitalise on the changes in their sector? - | | | Capacity for digital skills and competence to utilise data |
| 3.How good are farm management decisions based upon (remote) digital data compared to traditional management decisions? - | GOLD: What is the value that farmers get out of using these data compared with more traditional datasets and intuitive forms of decision making? | | Capacity to assess the value of data informed decisions |
| 4.What tools and protocols are needed to ensure farmers and others can analyse and use data in effective ways? (farmers struggle to make use of available data - there is too much of it and it is too complicated) | SILVER: How to support farmers in using digital technologies and do they need new skills, or just better solutions? | Capacity to create structures and processes so that farmers can use data | Capacity to analyse and effectively utilise and exploit new forms of data and technology |
| 5.How can we most efficiently and effectively deliver systems that enable integration of different 'real-time' data sources; for example from sensors, satellites, weather forecasts etc? - | | Capacity to deliver structures and processes that enable integration of different data sources | |
| **Theme 7: 25 voters** | | | |
| 1.What is the role of farmer-led innovation in the digitisation of agriculture? What should be the extent of farmer involvement at all stages - concept, development, application etc. to help ensure practicality? What involvement is there already? | GOLD: What is the role of farmer-led innovation in the digitalisation of agriculture and how can it be improved to ensure farmer views are present in the design and trajectory of digitalisation? | Capacity to create structures and processes to allow farmer involvement at all stages | Capacity to understand and contribute |
| 2.How do we integrate farmers and other users' experience and qualitative factors into the decision-making process so that digital tools are based on a user-centric and data driven system? | | Capacity to integrate farmers and other users' experience and instil a culture of a user-centric and data driven systems | Capacity to articulate experiences, knowledge |
| 3.Can agriculture learn from the success stories of other industries (such as finance, healthcare) in the roll-out of digital tools to farmers? What lessons have been learnt that could be applied to agriculture? - | | | |

| | | | |
|---|---|---|---|
| 4.How can different actors with vested interests, competing goals and hidden agendas work more collaboratively together on digital ag projects? - | GOLD: How can different actors with vested interests, competing goals and hidden agendas work more collaboratively together on digital agriculture projects? | Capacity to create structures, processes and cultures for working more collaboratively together | |
| 5.What action needs to be taken to ensure that digital divides do not deepen and to avoid a scenario where some farmers get 'left behind' (i.e. digital exclusion) – in particular for farming systems and sectors where technologies are not being developed in a similar rate to other areas; and for those farmers lacking digital literacy capabilities to adapt to new technologies? | SILVER: What action needs to be taken to ensure that digital divides do not deepen and to avoid a scenario where some farmers get 'left behind' (i.e. digital exclusion)? | | Digital literacy capabilities to adapt to new technologies |

Table 2. Participant numbers and types at each stage in the prioritisation exercise

| **Stakeholder groups** | Invitation to participate | Step 1 Questions | Step 2 Voting | Step 3 Workshop |
|---|---|---|---|---|
| Research community (academics (technical, natural resources, agri-food systems, law, humanities), research institutes (e.g. Rothamsted Research), research funders (e.g. BBSRC) | 48 | 19 | 12 | 14 |
| Agricultural research & consultancy (commercial/ private) (e.g. RSK ADAS) | 8 | 3 | 2 | 2 |
| Agritech - digital technologies & data services (e.g. Agri-EPI Centres, precision technologies, mapping and software services) | 45 | 8 | 5 | 3 |
| Farmer representatives (e.g. AHDB, NFU, Farming Connect, I4Ag) | 8 | 3 | 3 | 4 |
| Government depts & agencies (policy, research) (e.g. Defra, Natural England, FERA) | 7 | 3 | 2 | 1 |
| Agricultural suppliers of inputs & machinery (e.g. John Deere, YARA) | 20 | 0 | 0 | 0 |
| Other (NGOs e.g. LEAF, Food Ethics Council) | 12 | 2 | 4 | 1 |
| Total | 148 | 40 | 28 | 25 |

Table 3 Capacity concepts that informed the analysis

| ORGANISATIONAL CAPACITY | | | |
|---|---|---|---|
| **Organisations - public sector/NGOs** | **Firms** | **Innovation system** | **Different units of exposure** |
| **Organisation capacity-** leadership, strategy, structure/governance, skills, human capital, and accountability (Cox et al., 2018). Resource attributes and management functions are important for NGOs (Walters, 2020).<br><br>**Organisation culture-** collective beliefs, values, behaviours, attitudes, norms, artefacts and symbols (Cox et al., 2018). | **Capabilities framework-** recognises distinct non-market traits that enable firms to both create and capture value from innovation (Teece, 2017).<br><br>**Capacity building-** activities that strengthen the knowledge, abilities, skills and behaviour of individuals, and improve institutional structure and processes, so that the organisation can efficiently meet its goals (Ku and Yuen-Tsang, 2013). Described as both a process and an outcome (Brix, 2018).<br><br>**Capability-**-capacity is the potential of a system, while capability is concerned with how this potential is exploited.<br><br>**Absorptive capacity-** the ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends (Cohen and Levinthal, 1990). | **Innovation capacity** - the capability of interdependent and self-organising actors to continuously identify and prioritise constraints and opportunities, and in response coordinate and collaborate with others to mobilise new and existing knowledge, resources and capabilities, and to experiment with social, technical and institutional options (Hall, 2005). | **Adaptive capacity-** the ability of individuals or communities to adapt by reorganising through networks or institutions that learn, store knowledge and experience and are creative, flexible and novel in their approach to problem solving (Gunderson and Holling, 2002; Eakin et al., 2016). |
| **HUMAN CAPACITY** | | | |
| **Farms and their networks** | **Organisations and firms** | **Innovation system** | **Different units of exposure** |
| | | | |

| | | | |
|---|---|---|---|
| **Farm managers' organisational capacities-** embedded in the managers' skills and routines in acquiring information.<br><br>**Cognition capacities**- farm business technology investment and adoption decisions (Annosi et al., 2019).<br><br>**Capability requirements**- including adaptation, capability mapping and human capital (Eastwood, 2019; Hekkert, 2007).<br><br>**Digital/data sovereignty-** the capacity of an individual farmer for self-determination and to take actions and decisions in a conscious and independent manner when seeking information (Zscheischler et al., 2022). | **Individual capacity building-** (employees) inability to use or access (new) technology and lack of self-confidence, time or capacity to solve a given task (acts as a form of disempowerment) (Brix, 2018).<br><br>**Organisation capacity**:<br>Six dimensions: leadership, strategy, structure/governance, skills, human capital, and accountability (Cox et al., 2018). | **Actors' innovation agency**- relates to the resources and competence that an individual has that can contribute to innovation, with knowledge and skills as particularly important in successfully implementing new farming practices (Klerkx et al., 2012).<br><br>**Capacities- capacity** is having the right configuration of capabilities in sufficient amounts to be able to successfully innovate – so capabilities constitute capacity (Turner et al., 2017). | **Competencies-** digital development requires competencies, skills, knowledge and attitude. ICT users need not just the skills to access data online but also the knowledge to evaluate that data and turn it into information, and the attitude of trusting and valuing the information obtained (Heeks, 2016).<br><br>**Digital literacy** - ability to obtain, process, understand, evaluate and use data and (digital) technologies to make informed decisions (Gray, 2018; Boughzala et al., 2020); awareness and knowledge, information-seeking and decision-making skills and self-efficacy (Gray, 2018).<br><br>**Digital Intelligence** –addresses the what, why, where, when, who, how, and how much of digital technology to improve operational efficiency and outcomes (Boughzala et al., 2020). |