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Deliberative assembling: Tinkering and farmer agency in precision agriculture implementation

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ABSTRACT

Assemblage thinking is an increasingly influential approach in critical studies of food and farming, and particularly in research on new agri-food technology such as precision agriculture (PA). This research is important in highlighting the distributed forms of power and agency through which farming worlds are assembled, and what these engender for more sustainable and equitable farming futures. However, to date, there has been limited attention to assembling PA from the perspective of farmers, what Legun and Burch (2021) refer to as 'deliberative assembling'. This paper contributes to knowledge in this area by applying post actor network theoretical work to investigate across case studies in Australia, the Netherlands and France, the forms of *tinkering* by which farmers attempt to make PA workable, and what these engender for farmer agency. Through our analysis, we show that much of the tinkering by farmers is aimed at holding together their own priorities, routines, and experiences with practices inscribed in PA technology, such as dependence on commercial advice, data-driven knowledge, and commitment to a single technological platform/company. Integral to this tinkering work are support networks that include agronomists, advisors, machinery dealers and/or farmer discussion groups. We argue that whilst these support networks are critical to holding together different practices, and making PA workable, they also play a more diverse and nuanced role in PA implementation than what has previously been recognised. Our case studies provide insights into three key forms of tinkering used by farmers in navigating support networks to make PA workable – disconnection, experimentation and trial-and-error, and trade-offs and compromises – and the specific distributions of agency which these tinkering practices engender. In conclusion, we argue that a tinkering lens provides a valuable approach for enabling agri-food scholars to tease out in greater depth deliberative assembling practices and how these variously open-up or foreclose options for farmers in making PA workable.

1. Introduction

Assemblage thinking is becoming an increasingly important approach in critical research on food and farming (Dwiartama et al., 2016; Forney, 2021; Forney and Dwiartama, 2022; Jones et al., 2019; Konefal et al., 2022; Sutherland et al., 2023; Sutherland and Calo, 2020). Part of the broader 'relational turn' in agri-food studies, which dates back to the late-1990s, assemblage thinking is consistent with a

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relational approach in drawing attention to the contingency, indeterminacy and material heterogeneity in what might otherwise be conceptualised as totalising macro-structural patterns and processes (Carolan, 2017b; Darnhofer, 2020). Application of this approach has been significant in identifying the diversity of human and material participants, and the distributed forms of agency and power, through which farming worlds are assembled – particularly in the context of new technologies (Comi, 2020; Forney and Dwiartama, 2022; Legun, 2015). However, in work to date there is relatively limited attention to assembling from the perspective of farmers (Klerkx et al., 2019), and specifically the work of farmers in 'assembling and reassembling socio-material practices that are diffuse, tangled and contingent' (McFarlane, 2009, p. 562).

Sutherland and Calo (2020) provide a useful starting point in examining assembling from the perspective of farmers. Following Müller's (2015) advice that there is much to be gained from bringing assemblage thinking into dialogue with other social theories and theorists, Sutherland and Calo (2020) integrate assemblage theory with the Bourdieusian-inspired concept of the 'good farmer' to highlight how new entrants to crofting in Scotland draw upon a range of actants in assembling the farming business and in establishing an identity as a crofter. Legun and Burch (2021) also examine assembly work from the viewpoint of farmers. Integrating a Responsible Research and Innovation Framework with assemblage thinking, they investigate the different ways in which New Zealand apple growers are practically assembling their farms to anticipate the introduction of new robotic technologies. Their research emphasises 'the central role of producers' practical and material worlds' in shaping apple growers' 'intentions, explanations, and visions for the future' (Legun and Burch, 2021, p. 381). The work of Sutherland and Calo (2020) and Legun and Burch (2021) is important in highlighting the creativity, flexibility, and active agency in how farmers assemble their farms. For example, Sutherland and Calo (2020, p. 541) point to how crofters 'were creative in their mobilisation of new networks and opportunities for their crofts', while Legun and Burch (2021, p. 389) identify a large number of growers in their research 'exhibiting deliberative assembling tendencies' who 'were industrious in how they navigated complex institutional, political and ecological terrains in order to map their own trajectories'.

In this paper, we build on these deliberative conceptualisations of assembling by investigating how farmers assemble new technology and make it workable in the context of their existing support networks as well as farming knowledge, priorities, and practices. We do so through the application of post actor network theoretical work on *tinkering* (Law, 2010; Mol et al., 2010; Singleton and Law, 2013) to case studies of precision agriculture implementation within arable farming systems in Australia, the Netherlands and France. Precision agriculture (PA) – broadly defined as the use of information technologies to collect data on in-field variability, tailor input use to address that variability, and to monitor outcomes (Srinivasan, 2006) – is a burgeoning area of inquiry for social scientists interested in the future of food and agriculture (e.g., Eastwood et al., 2017; Gardezi and Stock, 2021; Klerkx et al., 2019). It also provides an important focus for this paper given the growing use of assemblage thinking in identifying the imaginaries and diverse forms of agency that the socio-material relations surrounding PA make possible or foreclose (Carolan, 2017a; Comi, 2020; Forney and Dwiartama, 2022; Legun, 2015; Legun and Burch, 2021; Sutherland et al., 2023).

In applying theoretical work on tinkering, we address the following two research questions: *(1) Through which forms of tinkering do farmers assemble PA to make it workable? (2) What do these forms of tinkering engender for farmer agency?* In engaging with these questions, the paper builds on scholarly thinking related to assembling processes in PA in two key ways. First, recent work has been oriented to shifting debate from what technology is to what technologies do, or what they engender (Carolan, 2017b, 2020b; Ogunyiola and Gardezi, 2022). Such a shift is valuable in moving away from totalising narratives of technology towards more distributed accounts of power and agency. Nevertheless, it has had the consequence of prioritising the ways in which socio-material relations assembled beyond the farm shape the practices or options that are thinkable and do-able by farmers, including the possibility of alternative farming imaginaries (Comi, 2020; Legun, 2015). This downplays what Forney and Dwiartama (2022) refer to as 'everyday digitalisation', which includes the deliberative forms of assembling used by farmers (Legun and Burch, 2021) that make PA workable and practicable on-farm, something that we address in this paper through a tinkering lens. Second, the application of assemblage thinking to PA, and food and farming more broadly, has tended to focus primarily on examples within, or from the entry point of, a single country, such as the United States (Comi, 2020), United Kingdom (Jones et al., 2019) or Switzerland (Forney, 2021; Forney and Epiney, 2022). We expand this focus by drawing upon case studies of PA implementation across three countries – Australia, the Netherlands and France. Our focus on the forms of tinkering involved with PA implementation in three countries provides important insights into the 'multiple spatial imaginaries and practices' (McFarlane, 2009, p. 566) involved in making PA workable. It also enables a multi-national grasp of the tensions and challenges involved as farmers navigate those practices, and a broader body of evidence to assess which imaginaries originating with farmers might have the potential for governing force across wider domains (Carolan, 2020b).

2. Theorising tinkering as deliberate assembling: holding together, separations, and experimentation

At face value, the notion of tinkering is similar to 'assembling' in its focus on the heterogeneous and experimental, yet also patterned, practices through which diverse socio-material relations are held together (Singleton and Law, 2013). Where tinkering builds on these concepts is in its explicit emphasis on the deliberative work of *human actors* in making new practices or technologies workable in the context of 'existing knowledge-practices and farming goals' (Higgins et al., 2017, p. 200). Significantly, tinkering is also conceptualised as *care-ful* work (Mol et al., 2010; Singleton and Law, 2013) in that it is oriented towards farmers engaging with practices and priorities beyond what they care for intrinsically or immediately, also what have been called 'non-local cares' (which vary from farmer to farmer). Farmers are expected to incorporate these non-local cares – such as food security, environmental management, and 'smarter' technology – in ways that fit with their existing farming knowledge, practices, priorities, and experiences (i.e., their 'local cares'). In this sense, tinkering is central in enabling farmers to make non-local practices, techniques, or technologies 'more acceptable and effective' (Krzywoszynska, 2016, p. 305). Yet, while tinkering is a potentially useful concept for exploring the deliberative assembling work of farmers, there has been limited effort to-date to provide a systematic conceptualization in the context of agri-food technology or PA more specifically. We argue that Law's work on 'care as choreography' is particularly useful for agri-food scholars in conceptualising the tinkering work 'that allows situated action' (Law, 2010, p. 67) on the part of farmers, and which in the context of this paper, enables PA to be made locally workable. For Law, managing wider cares in the context of localised farming practices, knowledge, experiences, and priorities is best conceptualised as *choreography*. Drawing from his research on veterinary practices, Law (2010, p. 67) defines the choreography of care as 'the intricate ordering and distribution of bodies, technologies, architectures, texts, gestures and subjectivities'. While in our paper we will not take care as a central concept, the relevance of the work on choreography of care for our analysis is that it involves three inter-related types of tinkering work which shape our analytical lens.

First, tinkering involves the use of routines (Law, 2010) or patterned practices (Singleton and Law, 2013) for *holding together* different elements and objects (e.g., bodies, technologies, architectures). These practices rest on situated expertise (Krzywoszynska, 2016; Legun et al., 2022) and forms of skilled craftwork – 'the application of knowledge through embodied skills and practical judgement, and skilled interaction via manual skills with the material world' (Higgins et al., 2018, p. 27). They provide the basis for making non-local sets of practices with which farmers are expected to engage workable on-farm. However, while routines are important for farmers in holding together wider sets of practices with their farming knowledge and priorities, they also give rise to tensions, often struggling 'with the flexibility and adaptation typical of farmers' activities' (Krzywoszynska, 2016, pp. 304–305). Such wider, non-local, practices may produce ways of knowing that collide with or rub alongside local practices and ways of working (Gill et al., 2017), or they may not recognise local practices as being important at all (Higgins et al., 2018). In this way, farmers may find their experiential knowledge and practical skills colonised, punctuated, disembodied, and rendered invisible (Singleton, 2010, p. 250).

Second, tinkering also involves creating *distance and separations* between local farming practices and wider practices. Farmers are simultaneously managing multiple elements and objects, and these are not always compatible or coherent (Law, 2010). These 'disconnection rituals' (Singleton and Law, 2013, p. 269) shape what is to be kept outside of or away from their on-farm practices. For example, Higgins et al. (2018) draw on the concept of 'fluid engineering' to identify two key practices used by Australian beef producers to establish distance between their on-farm biosecurity practices and those sites and spaces off-farm perceived as posing a high risk to the health of their cattle. These are selective purchasing of cattle combined with isolation on arrival to the farm, and the use of physical materials such as fencing and restricted entrance points to the property to control human and non-human movement across property boundaries. While separation is central to tinkering work, as illustrated by the example above, Singleton and Law (2013, p. 272) argue that some separation practices may also be understood as a form of practical resistance to wider practices by enacting forms of otherness *within*, and '*attending* to that otherness without attempting to capture it' (emphasis in original).

Third, routines for holding together *and* separating on-farm practices and wider practices are experimental in character. According to Law (2010, p. 68), routines grow out of repertoires of past practice – 'but they are themselves a form of trial and error, involving the creation of new practices for separating and handling tensions between different subjectivities and objectivities'. Experimentation and adaptation are central to the concept of tinkering. This reflects the observation by Mol et al. (2010, p. 15) that tinkering involves 'people willing to adapt their tools to a specific situation while adapting the situation to the tools'. Higgins et al. (2017) apply this approach to tinkering in their study of PA implementation by growers in the Australian rice industry. They use this distinction to highlight two forms of tinkering – adaptation of new technology to work with existing machinery, and the use by growers of other people's machinery with PA technology already installed. For Higgins et al. (2017, p. 200), these forms of tinkering are crucial for growers in negotiating and working around wider modes of ordering 'that they see as constraining their capacities to implement new technology'.

Law's choreography of care approach is thus useful in capturing the three core dimensions of tinkering work which inform our analytical lens – holding together, separations, and experimentation. It also provides insights into the different distributions of agency that are involved in tinkering. In the remainder of the paper, we examine how the three dimensions of tinkering are applied by farmers across our three case studies to make PA workable, and what the relationships between these dimensions engender for farmer agency.

3. Methodological approach

We employ a comparative case study approach (Bartlett and Vavrus, 2017) in order to understand how farmers make PA workable and how they implement PA technologies on their farm. This paper is structured around three different cases studies, situated in different countries. The case studies analysed in this paper were developed independently, which result in a slight variety in contexts, methods employed, and actors involved. Differences can be seen in the analysis of PA through a focus on a range of technologies (Dutch and Australian cases) or through focusing on a specific PA technology (French case). This way of doing a comparative case study fits well with the process-relational turn in agri-food studies (Darnhofer, 2020). This follows the approach of Bartlett and Vavrus (2017) to case studies, which includes a broader variety of cases in order to trace the phenomenon of interest. Rather than pre-determining cases and striving for generalisability, this approach is informed by a focus on a phenomenon (PA for our cases), where the case develops around the phenomenon and follows the research. Such an approach allows us to remain open to what arises from the cases, more than other case study approaches would allow (Yin, 2013). Bartlett and Varus's (2017) approach to comparative case studies fits well with the process-relational perspective on farming, as it allows for new facts to emerge during the research process and as it enables us to trace PA across the different cases. Rather than starting with a pre-defined research plan and goal in mind, we took the understanding of PA as a goal, and traced PA through the context of each of our cases. This takes different forms across the cases, which shows the attention to particularities of local contexts, but also shows similarities across the cases on the use of PA, how actors engage with PA and how PA is transformed in practice (Bartlett and Vavrus, 2017, p. 10). To trace the use of PA, the case studies employed similar methods, conducting semi-structured interviews, predominantly with farmers, across three countries – Australia, the Netherlands, and France.

The Australian data used in this paper draws from a larger two-year project conducted between 2015–16 which aimed to investigate the social factors influencing technology adoption by Australian rice growers across a number of examples including (but not limited to): new rice varieties; precision agriculture; water management technologies and electronic communication. To explore the social drivers and enablers of change, qualitative research consisting of semi-structured interviews was conducted with 59 rice growers who were currently using or who had previously used some form of PA technology from across Australia's three main rice growing regions – Murray Irrigation Area (Murray) (25 interviews); Murrumbidgee Irrigation Area (MIA) (25 interviews), and Coleambally Irrigation Area (CIA) (9 interviews). A purposive sampling technique was used to ensure that a diversity of enterprises and growers were represented.

The Dutch data draws on research conducted between November 2018 and February 2019. This research explored how Dutch crop farmers apply and make PA workable on their farms. Qualitative research consisting of semi-structured interviews was undertaken with 26 participants. Included in the research were crop farmers actively using PA (CF) (14 interviews), (farmer-)contractors (CON) (3 interviews), researchers (RES) (3 interviews), and people working in the industry (IND) (6 interviews). A purposive sampling strategy was used to select farmers who had experience with PA to some degree, ranging from the adoption of auto-steering technology to what some would call agriculture 4.0 farms (Wolfert et al., 2017), which integrate a wide range of digital technologies and data streams.

Finally, the French data was collected between 2018 and 2019 in the context of the European AgriLink H2020 project and focused on a specific type of PA technology: a decision support tool (DST) for fertilisation. The aim of this tool is to optimise nitrogen fertilisation for wheat and rapeseed by applying the optimal amount of nitrogen on the optimal spot on the field. Data were collected on farm structure, farm general management, PA adoption and the advisory environment. A total of 33 farmers (F) were interviewed: adopters (who had adopted DSTs and were still using them at the time of the interview), non-adopters (farmers who never used the innovation) and droppers (farmers who adopted the innovation but subsequently dropped it and were not using it at the time of the interview). Using a purposive sampling strategy, conventional

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farmers were selected for the research who grow wheat or rapeseed with different farm structures in one specific French region (Gers, NUTS3 level). French farmers involved in this study were all male between 21 and more than 70 years old. A large proportion of farmers had responsibilities in the farming sector: 30 per cent of farmers were affiliated with a farmer union and 18 per cent were board members of a farm cooperative.

The similarities and differences between the Australian, Dutch, and French cases allowed us to contrast and compare the cases for analysis. Through cases that have enough similarity (as in crop farmers from the global North who use PA), we can see how PA technologies are used across these different cases and how similar technologies in different contexts lead to locally situated practices. This form of analysis following Bartlett and Vavrus's (2017, p. 52) classification can be seen as a homologous horizontal case comparison (taking similar groups as cases in dissimilar contexts that share corresponding features). We made analysis concrete by first developing short narratives (2–5 pages) that were written by the principal investigators for each of the case studies. The goal of these narratives was to highlight how farmers make PA technologies workable. The narratives were developed independently, organised around the core question: how and in what ways do farmers make PA technology workable? Through discussing these narratives among the authors and by comparing the narratives, similarities and differences in themes and trends were identified that showed how farmers make PA workable, and the implications for farmer agency. We discuss these themes and trends in the discussion (section 5). The narratives were shortened in order to fit within this paper and are presented in the following section.

4. Tinkering and PA implementation: case studies from Australia, the Netherlands, and France

4.1. Australia: the role of local agronomists in holding together PA with grower knowledge and practices

Based upon thematic analysis of the Australian rice grower data, two key practices were identified – standardising of machinery and retrofitting of existing machinery – through which growers seek to make PA workable on-farm. These practices are reflective of broader tinkering work by growers in holding together PA technology with their existing routines. At the same time, cutting across both practices is another form of tinkering – disconnection. Growers draw upon the expertise of actors external to the farm – principally local agronomists – who are utilised to support growers in making PA technology workable but also in enabling them to disconnect from sources of advice that are seen as unhelpful or unreliable.

The first practice for making PA workable is the standardisation of machinery brands, or the conversion of a farms' machinery to a single brand. Whilst used by a minority of grower-participants, standardisation was reported as enhancing grower control over the implementation of PA. As such, it enabled growers to keep the implementation of PA as simple as possible and to use technologies seamlessly across different pieces of equipment. For example:

> It's less complicated [using one company's system]. It's compatible. Like you can take it out of the tractor and put it in the header, and then take it out of that tractor and put it in another one, and it's just all you have to do is plug it in. (CIA7)

> We're 100 per cent John Deere. One hundred percent. I just find it's easier because trying to teach dad and other staff, if we just try to learn one screen and one system it's just easier. We're just trying to keep it simple, everything's plug and play. (MIA5)

Despite standardisation working well for some, most growers were hesitant to standardise under the one brand. The key concern for growers who had already standardised, or who were considering standardising, their equipment was the likely trade-off they would face between simplification and ease of use on the one hand, and potential technological lock-in on the other. Such a trade-off was judged to be too risky to grower's autonomy and flexibility: 'John Deere like to keep everything in-house so they won't share, they don't share …. Because we're dealing with electronics and codes and things like that, it's so easy to lock the technology up so you're captive to their product' (MIA8). These concerns were exacerbated by past negative experiences with the after-sales service provided by machinery companies:

> Very rarely do [technicians] come out and fix the problem. They'll come out, half fix a problem and tell you you'll be right and then they're out the gate and you'll get a phone call from someone on a machine, this thing's gone down again. We are getting to the stage where we cannot work without it, and that's a big problem. Like your GPS goes down with your steering, you know you steer, but when we're doing stuff in row crop, if the GPS goes down, you stop, like you have to. (MIA10)

As a consequence of poor service and concerns about trade-offs, most growers opted to instead retrofit PA software on existing machinery.

Retrofitting involves installing and/or modifying PA technology on existing machinery. This was judged by growers to avoid the high cost of investing in brand new equipment that has the technology already installed. A number of growers had experienced success in retrofitting and expressed pride in their ability to adapt new technology to older machinery. For example:

> I've got a little tractor which has got the steering wheel and an early screen, I take it out of that and put in my 2000 year model Case header, so I've got John Deere GPS in the Case header, it works alright. It's just a matter of adapting things. (MIA7)

Retrofitting was reported as providing growers with greater flexibility in implementing PA technology at a pace aligned to their priorities: 'that's one of the really good things about precision ag, you don't have to do it all at once, you can do it bit by bit and you can update older gear' (MVIA7). Nevertheless, the capacity to retrofit was widely observed to be hampered by challenges in the availability and reliability of support from machinery retailers and companies, an issue applicable also to those growers who had opted to standardise their equipment under one brand. For example:

> But of course as soon as you're in the machinery thing and you sign the thing, yeah, mate, we'll look at it mate, we'll look after you, don't you worry about that. And you're out in the paddock and you're going oh shit, and you're on the phone. No, no, we're busy. Isn't there somebody else there? No. (MIA2)

The lack of support from machinery dealers and companies meant that growers tended to rely heavily on existing independent support networks, primarily advisors and agronomists, in making PA workable.

Some growers observed that agronomists, and especially retail agronomists, do not always have the specific PA technical knowledge or skills: 'They're not necessarily up to speed on the engineering side of things and they don't want to make a commitment that might be expensive for them later' (MVIA18); and, 'their business is weeds and chemicals and fertilisers' (MVIA21) rather than PA. Nevertheless, it was the trusted independent advice separate to the commercial interests of transnational machinery companies that was most valued in supporting growers in making PA technology workable. For instance:

> [Our agronomist] comes out and he'll give you advisory information, but he's not telling you you need to have, or trying to tell you anything's better than what you're doing. He'll come out and he might suggest what technology you've already implemented to use it while you're there, but he's not trying to get you to upgrade or do anything to improve your technology. He'll work with what you've got. (CIA4)

> My agronomist now runs on an I don't know what programme or format it is but he comes out and has a look and when we go round he's just got his computer and he's dot, dot, dot and he goes home and a couple of hours later, or whatever, it comes through on my computer and it's the paddock, the hectares, the picture of the paddock, the rates, the chemical, what I've got to do, everything called in under it. (MIA16)

As a consequence, independent advice and support from agronomists is critical in enabling growers to engage in two forms of tinkering work – holding together new technologies with their existing knowledge, routines and practices, whilst also enabling disconnection from those sources of advice that are viewed as unsupportive or unreliable. The support networks drawn upon by growers contrast with our Dutch case study below where machinery dealers and local ag-tech companies, rather than agronomists, are judged to provide the most valuable support in making PA workable.

4.2. The Netherlands: disconnections between farm advisors and farmers in the interpretation of PA data

Based on a thematic analysis of the Dutch data, three practices for making PA workable were identified: standardising under the one brand, modifying or retrofitting older machinery with PA technology, and the use of external actors such as advisors, machinery dealers, researchers, and other experts. These are outlined in more detail below. While these practices are similar to the Australian case study, in terms of their broader orientation towards holding together as well as disconnecting, we also find evidence of experimentation and trial and error by farmers in the process of navigating different support networks.

The first practice identified in the Dutch data is the standardisation of machinery brands. Because most Dutch crop farmers are typically not limited to a single brand of machinery, this is quite a radical step to take. Most of the Dutch participants discussed the *potential* of standardisation in solving connectivity and compatibility issues between PA technology and machinery. However, it was also generally dismissed as something that was either too expensive, or as something that would reduce their flexibility in purchasing equipment, two things that were seen as a large downside to this strategy. Nonetheless, two farmers in the research had taken the step of standardising their equipment, with all PA equipment from the same brand. One of them explained their rationale for standardising:

> Well, the simple thing is, I am a John Deere man. That will not change in my life. And I would have to get my tractors modified and all that if I would use the auto-steering from the brand where I previously bought it. So I would constantly be playing catch-up because you have two systems running at the same time. That wouldn't work. (CF9)

While standardising restricted flexibility in purchasing new machinery, the farmers in question judged that this was the simplest approach for their farming operation. This was described in similar terms by other farmers, although not always connected to standardising equipment. For example:

> The three-clicks-rule is a rule that my employees have implemented. If it's more than three clicks [to use a piece of software] they won't use it. Google and Facebook can do that right? […] And I remind the guys developing the software of that, they find me a pain-in-the-ass, but I will give them that feedback. (CF2)

Similar to the Australian rice case study, Dutch farmers were generally wary of standardising under the one brand. However, those that did so reported benefits in addressing compatibility issues and a more straightforward 'plug and play' experience.

In contrast to the limited interest in standardising, most participants had experience in the retrofitting of older machinery and the modification of (new) precision agriculture machinery. Modifications often occurred in collaboration with machinery dealers and local ag-tech companies at the time of purchase. Farmers engaged these companies to customise and change the machinery to fit their farm management practices. Several of the farmers interviewed had been directly involved in modifying aspects of PA technologies. For example:

> About five years ago I bought a second tractor with GPS. At the same time, I bought a new sprayer, but the issue was that I would have had to buy a second GPS system and section control for the sprayer. And I thought, I already paid 15,000€ for the GPS, I don't want to buy a separate one for the sprayer. Of course I was right, but in practice it didn't work like that. So I approached the dealer, an ag-tech company and the importer, and discussed whether we could connect that [the GPS across both machines]. Because of course it is nonsense that you have a tractor with GPS and five metres behind you have a sprayer with its own separate GPS. And then they managed to connect it all. And in spring it all worked and I could use a single GPS system. (CF7)

Concurrent with modifications to new machinery, farmers were also retrofitting older equipment and changing machinery to be able to use PA. The simplest example of this is the range of GPS systems that can be built into an older tractor, which most farmers had used at some point. However, farmers were also going further, modifying auto-steer and variable rate technology and installing it themselves without having to buy new and expensive equipment. The following conversation between the interviewer (INT) and a farmer (CF14) provides an illustration:

> [INT] Yes, and the machines you have, were they ready to use?
>
> [CF14] Well I modified them quite heavily actually. That might be my own stubborn side, because I believe I should be able to do it myself. So I built them myself, all the auto steering I built myself, but also some of the other technologies. Also because I like to do it. […]
>
> [INT] And how does it work, to build a machine like that?
>
> [CF14] Well, it is mainly looking it up on the internet, through Google. There is always someone who has done it before. […] And a lot of the variable rate applications, well it's just all electric motors that drive it and you can easily vary their speeds. So that is pretty standard and the rest you build yourself.

Specific to many of these modifications are the strong networks that many of these farmers had. Farmers often spoke about the key role for machinery dealers and local ag-tech companies in making PA useable. National ag-tech companies were judged to be particularly important to the implementation of PA in Dutch cropping systems. These are national companies that cater specifically to the Dutch market. This is something that was seen as important by the different interviewees, as it allows PA to work for the specific circumstances of Dutch arable farming. For example:

> Trimble is American, a fairly decent program. But well, you can only ask so much as a Dutch crop farmer. And then there are companies like DAKON, which are very active on the Dutch market, and they see our challenges and can switch much faster. (CF4)

In contrast, farmers judged that when it came to the *interpretation* of data generated by PA technologies, support from local networks was far from adequate. There is evidence from the interviews that some advisors were integrating PA into their business:

> Our question was, how do we get the most profitable yield from a field. […] And we went looking for solutions to this a few years back, what can we do with modern technology and tools for the crop farmer, and how can we be involved. […] And what we saw is that they have to purchase data, through scans or through drone flights, but that in the end that data has to be understood by the crop farmer. And we thought that we should change that, that the crop farmer

needs ready-made data that he can understand. And as an advisory service you need to prepare this for him and involve the farmer to understand how he wants to use it. (IND4)

However, this support was viewed as having a long way to go in providing the support needed to effectively interpret PA data. For example:

[INT] How do you see the advisors who work with precision agriculture?

[CF5] Their knowledge level? [...] Terrible. Yes. They might know how to make a variable rate map, but they haven't got a clue of how to use it. [...] My own advisor is more someone I can talk to. He knows what I can spray and when I should use it. [...] But with precision agriculture, if I discuss that with him? Well, he'd go crazy. He doesn't get that.

This was something that many of the farmers had struggled with, having to ultimately find their own way of interpreting the data they received through various technologies.

The problem for our farm is really the agronomic interpretation. You have soil scans, organic matter, and you want to do something, but which algorithms should you use? And then I often do it based on my own farmers' feeling. But it's not very scientific then. (CF14)

Thus, whereas in the Australian rice case study agronomic advice was trusted in supporting PA implementation and data interpretation, in the Dutch case such support from agronomists was judged to be almost entirely lacking. In these circumstances, farmers fall back on their own experiential knowledge for interpreting data, and they draw upon the support provided by machinery companies and national ag-tech firms to adapt the technology to their own priorities and goals. The different and complex ways in which support networks are central to tinkering work, variously facilitating or complicating efforts by farmers to make PA workable, is highlighted further in our French case study below.

4.3. France: integrating different sources of support to fill gaps in local advisory services and make PA workable

Based upon the thematic analysis of the French farmers, we identified a specific form of retrofitting and seeking support from different local advisory organisations as the main practices for making PA workable. To identify these practices, we focused on the goal of fertiliser optimisation, which is central to PA (Lowenberg-DeBoer & Erickson, 2019). We analysed specifically the use of decision support tool (DST) technology for fertiliser application. This technology is intended for farmers growing wheat or rapeseed and consists of two parts: software (that generates nitrogen recommendation maps) and hardware (machinery that applies the maps on fields).

The first practice we identified for making DST technology workable is a form of retrofitting of existing machinery. Contrary to the Australian and Dutch case studies, retrofitting does not seem to emerge from explicit strategies of farmers. Instead, it results from the structure of the DSTs' market. Farmers buy the software separately from the hardware, directly from their local advisory organisation, with whom they have long-term trusted relationships. To make DSTs workable, farmers often have to retrofit to enable the connection of their existing machines to the nitrogen recommendation maps generated by the software. Also, contrary to the Australian and the Dutch case studies, standardisation logics under one brand are not specifically present to make DSTs workable on farms. In France, local advisory organisations sell to farmers DST software that is independent from machinery brands and thus standardisation is not possible.

Adapting existing machinery to connect hardware to software on-farm requires specific skills. Some farmers explained that they managed to achieve this due to past technical training. For example:

Oh, it takes a little bit … how shall I put it: you have to have some electronics and computer skills, to make it easy to implement. (F25)

And,

[I have connected it] by tinkering on internet. And then by tinkering, I used mechanical stuff that I used to do. (F26)

In general, most farmers expressed difficulties in connecting their machines to the maps. The first difficulty reported by farmers is that older machines cannot always be adapted to read recommendation maps, and this often leads to less accuracy for in-field application of software recommendations:

We make an average dose [of what the DST software recommends]. If sometimes there are areas with big gaps of recommended dose as it can be the case possibly on clay rounds [...] then we can make [the difference] manually, we make it only manually. (F10)

The second difficulty reported by farmers is that local advisory organisations to which farmers turn for support in the implementation of DSTs often lack competency, even if they are the suppliers of that software. Below is an extract from a conversation between one farmer (F8) and the interviewer (INT) that illustrates this lack of competency from traditional advisors.

INT: So at [the moment to implement DST] the most important information for you was everything related to the tractor?

F8: Yes, absolutely. That was what was essential for me. And the lack here is what made me stop [buying] the [DST] service.

INT: Did you get any help at this moment?

F8: No, frankly no. I thought that the guy who sold me the [DST] service, a technician from [name of cooperative], I thought he was going to find me solutions. But in the end he didn't. He didn't know! I said to myself: the guy wants to sell me the service, but not necessarily give it back to me.

This situation may lead farmers to rely on machinery dealers that specialise in selling the hardware part of DSTs. For example:

[The software] didn't send me the right format [...], why I don't know. We had some problems at the beginning to read the maps. So I think that the first year even the first modulated contribution we couldn't do it because we didn't have the right format, we only had it on the second contribution. We had the help of the machinery dealer to make the spreader work. (F27)

The third difficulty farmers pointed out is a lack of coordination between farm advisors (that sell the software part of DST) and the machinery dealers (that sell the hardware part of DST). Farm advisors and machinery dealers sell distinct parts of the same innovation, without consulting each other. The sales are made separately and rarely take into account the different possible formats of software and hardware. Several farmers had difficulties solving their connectivity issues because machinery dealers and advisors are not used to working together. The following quote is from Farmer 8 who did not manage to make PA work on his farm due to a lack of adequate support from traditional advisors. To solve his connectivity issue, he had to organise a meeting between his advisor and his machinery dealer during a fair.

I don't do the work anymore, I just manage it, I delegate the work to two other farmers [...] one of whom is a bit sharp, he uses new technologies. That's why I went with [DSTs], because I thought he would be able to read the maps. But it was not the case. I am still followed by a technician from the Chamber of Agriculture so I asked him for support. The first year it was the trainee who suggested to me [to use DSTs]. Well, he didn't know how to use the interface between the console manufacturer and the distributor. He didn't know how! [...] Finally we solved the problem at [name of local fair] where I had gathered myself [name of the advisor from the Chamber of Agriculture], the manufacturer of the console and the manufacturer of the tractor distributor. (F8)

When it came to the interpretation of the data generated by DSTs, farmers persisted in their interactions with advisors from local advisory organisations despite their lack of expertise on implementation. They questioned their local advisors about how to interpret data and use it on their farms. We observed variations in how recommendation maps were applied. These variations are relevant in that they are linked closely to the different local networks in which farmers are embedded, as we explain below. On the one hand, some farmers trusted the recommendation maps and applied them strictly on their land. For example, one of them explains that he let his machine apply the nitrogen dose as stated in the recommendation map: 'We put the USB key [on the machine], it's the USB key that does everything' (F10). In this situation, farmers are usually embedded in strong trusted relationships with advisors that sold them the software. The conversation below between a farmer (F10) and the interviewer (INT) illustrates this point.

F10: It was a lot with the technician, yes we are almost buddies, we get along very well so I trusted him on the system, on the principle and I am happy with it.

INT: Did you have any problems with the implementation, the accounting with your spreader?

F10: At first, yes […] But now that it's up and running, it's very simple, you put in the USB key, you go and get the plot and it's done all by itself.

On the other hand, making PA workable does not necessarily mean strict application of the recommendation maps. Some farmers modified the nitrogen dose drawing upon their experience and past knowledge. Farmers who are integrated in local farmer discussion groups put PA on the agenda of those groups. They discuss the data generated by DSTs in groups and use the experience of other farmers to interpret it differently, in this case modifying the recommended fertiliser dose.

We have the advantage of being [in a local group] where we are about fifteen farmers. We meet every two weeks, on Tuesdays, on different themes, on the seeds to use, on new technologies, new software, phone applications, on all that, and we have the advantage we all get along well, so we discuss everything that works for us, what doesn't work, and we pool our efforts. And since there are no phonies who think they can do better than the others, it goes well because everyone tells the truth, they say when they don't succeed in something, so there's that too, we can discuss and know what to do, what not to do, what they tried. (F23)

In conclusion, involvement in different support networks has a strong influence on the way farmers make PA technologies workable on their farm. Similar to the Australian and Dutch case studies, French farmers tend to rely on specific forms of support – in this case, local advisory organisations – to hold together PA with existing routines, even if those forms of support lack specific PA expertise. However, in the French case, trial and error in using different types of support is far more evident than in the Dutch case study, and the work of disconnecting evident in the Australian case study is entirely absent. Farmers continue to use local advisory organisations *at the same time as* utilising machinery dealers and local discussion groups to fill the gaps in knowledge and practical support that advisory organisations are seen to lack.

5. Discussion

This paper has drawn upon the conceptual lens of *tinkering* to investigate two research questions: (1) Through which forms of tinkering do farmers assemble PA to make it workable? (2) What do these forms of tinkering engender for farmer agency? In engaging with these questions, we have sought to contribute to the application of assemblage thinking in agri-food studies, and research on PA specifically, by giving greater attention to how PA is assembled from the perspective of farmers across different countries. In this section of the paper, we reflect on the ways in which the three principal forms of tinkering outlined by Law (2010) are evident across our case studies, and how our findings advance scholarly understanding of the role of farmers, and farmer agency, in assembling processes.

First, through our analysis we have identified that across the three case studies much of the tinkering work performed by farmers is aimed at holding together what they value – e.g., local cares such as experiential farming knowledge (Higgins et al., 2017; Ogunyiola and Gardezi, 2022), trust (Gardezi and Stock, 2021; Rijswijk et al., 2023), and farmer autonomy (Forney and Epiney, 2022) – with non-local cares inscribed in PA technology. These non-local cares include dependence on commercial advice, data-driven knowledge, and commitment to a single technological platform/company (Bronson, 2019; Carolan, 2018; Rotz et al., 2019). This is consistent with the use of assemblage thinking in agri-food studies (e.g., Forney and Dwiartama, 2022; Jones et al., 2019; Konefal et al., 2022; Legun, 2015) that focuses on the processes and practices through which heterogeneous elements are provisionally held together. Our use of a tinkering lens builds on these understandings of assemblage by providing deeper insights into the *deliberative assembling work* of farmers (Legun and Burch, 2021) and the constraints they experience as part of efforts to hold together different elements.

The work of holding together is evident in the use of *practical judgement* by some farmers in the Dutch and Australian case studies to standardise their PA technology under the one brand. For these farmers, standardisation provided an efficient and simple way of making PA technology workable, or holding it together, with existing farming practices and priorities. Despite recognising the potentially 'intolerant and colonising' effects (Singleton and Law, 2013, p. 271) of using equipment from one brand in terms of reducing their autonomy, and risking technological lock-in, standardisation enabled farmers to establish distance from the potentially time-consuming work involved in connecting software and hardware from different brands. Holding together is evident also in the use of farmers' *skilled craftwork* in retrofitting and/or modifying equipment across all three case studies. This shows how farmers deliberatively re-arrange relations with different technological platforms so that PA is assembled in ways that align with their existing farming priorities, practices, and experiences, instead of rendering them as subjects without agency vis-à-vis PA technologies as others have also argued (e.g., Brooks, 2021; Gardezi and Stock, 2021).

However, our analysis also draws attention to the challenges farmers face in holding different elements of an assemblage together. These constraints revolve primarily around accessing appropriate support. Previous research highlights the importance of support networks in facilitating learning and reducing uncertainty for farmers in using PA (Eastwood et al., 2017, p. 2). Actors such as agronomists and consultants are argued to play a particularly important and trusted role in translating between the formal technical knowledge associated with PA technologies and the tacit and experiential knowledge of farmers (Ayre et al., 2019; Eastwood et al., 2012; Higgins and Bryant, 2020). To some extent, our findings reinforce these arguments. As we have seen, farmers across our case studies consult for advice and support in implementing PA technology those whom they trust, such as agronomists (Australia), local advisory organisations (France) and ag-tech companies (the Netherlands). Nevertheless, our results also reveal that these relationships are more complicated than what is documented in the existing research.

Each case study highlights how those actors who farmers trust to provide support also pose challenges in assembling PA, which connects with and deepens an emerging literature on how advisors adjust to digitalisation and are seeking and building new capabilities and alliances to deliver value to clients (Eastwood et al., 2019; Ingram and Maye, 2020; Klerkx, 2020; Rijswijk et al., 2019). Thus, in our Dutch case study, while advisors from ag-tech companies are important in making PA technology locally workable, they are judged to provide poor support in the interpretation of data produced by those technologies. In our Australian case study, agronomists are drawn upon to support PA implementation not because they necessarily have the technical expertise, but due to challenges in the availability and perceived quality of support from machinery dealers and PA specialists. Lack of on-ground technical support from local advisory organisations in our French case study means that farmers are forced to increase their reliance on machinery dealers. This is further complicated by a historical lack of coordination between these dealers and local advisory organisations. These findings show that while trusted support networks are important in making PA workable for farmers, this holding together is often partial and is also the result of compromises and trade-offs in accessing appropriate support, an issue that we expand on below.

Second, the use of a tinkering lens in this paper provides details on specific practices through which farmer agency is variously distributed in assembling processes. Applications of assemblage thinking in agri-food research show that distributed agency is central in understanding how farming worlds are assembled (Carolan, 2017a; Dwiartama et al., 2016; Jones et al., 2019; Sutherland and Calo, 2020), and the actants relevant to that agency are often identified (Comi, 2020). However, limited empirical insight is provided into how different distributions of agency are assembled (although see Forney and Dwiartama, 2022). Our research identifies three key practices of tinkering through which farmer agency is distributed – disconnecting, trade-offs and compromises, and experimentation. Similar to Forney and Dwiartama (2022) all of these practices emphasise the relational nature of agency.

Evident in our Australian case study is the *disconnecting* (Law, 2010; Singleton and Law, 2013) from those actors who are judged by farmers as making limited or poor contributions in making PA workable for them – in this case machinery dealers and the transnational companies who supply the machinery and technical support. This form of tinkering theoretically opens options for farmers in choosing the support that fits best with their farming priorities and practices. Yet, in practice it can restrict their options by increasing reliance on local agronomists who may be trusted by farmers, but who lack the technical expertise in PA. Our French and Dutch case studies highlight how farmers turn to forms of *experimentation or trial and error* (Law, 2010) for addressing gaps in support. This can be a creative strategy for sourcing appropriate technical support and enhancing the capacity of farmers to make PA locally workable – for example, Farmer 8 (French case study) who, frustrated with a lack of connection among different support networks, organised a meeting between his advisor and machinery dealer. At the same time, it can also be a necessary fall-back where there is lack of adequate PA support, as in the Dutch farmers who reported falling back on their own experiential knowledge to interpret PA data.

All our case studies point to the significance of *trade-offs and compromises* by farmers in assembling PA. This is something that is little recognised in existing agri-food research using assemblage thinking. It is also an important dimension of tinkering that has been previously unexplored. Across our case studies, farmers persist in drawing upon the support of agronomists/advisors despite the reported limitations of their PA expertise, and, in the Dutch case, their lack of data interpretation skills. Similar to disconnecting, this ensures that farmers can access trusted advisory services in implementing PA. However, due to the lack of technical expertise it restricts what farmers can do in making effective use of PA technology on their farm and can lead to greater reliance on farming experience and farmers' tacit knowledge of technology. Trade-offs are evident also in the standardising of technology used by some farmers in the Australian and Dutch case studies. These farmers recognised the potential limitations of using equipment from the one brand in terms of reducing their autonomy, and risking technological lock-in (echoing arguments by Carolan, 2020a; Clapp and Ruder, 2020; Stock and Gardezi, 2021). Yet, this was a trade-off that they were willing to make because standardisation provided an efficient and simple way of making PA technology workable, or holding it together, with existing farming routines and priorities. It also enabled them to establish distance from the potentially time-consuming work involved in connecting software and hardware from different brands.

Third, and finally, the use of a tinkering lens across our three case studies located in different countries extends agri-food research on assembling by enabling engagement with Carolan's (2020b) call to identify alternative imaginaries that have the greatest potential for governing force (or 'extension') across wider domains. At face value, the practices of retrofitting and modification, used by farmers in all three case studies, have this potential as they enable farmers to make PA workable in ways that suit their priorities and needs. Their use demonstrates the significance of farmers' skilled craftwork in the deliberative assembling of PA technology on-farm. While these practices depend on the availability and adequacy of trusted local support, they engage with all three dimensions of tinkering. That is, they enable farmers to hold together PA implementation with existing on-farm practices in a way that is flexible, adaptable, and is sufficiently disconnected from the risks associated with standardising under the one brand. Indeed, these practices seem to provide what Singleton and Law (2013, p. 272) call 'alternative breathing spaces' or a form of 'practical resistance' for farmers that enable a degree of separation from the otherwise colonising realities but also inaccuracies of PA technology (Brooks, 2021; Carolan, 2020a; Clapp and Ruder, 2020; Stock and Gardezi, 2021; Visser et al., 2021). Nevertheless, because farmers were mostly reliant on various support networks to retrofit or modify, future research needs to assess how and to what extent different actants enable and/or constrain farmers' capacity to retrofit and modify equipment.

6. Conclusion

This paper contributes to the application of assemblage approaches in agri-food studies, and research on PA specifically, by investigating the forms of tinkering used by farmers to assemble PA across arable farming systems in Australia, the Netherlands, and France, and what these engender for farmer agency. Theoretical work on tinkering enables detailed insights into the deliberative assembling practices through which farmers make PA workable, and the constraints they face in doing so. Our analysis highlights the significance of practices of skilled craftwork and practical judgement in managing PA implementation in the context of localised farming routines, knowledge, and experiences. These practices are consistent with previous research showing how farmers are active agents in assembling farming worlds and are not passive subjects to PA technologies. At the same time, our research points to how that agency is contingent on the complex ways in which farmers navigate various support networks. Farmers across our case studies experience challenges in accessing adequate and/or appropriate PA support. This gives rise to a range of tinkering practices – disconnecting, experimentation, and trade-offs – that can both open-up or foreclose options for farmers in making PA workable.

We argue that a tinkering lens provides a conceptually coherent approach for teasing out the different ways in which farmers navigate and contribute to assembling processes, and the nuances in farmer agency that this engenders. We agree with previous research that farmer agency is enacted through different relations in an assemblage. However, application of a tinkering lens reveals the specific practices and forms of support through which those relations are variously held together, disconnected, experimented with, or traded off. As such, we conclude that tinkering provides a valuable approach for enabling agri-food scholars to tease out in greater depth farmers' deliberative assembling practices and how these are made workable in the context of other relations and actants.

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Data availability

Data will be made available on request.

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