

# *Responsible development of autonomous robotics in agriculture*

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# 1 **Responsible development of autonomous robotics in agriculture**

2 *David Christian Rose<sup>1</sup>, Jessica Lyon<sup>1</sup>, Auvikki de Boon<sup>1</sup>, Marc Hanheide<sup>2</sup>, Simon Pearson<sup>2</sup>*

3

## 4 **[Standfirst]**

5 Despite the promise of autonomous robots to contribute to agricultural sustainability, a number of  
6 social, legal, and ethical issues threaten adoption. To understand these challenges, we discuss how  
7 responsible innovation principles can be embedded into the user-centred design of autonomous  
8 robots and identify areas for further empirical research.

## 9 **[Main]**

10 Adding to the list of environmental challenges facing agriculture, COVID-19 and the  
11 demographics of age, migration and urbanisation poses a serious threat to the sustainability of farm  
12 businesses and food security<sup>1</sup>. In particular, farm businesses across the world are struggling to fill  
13 vacancies and provide safe working conditions for labourers.

14 Autonomous robots could help address these immediate challenges<sup>2</sup>. Whilst their physical  
15 manifestation comprises hardware, such as a vehicle combined with manipulators, their autonomy  
16 is derived from sophisticated algorithms routed in artificial intelligence. These algorithms fuse  
17 sensor data to enable control and real-time decision support. Autonomous robots perform tasks  
18 with a high degree of autonomy and may work collaboratively alongside human workers (so-called  
19 co-bots) or on their own<sup>3</sup>. Apart from isolated examples of these technologies being demonstrated  
20 on-farm, autonomous platforms with robotic mobility which fuse multiple technologies across a  
21 single fleet (e.g. crop forecasting, planting, harvesting, packing) are not yet fully implementable,  
22 and substantial barriers need to be overcome before they will be. However, there is already  
23 adoption of static robotic milking technologies in the dairy sector, and in-field deployment of  
24 tractor mounted robotic manipulators to remove weeds and protect crops from pests and diseases<sup>2</sup>,  
25 for example.

26 We know, however, that the history of innovation in agriculture is littered with examples of failure  
27 or slow adoption, and the legal, ethical, and social concerns associated with autonomous  
28 agriculture are controversial<sup>4,5</sup>. Potential challenges, opportunities and consequences of  
29 autonomous agriculture, illustrated in Figure 1, are interlinked and depend on how technologies  
30 are designed and implemented. Many of these aspects have been discussed in the burgeoning  
31 literature on the social and ethical impacts of digitalisation in agriculture<sup>6,7</sup>. For autonomous  
32 robotics in farming, where empirical research remains limited, potential issues have largely been  
33 identified by extrapolating views gathered from empirical research on smart farming technologies  
34 in general, or from the use of autonomous robots in other workplaces. Here we identify examples  
35 of where responsible innovation principles are being implemented and indicate where more needs  
36 to be done.

37 **Figure 1**

### 38 **Responsible innovation in agriculture and beyond**

39 The most widely used framework for responsible innovation was proposed by Stilgoe and  
40 colleagues<sup>8</sup> and involves four key components: *anticipating* the impacts of innovation; reflecting  
41 on one's work and adapt accordingly (*reflexivity*); *including* a wide range of stakeholders in the  
42 design process; and *responding* to stakeholders' concerns, ideas and knowledge by constructing  
43 appropriate institutional structures.

44 Guidance on responsible innovation – provided by funders such as Engineering and Physical  
45 Sciences Research Council<sup>9</sup>, InnovateUK<sup>10</sup>, and the European Commission – encourages  
46 companies to be cognisant of their responsibility and committed to RRI principles, by exploring  
47 the challenges that could arise from innovation and acting on their findings in a transparent,  
48 inclusive, and timely manner. Despite frequent calls for companies to conduct a transparent and  
49 iterative process of responsible innovation, there is a lack of either a commitment to, or reporting  
50 of, the steps taken in technology development in the agriculture industry.

51 In the following sections we discuss how the four key components mentioned above can be  
52 operationalised to guide technology development in agriculture<sup>11</sup>, outlining key research needs to  
53 better understand how to operationalise the idea. Examples referenced in this paper and the

54 guidance from Stilgoe *et al.*<sup>8</sup> and Eastwood *et al.*<sup>11</sup> provide a good overview of techniques that can  
55 be used to apply responsible innovation principles.

## 56 **Anticipation**

57 With the objective of minimising negative, unintended outcomes<sup>8</sup>, ‘anticipation’ involves  
58 identifying, predicting, and exploring the potential short- and long-term consequences of future  
59 innovation across society and is therefore essential for the responsible development of autonomous  
60 robots.

61 There has been little empirical anticipatory work for autonomous robots in farming that has  
62 included a variety of stakeholders in the process, though a recent paper by Legun and Burch<sup>12</sup>  
63 begins to describe a process of co-design in the context of robotic apple orchards in New Zealand.  
64 Empirical studies have otherwise been limited to the narrow use of foresight exercises in the form  
65 of technology use and acceptance surveys and farmer<sup>13</sup> or public opinion surveys<sup>14</sup> using online  
66 questionnaires and short interviews. Foresight is also used to elucidate future benefits and  
67 challenges associated with a technology in combination with other methods, such as the Delphi  
68 technique (which relies on anonymous rounds of voting)<sup>15</sup>. Other anticipatory processes include  
69 ‘horizon scanning’ (scanning data sources to detect early developments<sup>16</sup>) and ‘socio-literary  
70 techniques’ (using science fiction as a tool to encourage dialogue about technology futures<sup>17</sup>,  
71 possibly through ‘Ag-Tech movie nights’<sup>18</sup>). A typical methodology in robotics and human-robotic  
72 interaction are “Wizard of Oz” studies<sup>19</sup>, where autonomy is “fake”; robots are usually remote-  
73 controlled, anticipating the abilities they may have once fully implemented. Another useful  
74 technique often employed are video studies<sup>20</sup>, where participants are presented with recordings of  
75 robot behaviour and assess it from a third person perspective.

76 One further method to consider is backcasting, which involves building an (ideal) future scenario,  
77 and working backwards to identify the steps needed to get to that scenario. This is done in  
78 anticipatory governance approaches, for example. A key area for future research will be to use  
79 different anticipatory methods with diverse stakeholders specifically on the subject of autonomous  
80 robots in agriculture. Those included in the process of anticipation should be those directly affected  
81 by the adoption of robotics, including farmers, farm workers, and consumers of food produced in  
82 that way. Including such a wide range of stakeholders will create a number of practical challenges

83 related to power inequality (farm managers v farm workers) and language barriers (migrant farm  
84 workers) and these will need to be managed sensitively by trained facilitators.

## 85 **Reflexivity**

86 Reflexivity entails ‘holding a mirror up to one’s own activities, commitments and assumptions,  
87 being aware of the limits of knowledge and being mindful that a particular framing of an issue may  
88 not be universally held’<sup>8</sup>. Constant analysis and critique of one’s work among peers is an embedded  
89 practice of rigorous science. However, scientists and engineers typically carry out reflexivity and  
90 other responsible innovation practices ‘behind closed doors’, in the lab, and do not recognise these  
91 processes as ‘reflexivity’ in responsible innovation terms<sup>21</sup>. Opening these conversations up to the  
92 public and acknowledging and listening to other actors can improve the quality of reflexivity.

93 Reflexivity in the realm of autonomous robots in agriculture has mostly come from the user-  
94 centred design (UCD) process. Work to date in this space has recognised that robotic systems  
95 interacting with humans need to undergo an iterative development approach<sup>22</sup>, bringing together  
96 subjective user experience with actual system logs. After including stakeholders and seeking their  
97 information requirements and preferences for autonomous robots through surveys<sup>23</sup>, workshops<sup>24</sup>,  
98 and field experiments<sup>25,26,27</sup>, designers have altered prototypes and design paths to ensure that the  
99 robots work for the user. Yet, this is narrow reflexivity; it involves developers tweaking design  
100 based on user feedback, rather than conducting a fundamental analysis of the assumptions and  
101 values underlying the proposed solution or questioning if agricultural robotics is really the path we  
102 want to take as society. We rarely carry out a deeper form of reflexivity, possibly missing  
103 alternative solutions.

104 The development of and engagement with best practice guidelines, codes of conduct and  
105 international standards is another form of reflexivity that can guide industry to conduct innovation  
106 in a responsible manner, although it is not always clear whether they continue to serve the purpose  
107 of reflexivity once adopted. In Australia, a code of practice for ‘Agricultural Mobile Field  
108 Machinery with Autonomous Functions’ is currently under development to help guide safe  
109 working procedures in the field; this code of practice is intended to hold some legal weight.  
110 International standards for the use of autonomous robots such as ISO 10218 provide norms for  
111 worker safety when collaborating with robots in a structured, industrial environment. In ISO

112 10218, safety aspects such as tactile and pressure sensors, safe maximum speed, proximity sensors,  
113 human detection cameras, and emergency stop are described to ensure the safety of human-robot  
114 collaboration. Other relevant international standards include: ISO 18497 (design principles for  
115 safety with highly automated agricultural machines – operations of robots in-field are not covered)  
116 ; ISO 17757 (for use of autonomous machinery in mining); and ISO/SAE DIS 21434, currently  
117 under development (for cybersecurity in road vehicles). The agricultural industry can glean  
118 insights from these standards, however there is a necessity to further develop agriculture specific  
119 standards and codes of practice that account for human-robot collaboration in flexible,  
120 unstructured environments such as in the field. Understanding how this might be done effectively,  
121 bringing together relevant stakeholders, is an important future area for research.

## 122 **Inclusion**

123 Concepts of ‘inclusion’ are frequently limited to the ‘consideration’ of how stakeholders may be  
124 impacted or react to innovation by a limited group of experts<sup>28</sup>. Genuine inclusion should involve  
125 the participation of a full range of stakeholders through processes. If we do not pursue methods  
126 for the substantive inclusion of a full range of actors, not just the ‘usual suspects’, and do not give  
127 due attention to power inequalities between stakeholders throughout the participatory process, then  
128 we risk reinforcing unequal participation under the guise of inclusivity. It may appear that  
129 increased participation from the start is time-consuming and resource-intensive, but user-centred  
130 design can prevent problems further down the line.

131 Within the development of autonomous robots in agriculture, inclusion has mostly taken the form  
132 of consultation and sometimes collaboration, involving feedback from farmers and farm workers  
133 on the technical side of robot development. Simulation experiments<sup>29,30</sup> and field-based  
134 workshops<sup>23</sup> have allowed farmers and farm workers to test the usability of a technology.  
135 Researchers have used task scenarios, observations, and participant feedback to feed into prototype  
136 development. The social sciences have developed a number of participatory methods that allow  
137 substantive inclusion, such as citizen juries and deliberative workshops, and a greater selection of  
138 these should be brought to bear for inclusion surrounding autonomous agriculture<sup>31</sup>.

139 Stakeholders identified in the PAS 440 Responsible Innovation framework developed for  
140 InnovateUK<sup>10</sup> include co-developers; markets, customers, end-users; regulators and standards

141 bodies; NGOs representing civil society stakeholders and individual citizens likely to be affected.  
142 Beyond the ‘usual suspects’, it is important to engage with ‘harder to reach’ stakeholders. Schillo  
143 and Robinson<sup>28</sup> discuss the importance of engaging with historically marginalized groups. In the  
144 case of autonomous agriculture, this could involve small farmers (who may be pushed out of the  
145 industry by larger farmers with more capacity to adopt and adapt), organic farmers (whose farming  
146 strategy may be more difficult to align with autonomous robots focussed on precision  
147 fertilisation<sup>32</sup>), as well as farm workers (who could lose jobs as they are replaced by robots). Blok<sup>33</sup>  
148 argues that stakeholder inclusion and participation can typically become reductive as it focuses on  
149 the cognitive approach to understanding the perspectives of stakeholders in a self-serving  
150 ‘immunization strategy’, where the goal is to convince others, prevent criticism and portray the  
151 company as having good intentions. We should ultimately ensure that we are undertaking  
152 substantive, rather than tokenistic inclusion.

153 The involvement of stakeholders should not be restricted to the exploration of consequences in  
154 terms of economic opportunity or technology acceptance, but include wider implications and  
155 society’s ‘grand challenges’. To date there are limited examples of this work; Pfeiffer *et al.*<sup>14</sup>  
156 explored public’s opinions of digital farming technology through surveys and spontaneous  
157 associations; Kester *et al.*<sup>13</sup> surveyed farmer’s views of the future of automation on topics such as  
158 perceived value, applications and expectations; and Baxter *et al.*<sup>26</sup> asked fruit pickers questions  
159 regarding the impact of autonomous robots on their job security.

## 160 **Responsiveness**

161 Identifying potential consequences, reflecting on underlying assumptions, values, and problem-  
162 solving processes, and including stakeholders in the innovation process can only lead to  
163 responsible innovation if newly gained insights are enacted upon. Actors should be reactive to new  
164 knowledge and ensure development is iterative. This could be in the form of adapting R&D  
165 projects or early design prototypes based on information feedback from stakeholders. Other actions  
166 that result from new information could include adjusting business models, altering control or  
167 access to software, amending workers contracts and working conditions<sup>3</sup>, or refraining from  
168 developing a certain robot altogether if it is not desired by society.

169 Responsiveness is also important within institutional structures, which should respond promptly  
170 to new information, in policy, law, and regulatory environment. Regulation can restrict innovation  
171 (e.g. GM crops in Europe), efficiency, and competitive advantage, however legal structures will  
172 be important to ensure protection for users of autonomous robots and for clarifying the liability  
173 framework. Hence, regulation can act as both a barrier to and an enabler of adoption. Basu *et al.*<sup>5</sup>  
174 describe the current legal frameworks, regulations and standards that are relevant to the  
175 development of autonomous robots in agriculture, as well as the gaps in areas such as data  
176 protection law, ethics of robot autonomy and artificial intelligence. Similarly to how the European  
177 Union embedded ‘Privacy by Design’ into its General Data Protection Regulation, others are  
178 calling for ‘Equality by Design’ in artificial intelligence (AI) regulation to safeguard against bias  
179 and discrimination that may inadvertently be engrained in technology and machine learning<sup>34</sup>.  
180 There are examples of “technological redlining” as well as technological limitations of  
181 measurement such as unequal object detection or lower quality heart rate measurement for those  
182 with darker skin<sup>34</sup>. A lack of transparency with algorithms, machine learning and AI – the “black  
183 box” problem – can lead to bias and discrimination issues within machine learning to become  
184 further entrenched and replicated. Regulatory oversight of “Equality by Design”<sup>34</sup> is key to ensure  
185 that programmers address any bias and discrimination that may be produced in algorithms,  
186 ultimately ensuring that technology treats users fairly.

## 187 **Conclusion**

188 Addressing the social, legal, and ethical implications of autonomous robots is arguably a greater  
189 challenge than the development of the technology itself. More research is needed to ensure that  
190 anticipation, reflexivity, and inclusion efforts are turned into responsive action on the ground. As  
191 highlighted in this paper, most empirical work for the development of autonomous agriculture has  
192 been focused on the technical aspects of robot operation with some level of inclusion and  
193 reflexivity to ensure improvement of technical performance. Little published work has gone  
194 beyond this to use methods that allow for substantive inclusion and deeper reflexivity on the  
195 subject. Yet, if society decides that autonomous robotics for farming is the way to go, then  
196 practising responsible innovation in their development is vitally important to prevent future  
197 controversy, implementation delays, and negative consequences. Ultimately, the success or failure



198 of autonomous robots in agriculture will not rest on the limits of our technical enterprise, but on  
199 our ability to include society and maturity to listen, learn, and respond.

200

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## 205 **Author information**

### 206 **Affiliations**

207 <sup>1</sup>School of Agriculture, Policy and Development, University of Reading, Earley, Reading, RG6  
208 6EU, UK

209 <sup>2</sup>Lincoln Institute for Agri-Food Technology, University of Lincoln, Riseholme Campus, Lincoln,  
210 LN2 2LG, UK

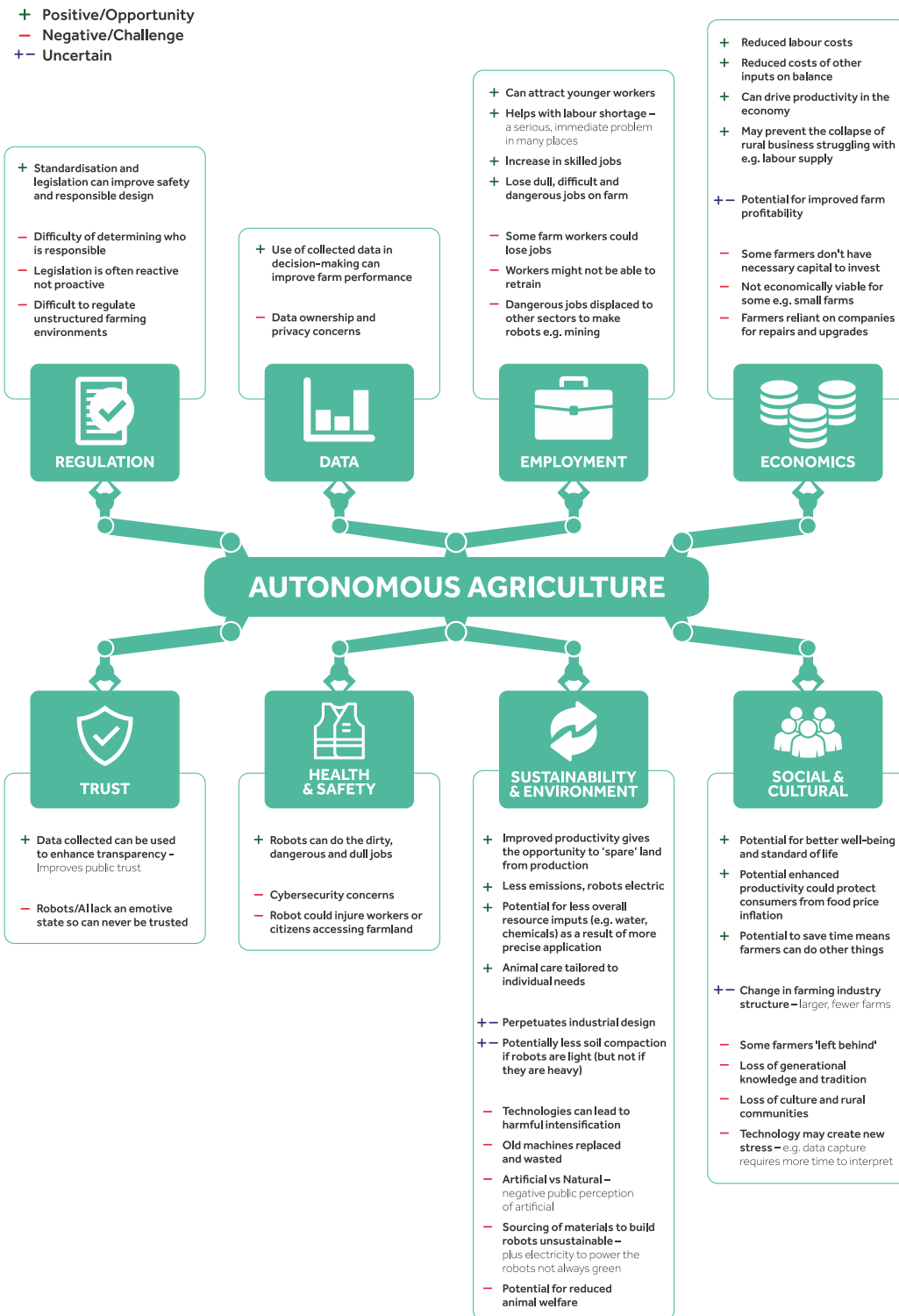
### 211 **Corresponding author**

212 David Christian Rose | [d.c.rose@reading.ac.uk](mailto:d.c.rose@reading.ac.uk)

### 213 **Ethics declaration**

### 214 **Competing interests**

215 The authors declare no competing interests.



216  
 217 **Figure 1: Overview of challenges, opportunities, and potential consequences of autonomous**  
 218 **agriculture.** The signs +, - and +- indicate positive, negative and uncertain consequences,  
 219 respectively. Positive consequences denote opportunities to be harnessed, whereas negative  
 220 consequences denote challenges to be overcome concerning the operationalization, adoption  
 221 and/or deployment of innovations (see Sparrow and Howard<sup>4</sup> and Basu et al.<sup>5</sup> for more detail).

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