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Fair agricultural innovation for a changing climate

Zoë Robaey* and Cristian Timmermann**

* Biotechnology and Society, Delft University of Technology, The Netherlands
** Centro Interdisciplinario de Estudios en Bioética & Instituto de Estudios Internacionales, Universidad de Chile, Chile

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Introduction

Agricultural innovation happens at different scales and through different streams. In the absence of a common global research agenda, decisions on which innovations are brought to existence, and through which methods, are taken with insufficient view on how innovation affects social relations, the environment, and future food production. Mostly, innovations are considered from the standpoint of economic efficiency, particularly in relationship to creating jobs for technology-exporting countries (Zwart, Landeweerd, and van Rooij 2014). Increasingly, however, the realization that innovations cannot be successful on their technical prowess alone calls for a broader investigation (Schomberg 2015, Stilgoe, Owen, and Macnaghten 2013).

When thinking about the role of agricultural innovations in tackling climate change, one recalls, for instance, promises of biotechnology companies to create crops that can adapt food production to changing climate conditions (Saab 2015). For instance, a 2010 policy brief issued by the International Centre for Trade and Sustainable Development and the International Food & Agricultural Trade Policy Council states, “The core challenge of climate change adaptation and mitigation in agriculture is to produce (i) more food, (ii) more efficiently, (iii) under more volatile production conditions, and (iv) with net reductions in GHG emissions from food production and marketing" (Lybbett and Sumner 2010). These types of manifestos tend to assume that innovations are placed in a neutral social environment, and so they ignore crucial ethical considerations, such as historical emissions contribution, importance of heirloom varieties, vast inequalities in purchasing power and scientific capacity, quality of agricultural work, corruption, honesty among seed retailers, and extreme poverty. They also ignore the high diversity of personal motivations and circumstances of actors engaging in innovation.

As extreme weather events are on the rise, it has become clear that we need a broader ethical assessment tool to judge the desirability of agricultural innovation in order to make sure food production becomes resilient to the added environmental and social stress factors caused by climate change (McMichael 2017). Moreover, food is a basic need and its production requires continuous innovation to maintain harvest yields. Given the importance of food production, how are decisions made regarding agricultural innovations?

Typical assessments for new technologies involve risk assessments, environmental impact assessments, socio-economic assessments, and participatory technology assessments. These are dictated by the legal landscape where the innovation is developed and introduced. Assessments are meant to point to problems with an innovation and to make suggestions to address these issues. The problem with these assessments is that they typically consider issues after an innovation is developed and is about to be introduced, leaving insufficient room for outsiders to shape the technology (Beyleveld and Jianjun 2017). This exclusion raises several issues regarding fairness.

Our aim in this chapter is to address this lack of attention concerning fairness by focusing on three major stages of agricultural innovation: goal setting, research and development, and empowerment strategies. To do this, we analyze two approaches for an ethical assessment of innovation systems: one using the insights from Responsible Research and Innovation (RRI) and the other applying theories of justice (see Table 1). To compare both perspectives, we show their contributions to addressing five major social challenges we have identified and which are manifest in the agricultural concerns that are worsened by climate change: (i) availability, (ii) accessibility, (iii) participation in science, (iv) arbitration and rectification measures, and (v) long-term sustainability.

By using two distinct ethical approaches (RRI and theories of justice) we build an ethical assessment framework that has the capacity to identify a wider set of social justice challenges, and combines the strength of both approaches in a single assessment tool. By extending the focus beyond the innovator, we place a strong emphasis on issues of empowerment for our ethical assessment. The benefit of this approach is that the assessment does not stop once the agricultural innovation is delivered to the market, instead, it is taken up by users. Users then become empowered to continue assessing and innovating, thereby reinforcing the ethical assessment and contributing to scientific advancement. Through this dual ethical framework, we build an ethical assessment tool that is better tailored to identify and address the abovementioned social challenges as they arise in agricultural innovations for climate change.

Why is Fairness a Special Concern for Innovation in a Changing Climate?

Climate change obliges humanity to speed up the rate of agricultural innovation and to redirect the course of innovation towards addressing new vulnerabilities. However, the necessity to speed up innovation due to climate change is not morally neutral. The countries of the Global North have made a far greater per capita contribution to climate change than the countries of the Global South (McMichael 2017). Yet, the effects of climate change vary on the different regions of the world. While the harvest yields will increase in some parts of Canada and Russia, areas near river deltas and in the tropics are already suffering major losses due to the salinization of waterways and droughts (Cline 2007). These factors underline the need for a normative assessment of climate change adaptation innovations. While making an invention publicly available can be generally considered as providing a public good, the provision of inventions to adapt to climate change by the Global North has also a reparatory character (Gosseries 2004).[2] The failure of the Global North to provide adequate compensation for the harms asserted by climate change makes the commercialization of climate change adaptation technologies particularly problematic (Biddle 2016).

Nowadays, adaptation is necessary as climate change mitigation is no longer sufficient due to the failure to curb emissions (McMichael 2017). This raises major global justice issues. While seed companies and biotechnology laboratories in the Global North are developing seeds that are ready to adapt to the new environmental conditions, the smallholders in the Global South

[2] For criticism, see Meyer and Roser (2010)

have practiced and developed a variety of farming methods that allow the capture of large amounts of carbon by making effective use of the synergies of different plant associations and plant-animal interactions (Timmermann and Félix 2015a). An excessive delay to take action by the Global North may cause ecological disruptions that will impede smallholders to use the varieties they know how to use and to stimulate symbiotic relationships. Ultimately, because of these disruptions smallholders might be obliged to opt for a technology they did not produce, which could lead to technological dependency.

Together, this means that companies in the Global North might be in a position to exploit climate vulnerable markets by selling climate change adaptation technologies is not morally neutral, and guidelines need to address this unfair advantage.

Nowadays countries of the Global North are not only carrying much less of the burden of climate change compared to countries in the tropical region, but a few countries in the Global North are even benefiting economically by selling agricultural innovation to adapt to the new climatic conditions they created collectively, for example, by marketing varieties that have a higher salinity tolerance or more resistance to droughts.

Innovation: Goals, Process, and Empowerment

Historically, the idea of innovation has not always been a positive one. Tracing the Western history of the concept since antiquity, Benoît Godin finds that while in today's societies, innovation is seen as good, even as necessary, it was not always the case (Godin 2015). In Ancient Greece, concepts akin to innovation were considered the disruption of a working order. He writes, "Innovation is a concept for inducing actions oriented toward practicality" (Godin 2014, 53). Nowadays, innovation is intricately linked to technology.

Innovation is commonly recognized by means of patents. The general rationale for patents is to grant the inventor a right to exclude others from the use of the invention in order to gain an economic advantage, and be able to recover her investments in research and development. Traditionally this approach has been seen as a driver for innovation. Patents, however, bring a number of social problems, such as hindering poorer people's access to the fruits of innovation and fostering a secretive research environment, which is not necessary for stimulating innovation, especially when considering other models such as open innovation (Bartling and Friesike 2014, Gupta et al. 2016, Koepsell 2016). In other words, patents are a tool for controlling access to knowledge about an invention, its functioning, and for blocking the possibility of making further modifications to the innovation. These restrictions hinder taking active moral responsibility for the innovation because of the patent restrictions limiting the user's intervention on the technology itself (Robaey 2016b).

If an innovation is a practical and technical solution to a problem, then, under the circumstances of a changing climate, access to these innovations and their knowledge should be key. However, when it comes to knowledge, different streams of agricultural innovations present different ways of concentrating, sometimes withholding, and distributing knowledge. In order to be morally responsible for risks of technologies, as well as to be able to properly assess them, knowledge is an important condition (Robaey 2016b, van de Poel et al. 2012).

Knowledge is not only about responsibility but also about justice, in several dimensions. For the purpose of our analysis, we distinguish between three components of innovation that raise issues of knowledge, responsibility, and justice and are found at different stages of innovation: the definition of goals at the beginning, the process of innovating (research and development), and empowerment, after the innovation is delivered to society.

The *goal* of an innovation refers to what we want to achieve with the innovation. If one defines the problem for which a solution is sought, then one also decides for others what the problem entails and how to solve it. We can ask: what problem does an innovation solve? How was it defined and who defined it? And, for whom does it solve a problem, i.e. who is meant to benefit from this innovation?

The *process* of innovating refers to how we produce, use, and share knowledge. This process needs, as much as possible, to be inclusive, so the system can harvest and integrate ideas from any interested party. Injustice occurs if you are able to meaningfully contribute but are not allowed to (Timmermann and Félix 2015b). The process should therefore consider different types of experts. Ideally, an innovation system should be able to incorporate such things systematically. In the process of innovation, we ask who has access to what knowledge about the agricultural innovation? Is the innovation the result of participatory processes?

The level of *empowerment* that an innovation may stimulate depends on both its design and contractual arrangements. Empowerment implies that an innovation is not finished at the end of the innovation process – it continuously welcomes and encourages user innovation. Therefore, it is crucial that during and after the innovation process, means to participate are facilitated. While readers might be more familiar with stakeholder participation during the process of innovation, its extension beyond this stage is often not considered. Technologies are usually designed with one specific function that links the object to its goal. This can lead to technologies becoming a black-box to the user for the sake of efficiency. Yet the contrary is possible: the design and contractual arrangements of an innovation may not only allow the user to use the technology in other ways than was foreseen, but actually encourage user experimentation. All in all, empowerment relies on having sufficient access and being able to create a range of action with a given technology (Robaey 2016a).

From the Field to the Laboratory and Back: Innovation in Agriculture

Nature is continuously evolving to adapt to new threats, challenges, and opportunities, as living organisms search for survival and propagation. Agriculture, as the most extensive human intervention in nature, also has to adapt to these changes (Mazoyer and Roudart 2006), which makes innovation mandatory to improve food production and to maintain current production levels.

In the field, innovations are often not implemented in a strictly prescribed form: many farmers adapt and use innovations to make best use of available resources or meet regulations. For example, much of organic agriculture continues to use the principles of conventional agriculture but replaces fertilizers and pesticides with the components permitted by organic certifiers (Rosset and Altieri 1997). The differences in risk adversity among farmers, together with the existence of crop insurance programs, intellectual property restrictions, type and level of education, and availability of financial resources, affects the choice and usage of innovation. People naturally avoid novel or unfamiliar procedures if they have too much to lose.

For the purpose of this paper, we differentiate between three emblematic streams of innovation destined to improve crop production and reduce the ecological footprint of agriculture: conventional agriculture, precision agriculture, and agroecology. These three innovation streams differentiate not only in their research goals, but also in their research processes and the way they empower users to keep innovating.

Conventional agriculture is the most propagated form of food production among large-scale farmers. The goal is to increase yields of key staple crops and reduce labor inputs. This farming method is characterized by the use of improved seed varieties, externally produced pesticides and fertilizers, and heavy machinery. Conventional agriculture is characterized by using standardized solutions, or use guides (Robaey 2016b), thereby reducing the risk of losses due to absenteeism or the unavailability of a skilled labor force (Timmermann and Félix 2015b). Little innovation is done on farms themselves, as much of the research and development is outsourced to specialized laboratories and industry, and requires biotechnological, chemical, and mechanical knowledge. Knowledge is produced and exchanged in academia, public institutions, private-public partnerships, and industry, but its full access is restricted by the use of intellectual property rights (Robaey 2016b). This applies both to conventionally bred crops and genetically modified ones. This innovation stream often uses controlled test sites or model organisms in the knowledge acquisition process. Typically, user innovation in this stream is limited as indicated in contracts, use guides, and intellectual property law.

Precision agriculture seeks to overcome the shortcomings of conventional agriculture and strive for sustainability by using forefront technology (Lindblom et al. 2017). For instance, sensors and the use of satellites for detailed mapping help avoid the use of excessive amounts of agrochemicals, thereby reducing contamination and the destruction of non-target organisms (Gebbers and Adamchuk 2010). In general, innovation is done in specialized industry sectors and research institutes. However, there is a key difference with conventional agriculture. The high technologization of agriculture demands a skilled labor force that is able to read the instruments on site and adjust inputs. The use of information technology allows for the integration of users' data and observations back into the innovation system. Whether the users are delegated to being a mere data collector or an autonomous user of such data depends on the technology design. Different possible scenarios can therefore occur in terms of user innovation.

Agroecology seeks to develop farming systems that are self-sufficient by closing ecological cycles and producing the necessary inputs to allow an ecological intensification of food production. As a principle-based approach, farmers need to learn how to use biodiversity to their advantage, mimic the functioning of local ecosystems for food production, and build long-term synergies between the living organisms of the farm and the surrounding social and natural environment (Altieri, Nicholls, and Montalba 2017, Gómez Echeverri, Ríos Osorio, and Eschenhagen Durán 2017). Farmers gain knowledge as they experiment with plant associations, composting methods and biological fertilizers, and observe how and if these changes contribute to the closing of nutrient cycling, the maintenance of moisture levels, and the improvement of harvests and soils. The knowledge gained on farms is often exchanged among farmers, yet efforts are needed to network farmers with other farmers and ecologists in distant locations to improve knowledge exchange. Here, given that innovations rely on practices and experimentation, user innovation is increased.

Given this brief characterization of the three streams of agricultural innovation, we now move on to analyze how innovations address key social challenges and meet the different criteria of fairness.

What Makes an Innovation Fair?

Responsible Research and Innovation

Responsible research and innovation (RRI) grew out of a European research agenda and is a concept that has gained traction in academia, industry, and policy (Stilgoe, Owen, and Macnaghten 2013, Schomberg 2015), and is slowly gaining interests in other parts of the world (Macnaghten et al. 2014). Von Schomberg defines RRI as, "a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)" (2012, 49).

This approach suggests that many social issues can be taken up and addressed during the design phase, before a technology is ‘released’ in society. This is realized through a process centered on the innovator. In RRI, the innovator must carry out a range of activities around the four pillars of RRI: anticipation, inclusion, reflexivity and responsiveness (Stilgoe, Owen, and Macnaghten 2013). For instance, an innovator must anticipate the broader societal and environmental effects of its innovation. This process needs to include stakeholders to gain a more accurate picture of the possible effects of the invention. After gathering this information, the innovator is invited to reflect on their work, and should respond to social and environmental concerns. RRI suggests that carrying out these activities will lead to more responsible innovations.

As a process, RRI connects the formulation of goal definition to the process of innovation. The process of RRI, and its creation of activities and spaces of inclusion, allow for the anticipation of how a technology might impact certain users or groups. In addition, reflection and responsiveness come in as a sort of virtual iteration where changes can be made to the technology, or to the institutions around the technology in order to respond to identified concerns. For instance, a technical change could be in the choice of an affordable material for a design, so that it could be reproduced at low-costs. A non-technical change would be choosing an open license instead of a patent so that the innovation would be more accessible. In other words, under RRI, an innovation comes to solve a problem *for* a group.

As a concept, we can understand RRI as a notion of forward-looking moral responsibility, i.e. moral responsibility to fulfill certain desired outcomes, duties, or virtues (van de Poel 2011). This suggests that a fair innovation according to RRI is the result of participatory processes and a redefinition of goals. However, fairness is not necessarily a goal of RRI in itself, as it will depend on the stakeholders involved. In the same manner, the acceptability, sustainability and social desirability of the innovation will also be dependent on the extent of participatory activities. Identifying and addressing social challenges is therefore dependent on those who manage the process of participation, how they ask questions, and what space they leave for discussion. Also, the innovator is most often in the private sector or at a university research center, so setting the goals and deciding on the process is necessarily constrained by these settings.

Depending on its depth, any given activity runs the risk of remaining superficial and not actually leading to changes in the goals or design (De Hoop, Pols, and Romijn 2016). Yet by having a starting point for innovation with industrial agendas, RRI, “may lead to silencing of critical, ‘rogue’ voices and outsiders in the debate, due to increased dependency on private sector parties and policy agendas” (Zwart, Landeweerd, and van Rooij 2014, 17). By working closely with industry RRI gets additional insights and accuracy, but may lose its ability to argue for radical shifts in research agendas and marketing practices.

Theories of Justice

Complementing RRI with theories of justice might provide for a further elaboration of the concept of fair innovation. As we will see, being inclusive, responsive, reflexive, and anticipating impact are only part of what constitutes a fair innovation. We need points of reference, or ethical guidelines, that are independent of processes like RRI, in order to guide it. Towards this end, we can identify five dimensions of social justice that affect fair agricultural innovations. These are distributive justice, commutative justice (i.e. justice in transactions), contributive justice, restorative justice, and intergenerational justice (Timmermann forthcoming). Table 1 summarizes the observations that the two theoretical approaches contribute to the assessment of the five social challenges.

Distributive Justice

Distributive justice is generally concerned with the fair distribution of a good or set of goods. There are different ways we can interpret how distributive justice applies to innovation. One way is to argue that research attention is a good to be distributed, and therefore should be distributed according to principles of justice, for example, by aligning the distribution of research attention to the social goal of reducing suffering. This would demand research attention in proportion to the urgency of the needs of people and the environment. In the context of food and climate change, this translates to doing more research on adapting tropical agriculture to climate change, on developing appropriate technologies to reduce the carbon footprint of agriculture, and studying methods to capture carbon in farm lands as a climate change mitigation strategy. Conversely, it condemns the spending of large amounts of resources in ornamental plants and minor aesthetic attributes. This could mean focusing more on flood resistant varieties, and less on selecting for shape or color. This dimension of justice provides a base to formulate ethical guidelines for defining the goals of innovation.

Commutative Justice

Principles of commutative justice (or justice in transactions) demand that exchanges involve informed consent, avoid causing harm, and are not exploitative or usurious. Market practices such as intentionally deceiving buyers or sellers are condemned. And, principles of commutative justice demand that prices should not be set according to what the market will bear, but instead to recoup necessary costs and to earn a reasonable profit. For instance, a flood resistant crop could become extremely necessary; it would be important to have justice in transactions in order to avoid a black market selling counterfeited seeds, or inflated prices. This dimension of justice is important in defining ethical guidelines for the goal of innovation, since a socially sensitive design can make sure that innovations do not incorporate superfluous features that inflate prices and thus limit access.

Contributive Justice

The aim of contributive justice is to create the conditions where people are willing and able to contribute to society. To make innovation fair, this notion of justice demands an increase in participation opportunities, as well as more diversified participation opportunities that stand in meaningful and respectful relation to others. If we continue with the example of flood resistant varieties, contributive justice demands that this variety be not developed outside of its context and the farmers who plant it. This dimension of justice provides criteria to formulate ethical guidelines for defining how an innovation can empower social groups by providing sufficient access.

Restorative Justice

This idea of justice seeks to restore good social relationships after an injustice or misunderstanding. Innovation, as a social enterprise of considerable magnitude, will inevitably give rise to problems that will demand penalization mechanisms and proper reconciliation measures. Living in a world with common threats, such as pathogens and climate change, requires good relations to be able to work together towards solutions and contention strategies.

This dimension of justice is relevant to providing ethical guidelines for the process of innovation, so that future cooperation is not hampered by injustices committed during research and development.

Intergenerational Justice

This last dimension of social justice condemns the decisions of earlier generations that make it difficult future generation to live a flourishing life. This demands that innovators offer adequate compensation for the destruction of exhaustible resources that the use of their innovations directly or indirectly causes. For instance, a new crop might provide benefits in the immediate future at the cost of rapid soil erosion. What measures will be taken to ensure the quality of soils for future generations? This dimension of justice can serve as an ethical guideline for thinking about the sustainability goals of innovation.

Application to Social Challenges

For each social challenge (listed below), we can see how RRI and the different dimensions of social justice can help formulate guidelines for fair agricultural innovations in the context of climate change when it comes to the goals, processes, and opportunities for empowerment surrounding these innovations. Table 2 summarizes the ethical guidelines proposed for each social challenge and identifies the part of the innovation process to which they matter.

Availability is linked to the process and the goal of an innovation, mostly because availability is dependent on early decisions in the innovation process. From an RRI perspective, reflexivity can provide the space to make design choices that would increase availability. From the perspective of theories of distributive justice, reflection should create awareness of problems, which demand priority for social challenges. The guideline for addressing availability is therefore: in the definition of the goal and in the process resulting thereof, innovators should think not only about the availability of their innovation, but also about the context and the scope of their innovation, as well as whether it is addressing issues of need. Dealing with climate change requires prioritizing pressing issues such as adaptation or mitigation innovations.

Accessibility is important both at the beginning of innovation when decisions are made about the design, and towards the end, when strategies are made to improve inclusion and participation to allow empowerment. From the perspective of theories of commutative justice, attention should be paid to ensure just transactions between innovators and farmers. The guideline for addressing accessibility is, therefore, a result of participatory actions before and after the innovation process, which derives from an RRI perspective; innovators and other actors should create a responsive agreement that creates just transactions. The adoption of agricultural innovations for climate change will depend on how distribution channels are set up.

Participation in science and governance is linked to the process, which, if responsive, will relate to a redefinition of goals. These stem from both theories of contributive justice as well as the inclusive and responsive aspects of RRI. This requires including different voices in the process, including traditionally underrepresented ones. The importance of considering these various voices is primordial for fairness – this is a requirement for both participation in innovation governance and inventive endeavors. Here, the guidelines for addressing participation are the inclusion of as many voices as possible, especially from affected areas, the explication of choices made to their consideration in a democratic way, and the creation of opportunities to participate after the innovation is 'released' in society.

Arbitration concerns the process of fair innovations. This has to do with the limited range of action of innovators, meaning that not all the decisions are in their hands. Here, from an RRI perspective, responsiveness is not limited to them. Instead, institutional agreements, such as decisions about a Global Climate Fund, or how to address issues of restorative justice, must also be responsive. For instance, rising sea levels will affect many countries that will need a range of innovations to adapt. Agreements regarding those agricultural innovations should look to support those facing imminent threats in order to avoid exploitative sales practices.

Last but not least, *long term-sustainability* is essential to the process of innovation, and can also help redefine the goals of innovation. As a guidepost for fair innovation, sustainability requires a process of anticipation from an RRI perspective, where activities are carried out by and with different actors, including innovators, with regard to intergenerational justice issues. This social challenge is inextricably linked to society's realization that we must deal with climate change to not overburden future generations.

Table 1: Defining fairness from between RRI and Theories of Justice

5 key social challenges	**Responsible Research and Innovation**	**Theories of justice**
Availability	Reflexivity (self-scrutiny, or institutionalized scrutiny, e.g. social responsibility to assist)	Fair distribution of research attention
Accessibility	Responsiveness (fairness)	Just transactions
Participation in science and governance	Inclusion (a dialogue with diverging voices) Participatory decision-making	As a social mandate to include in innovation processes (open science) Condemns exclusion in democratic processes
Arbitration	Limited to the range of action of innovators Responsiveness (capacity to change)	Everyone needs to commit to principles of social justice to avoid systemic deprivation Address historical injustices
Long-term sustainability	Anticipation (capacity of foresight)	Fair shares for each generation

Table 2: Guidelines for fair agricultural innovations

5 key social challenges	**Innovation stage**	**Guidelines**

Availability	Process and goal	- Design choices for availability - Direction of innovation: does it respond to socially relevant needs?
Accessibility	Goal and empowerment	- Responsive agreements for just transactions
Participation in science and governance	Empowerment	- Inclusion of all actors - Democratic process - Explication of decisions
Arbitration	Process	- Support those facing imminent threats in order to ensure fair innovations.
Long-term sustainability	Process and goal	- Anticipation activities are carried out by and with different actors, including innovators, with regard to intergenerational issues

Assessing Fairness of Agricultural Innovation

We see our ethical framework as a procedural approach for fair innovation, incorporating issues of social justice. Here, we briefly apply our framework to the three innovation streams.

Conventional Agriculture

Availability: Under a proprietary science regime, where market demands set research agendas, research attention may not be granted to the needs of the poor. In agriculture, this means that the regions with the largest numbers of hungry people will continuously remain underserved. Well-funded public research institutes are needed to make technological solutions available and accessible to this group. This is a huge issue for social justice as conventional agriculture foresees that the objects of innovation have to be acquired, primarily by farmers purchasing these from innovators and suppliers (Thompson 2009).

Accessibility: Technologies in this stream are sold or licensed under contracts, which limits their access. For instance, in the case of genetically modified seeds, contracts typically dictate the extent of use, often not allowing farmers to save seeds or experiment (Robaey 2016b). Different choices can be made for accessibility in this stream. They can be licensed under contracts and farmers can be prevented from saving seeds; another choice is to give them freely, allowing wider access. Taking accessibility seriously can empower farmers.

Participation in science and governance: The nature and existence of intellectual property regimes make participation in science and science governance particularly difficult, unless the patent holders welcome participation. Intellectual property rights can restrict access to innovation and meaningful participation.

Arbitration: Arbitration is extremely difficult and costly, as when insufficient knowledge is publicly available. Involved parties will have to come to a consensus and settle disputes. Here special care needs to be taken that specialists, such as lawyers and scientists, are not exploiting weaker negotiation partners.

Long-term sustainability: Finally, the weak record conventional agriculture has in internalizing negative externalities makes this form of food production inadequate in terms of long-term sustainability (Tittonell et al. 2016). Innovation has to take into account the full costs of food production, including carbon footprints, fossil fuel dependency, and pollution.

Precision Agriculture

Availability: In terms of availability, many of the sensor and ICT technologies that precision agriculture uses need not be context specific. The challenge lies in social and infrastructural limitations, as these technologies require a skilled labor force (Aubert, Schroeder, and Grimaudo 2012) and easy access to technical service centers.

Accessibility: By relying on vanguard technology, precision agriculture continuously faces struggles with accessibility. Who can purchase and operate these technologies? But also, even if affordable, who owns the data and who has the power to make decisions about it? Access to data has the potential to empower farmers (Fountas et al. 2005), by helping them make better decisions for the management of their farm. However, access and ownership of data can also lead to different corporate decisions by those who collect the data (Bronson and Knezevic 2016). Such corporate decisions could threaten access to certain essential technologies in view of increased profit. For instance, learning about farming practices and behavior can inform industrial decisions on pricing for their services and technologies.

Participation in science and governance: The use of information technologies allows, in principle, a higher level of participation, both in scientific work and in governance. However, allowing participation needs to be in the interest of technology developers. As far as participation in the development and governance of equipment goes, we may find the same hurdles as with conventional agriculture, due to intellectual property restrictions.

Arbitration: The case with arbitration is also very similar to the one with conventional agriculture. However, we speculate that as more data produced by precision agriculture becomes publicly available, the more likely it is to be used by civil society and government agencies to make comparisons and assert pressures on farmers.

Long-term sustainability: In terms of long-term sustainability, the very aim of precision agriculture is to use more technology to reduce the environmental footprint. Yet, it is a costly variant, making its expansion slow and, for many, a luxury. This may lead to a social justice issue, as richer regions will be able to grasp the benefits of such scientific advancement at a much greater scale than poorer regions.

Agroecology

Availability: Agroecology offers a wide range of innovative solutions that are particularly well-suited for the tropical environment, as it draws heavily on the methods and knowledge that indigenous communities have used to build resilient farming systems in these latitudes. Studies that apply agroecological principles to temperate climates and urban settings are much more recent and therefore more uncommon.

Accessibility: While offering innovations that depend largely on local resources, economic incentives to diffuse and test agroecological innovations are insufficient. As a result, most agroecological innovations are underused, despite being freely accessible.

Participation in science and governance: As a principle-based approach, agroecology foresees that innovations be adapted to local circumstances, and encourages participation in its development. This requires tacit knowledge, the ability to apply principles, and good observation skills (Timmermann and Félix 2015b). Unfortunately, even though farmers' organizations are very large, the modularity of most agroecological farms does not provide a compulsory platform where innovation governance issues are discussed. Also of concern is that non-farming citizens will rarely be involved.

Arbitration: As agroecology seeks to eliminate the use of agrochemicals and to live in harmony with adjacent ecosystems, it perceives itself as non-intrusive, working towards avoiding annoyances rather than establishing mechanisms to settle them. By not claiming exclusivity and welcoming a farmer-to-farmer knowledge exchange, agroecologists have treated traditional knowledge as common heritage, a practice that may lead to disputes, and over which no commonly agreed arbitration principles exists.

Long-term sustainability: Agroecology strongly embraces long-term sustainability, both socially and environmentally (Altieri, Nicholls, and Montalba 2017). An example of a noteworthy innovation is the use of termites to recover deteriorated soils. By filling small holes with woody scrubs farmers attract termites that forage on the woody amendments, thereby allowing water and air to come in the lower layers of the soil which ultimately contributes to their restoration and thus allows to grow food again in arid areas (Félix et al. 2018). Here the benefits of the farming systems are fully acknowledged, including the benefits to ecosystem services and farm workers' health.

In sum, each of the three streams of agricultural innovations presents room for improvement to varying degrees concerning fairness. We see this as an opportunity to innovate for social justice, regardless of technological preferences.

Conclusion

Climate change presents serious challenges to the environment and food systems. As a result, there is an increasing need for agricultural innovation in the regions that count the highest number of hungry people, which are also the regions most underserved with regard to agricultural innovation. Moreover, the regions with the largest number of hungry people have historically benefited the least from the past liberty to emit greenhouse gases. These issues are morally relevant and require an ethical assessment of agricultural innovations. Due to the dire conditions climate change is creating and their unequal impacts, this ethical assessment needs to address five major social challenges: accessibility, availability, participation in science and governance, arbitration mechanisms, and long-term sustainability. Complicating the ethical assessment is the diversity of agricultural innovations: conventional agriculture, precision agriculture, and agroecology.

How do we assess agricultural innovation in light of these social challenges? How can we support addressing the shortcomings of the agricultural innovation systems? We suggest an assessment using a double ethical framework of RRI and theories of justice. The formulated guidelines (Table 2) address a specific social challenge and a specific component of innovation in relation to its goals, processes, and empowerment.

After a brief and general assessment of each agricultural innovation stream, we have identified the following overarching shortcomings: (1) the need to improve the availability of agricultural innovation to adapt to climate change for the areas where they are most needed, (2) the need to make sure that these innovations are accessible for those who urgently need them, and that users are empowered, without neglecting regions most vulnerable to climate change, (3) the need to improve participation in agricultural innovation, especially in the context where those innovations are meant to be used, (4) the need to enforce strong arbitration measures in the innovation system, by placing a special consideration to the problem of commercial exploitation of climate vulnerable countries, and (5) the need to work towards long-term sustainability by incorporating both climate change adaptation and mitigation strategies.

Further research would help to pinpoint specifically where responsibilities lie for each of these components of innovation and social challenges. For now, the guidelines we suggest can be used either to assess recent innovations and make adjustments, or to set up a process with clear guideposts that would result in fairer agricultural innovations. Ultimately, these guidelines aim to redress the unequal balances in access to knowledge, participation in innovation decisions, and the governance of these innovations.

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