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A cooperative governance network for crop genome editing

The success of governance networks in other areas could help to find common ground for applying genome editing in agriculture

Nicholas R Jordan[1,†], Kevin M Dorn[2,†], Timothy M Smith[3], Katie E Wolf[4], Patrick M Ewing[1], Adria L Fernandez[1], Bryan C Runck[5], Alwyn Williams[1], You Lu[6] & Jennifer Kuzma[7]

Emerging biotechnologies, such as genome editing, may revolutionize agricultural development through rapid and precise genetic manipulation of a wide range of crop traits without having to transfer foreign DNA [1]. If so, these new genetic-engineering (GE) technologies can help to generate crop varieties to address critical challenges in agricultural development, such as climate resilience or nutrient uptake, or diet-related problems in nutrition and health in poorer countries. However, society must also be protected from potential harmful effects of genetically manipulated crops on the environment, human health, or social welfare. Governance of these crops must therefore balance agricultural developments with risk assessment and prevention of potential harm.

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Presently, genome editing is being used to improve the characteristics of major crop plants, but the governance of crop genome editing is poorly defined and developed. Influential groups concerned with the potential hazards of such crops view this situation with growing alarm, which has created tensions with the academic community and regulatory agencies [2]. Both the USA and the European Commission are currently reviewing the governance of crops produced by genome editing and other new technologies. On the US side, at least, the review process appears unlikely to result in governance approaches that will satisfy parties that are concerned with either over- or under-regulation of such crops, and tension and conflicts about them are likely to heighten.

We propose an alternative approach for governance of these crops that may help to defuse tensions and enable exploration of genome editing technologies' potential while protecting society from harm: a cooperative governance network. Such networks have performed well in comparable situations by defining broadly acceptable sustainability criteria for commercial products and processes and establishing institutional capacity for adaptive governance and enforcement in situations where government-based regulation is neither established nor sufficient [3].

Cooperative governance networks

In cooperative governance networks, different societal sectors—private companies, non-profit organizations, researchers, and governmental agencies—cooperate to manage complex issues related to particular products and processes. Such networks devise and enforce rules for members, who voluntarily consent to be governed. A network's legitimacy and authority to govern stems from several factors: participation of reputable key stakeholders; heterogeneity of represented interests; and internal rule-making processes and outcomes that seek to accommodate the different interests of its participants. Importantly, such networks, if they include influential private interests and reputable civil actors, can exert influence even on actors that do not participate [3].

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In a number of cases—governance of coffee, fisheries, electronics, or industrial cleaning products—cooperative governance networks have emerged, competing or consolidating over time, and often converging toward a common sustainability

1 Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN, USA. E-mail: jorda020@umn.edu
2 Department of Plant Pathology, Kansas State University, Manhattan, KS, USA
3 Department of Bioproducts & Biosystems Engineering and Institute on the Environment, University of Minnesota, St. Paul, MN, USA
4 Humphrey School of Public Affairs, University of Minnesota, St. Paul, MN, USA
5 Department of Geography, Environment and Society, University of Minnesota, St. Paul, MN, USA
6 Department of Plant and Microbial Biology, University of Minnesota, St. Paul, MN, USA
7 Genetic Engineering and Society Center and School of Public and International Affairs, North Carolina State University, Raleigh, NC, USA
†These authors contributed equally to this work
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standard. Through this dynamic process, accepted norms and practices emerge, evolve, and become codified. For example, several cooperative governance networks, organized by civil-society organizations or the private sector, have defined sustainability standards for producing coffee that address issues such as ecological conservation, community development, and fair prices for farmers. Organic (1978), Fair trade (1988), SAN/Rainforest Alliance (1995), and Bird Friendly (1996) coffee standards have largely been created by social and environmental organizations, whereas UTZ Certified (1997), Nespresso AAA (2003), and Starbucks C.A.F.E. (2004) are examples of company-led initiatives. Over time, these networks have converged around surprisingly similar goals and rhetoric for sustainable coffee. Networks organized by the private sector have typically placed more emphasis on economic and quality dimensions of performance [4], but all networks have maintained strong and visible support from advocacy and academic organizations: for instance, Nestlé-Nespresso AAA Sustainable Quality Program partners with organizations such as the International Union for Conservation of Nature (IUCN), Fair Labor Association (FLA), and Fair-trade International. Within networks, these advocacy and academic organizations have maintained independence, thereby reserving the right to publicly criticize network performance, and their continued affiliation suggests that these organizations view network participation as a means to advance their sustainability goals. In addition, UTZ and Rainforest Alliance recently announced their intentions to merge later this year in an effort to better coordinate innovations, streamline the certification process, and consolidate market power.

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Assessments of leading sustainability governance networks for organic farming (IFOAM), fair trade (FLO), sustainable agriculture (RA-SAN), sustainable forestry (FSC & FEFC), sustainable fisheries (MSC) have found evidence of beneficial environmental effects, through higher levels of adoption and implementation rates of management practices consistent with sustainability criteria [4]. For social and economic aspects of sustainability, anecdotal and competitive claims of positive impacts are common: enhancements in income, market access, working and living conditions, and relationships with the wider community. However, there is little rigorous assessment of these effects, due to methodological challenges and limited research resources.

A cooperative governance network for genome editing

Cooperative governance networks have not yet emerged for the application of genetic engineering or synthetic biology in food and agriculture. Several precursor projects have been initiated, but none led to standard or certification schemes. Industry groups, and environmental and consumer NGOs participated in a two-year project on governance of GMOs in the USA in the early 2000s to develop consensus recommendations on regulatory policy and programs. This goal was not achieved, but the participants did agree on general principles, outcomes, and features of a regulatory system for agricultural biotechnology.

"... cooperative governance networks are not intended to enlist all interested stakeholders, and they cannot address all societal objections to GM technologies."

Given that other governance networks have been successful in establishing standards, rules, and procedures, we propose such an experimental network to address the current tensions around genome-edited crops by developing governance structures to explore their potential role in agriculture, and manage associated risks for society. It would be constituted of voluntary representatives from three core sectors: crop-breeding companies and academic institutions, capital investors, and organizations that represent a broad range of interests in agricultural development, including governmental agencies, industry and research organizations, and NGOs concerned with environmental, human health, and social-welfare issues. The network will exert power by guiding the flow of capital to crop breeders, based on assessments of genome-edited crops that cover a wide range of cultural, social, economic and scientific perspectives, and knowledge sources.

"Given the explosive rate of innovation in biotechnologies, new approaches to governing their exploration and evaluation are urgently needed."

Initially, the network could carry out its assessments using methods from so-called responsible innovation [5] and similar techniques. One relevant method here is narrative-based foresight analysis, which constructs scenarios of broad adoption of genome-edited crops to assess and evaluate their social, environmental, economic, ethical and cultural effects. Such analyses have proven useful in addressing a range of complex and polarizing issues [6]. For example, a recent application of foresight analysis to crop development showed that expected sustainability benefits of wide adoption of new high-yield oil palm varieties might be largely negated by previously unanticipated market dynamics. Responsible innovation techniques also emphasize anticipatory and pluralistic elucidation of ethical questions about emerging innovations, as applied recently to potential applications of genome editing for *de novo* domestication of wild plant species.

All core sectors—investors, breeders, and agricultural organizations as noted above—would have strong incentives to participate in such assessments. Investors and breeding entrepreneurs will be very interested in the ability of the network to "de-risk" novel applications of genome editing in crop plants. By closely coupling crop development with broad-based social and environmental assessment, the network will reduce the risk for investors and breeders to produce crop varieties only to see these attacked by influential NGOs. In particular, such de-risking is strongly in the interest of a growing number of so-called impact investors that are concerned with sustainability issues, societal impacts, and broad societal acceptance, in addition to financial returns. These include philanthropies such as the Gates and Buffett Foundations, wealthy individuals, and pension funds. The rapidly growing number of breeding companies that use new biotechnologies also have a strong incentive to participate so as to access funding, because most of these entrepreneurs are small firms that are likely to be capital-limited.

Other organizations with different perspectives on genome editing and similar technologies would also have strong incentives to participate in a cooperative governance network. As the discourse on GMOs in food/agriculture has been taking away attention from pressing issues, food/agriculture organizations and regulatory agencies would have a shared interest in avoiding an overspill of the ongoing debate to genome editing and other emerging technologies. The network should also be relevant to NGOs that have supported or opposed current GE crops, and firms, such as retailers, that are concerned with sustainability of agricultural production. Participation enables them to address their core concerns about agricultural use of these technologies and to participate in the design, conduct, and oversight of assessments of genome-edited crops. In addition, the network may appeal to regulatory agencies that value the voluntary and market-based nature of this governance approach. In the USA, network participation by federal agencies would also position them to take regulatory action under the US Coordinating Framework, should these agencies perceive safety risks that would mandate such action [7].

Initial scope of cooperative governance

To increase the likelihood that the network will attract participants, it would help to limit its scope to the least intrusive and controversial application of genome editing: using site-directed nucleases to induce genetic changes that could also be achieved by non-GE crop breeding or chemical mutagenesis [8]. Further, we recommend focusing on crops that would add ecological and economic diversity, rather than dominant staple crops such as maize or rice. Winter-hardy crops for temperate zones are one example of such "diversification" crops [9]. Such plants grow in fall and spring, produce marketable commodities such as grains and oilseeds, and make way for crops that mainly grow in the summer. They increase productivity and sustainability and may improve resilience to climate change.

Another focal point might be legumes for intercropping for smallholder farms in Africa, where opportunities have been identified for improving the food value of locally adapted landraces as well as wider adaptation of regionally marketable crops. An important application of these nitrogen-fixing plants is intercropping with maize production, which can provide major improvements in yield, soil quality and fertility, efficiency of water and fertilizer use, and nutrition for people and livestock. Many annual and perennial legume species have been used in this way, but almost all require breeding to address the trade-off between food value and the production of biomass, which is critical for their beneficial effects. These crops represent opportunities for focused, locally driven breeding projects to improve human welfare if certain contested aspects, including issues of intellectual property around traditional crops, are successfully navigated through cooperative governance. Legumes for African smallholders and winter-hardy crops for temperate zones share a common problem: There are many potential species that need to be adapted to different climates, soils, dietary needs, and production systems. Yet, public funding for such research is limited, and there is little interest by major breeding companies.

We believe that focusing on site-directed nucleases and diversification crops would enhance the legitimacy and salience of a governance network for many potential participants and heighten incentives for participation. Many critics of genetic engineering are particularly concerned about the risks of transgenic crops, but may be more willing to participate in governance of genome editing of diversification crops. Entrepreneurial breeders of diversification crops are likely to be particularly interested in access to capital via participation. Impact investors are likely to view such crops as attractive targets for sustainable development.

However, cooperative governance networks are not intended to enlist all interested stakeholders, and they cannot address all societal objections to GM technologies. Rather, the network should seek criteria for applying gene-editing technologies that are acceptable for a reasonably heterogeneous network of participants. If such criteria are produced, and if the network has sufficient authority to influence markets or public policy, stakeholders that choose not to participate come under pressure. They can join the network in an attempt to influence its evolution, or form a competing network to battle for the hearts and minds of influential stakeholders.

A governance network must also have "teeth", that is, the power to impose its rules on its participants. Principally, it could mean that its investors deny funding a particular project in face of an unfavorable assessment. The network's legitimacy will therefore depend on its ability and willingness to deliver verdicts based on compromise. That is, if GE skeptics are to be meaningfully involved, breeders and investors will have to accept decisions that incur costs to enhance transparency, alterations in the development process, or abandonment of certain projects. At the same time, the price for GE skeptics might include a willingness to find compromise rather than entering the process with a blanket mandate to block these technologies.

A potential application of genome editing

We briefly illustrate the network's assessment process as it might be applied to a winter-hardy crop that could be used to diversify temperate-zone agro-ecosystems. As noted above, such crops produce commercially valuable products, protect soil and water resources, and provide a range of other benefits. However, most of these crops have traits that limit their agricultural and commercial viability. Potentially, genome editing could be used to rapidly improve various traits to promote their wide adoption and resultant benefits.

A broad-based assessment process would engage a wide range of stakeholders concerned with social, environmental, and economic sustainability in foresight analysis [9]. This effort (Fig 1) begins with a framing question that highlights the characteristics of a particular winter-hardy crop itself, prior to any application of genome editing: If the crop were widely integrated into temperate-zone agriculture, what range of social, economic, environmental, and cultural effects might ensue?

Crucially, this deliberative foresight assessment sets the stage for judging the

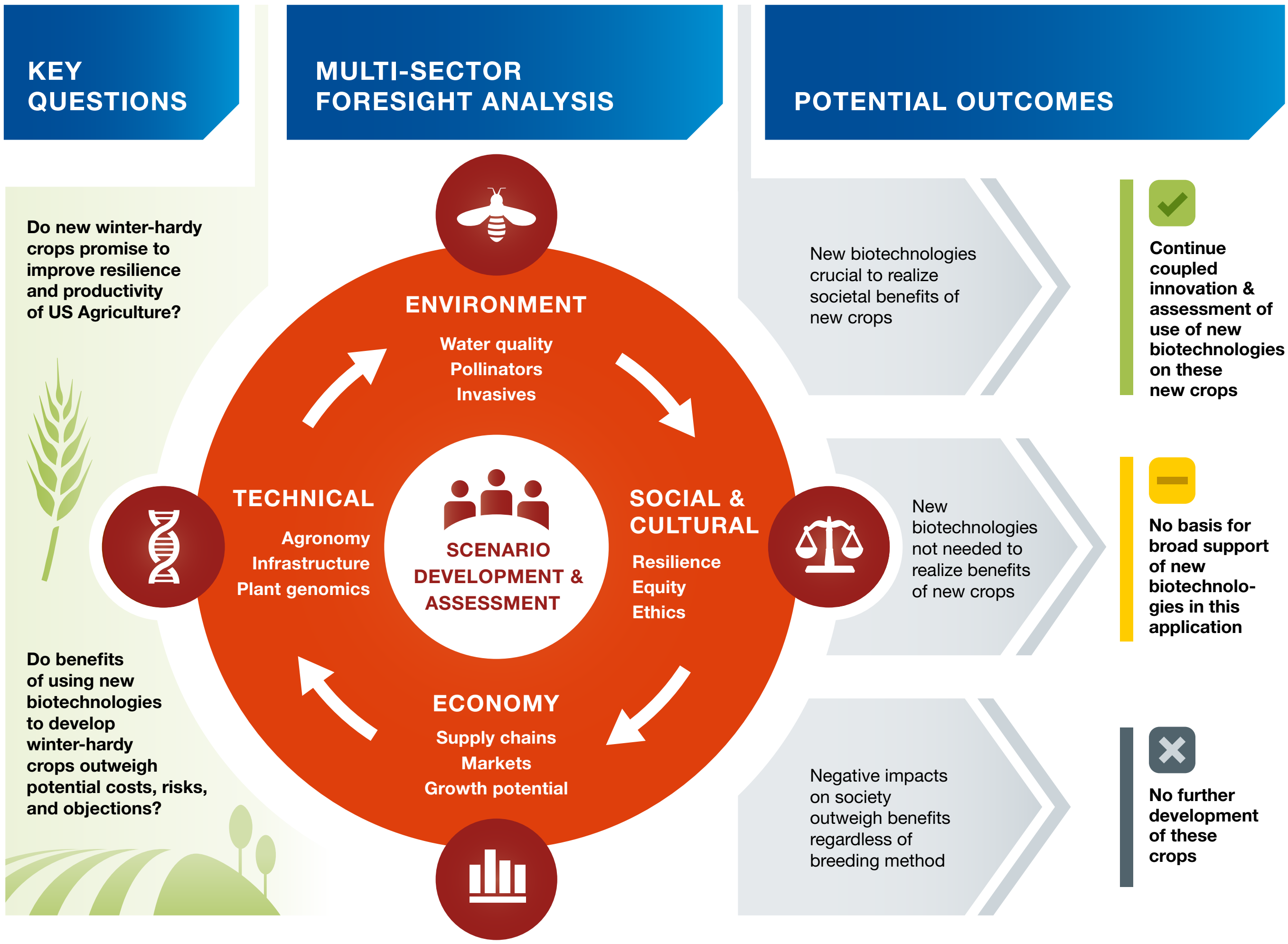

Figure 1. Example of deliberative scenario-based foresight analysis applied to winter-hardy crops for development via genome editing.
Initial analysis focuses on assessment of the crops and their effects on a broad range of biophysical, socioeconomic, and cultural dimensions. This provides the context for evaluation of merits and demerits of the use of biotechnologies to develop new crops traits.

merits and demerits of using genome editing to enhance particular traits of these crops. For example, assessment may forecast large benefits, such as improvement of soil and water resources. However, these benefits might be undermined by potential problems, such as intensified use of irrigation and agrochemicals, or damaging effects on soils and the production of other crops, or other effects of large-scale use, such as disruptions of regional hydrology. Moreover, widespread cultivation of the crop may transform agricultural economies and landscapes, with potential for societal, economic and cultural impacts.

After the assessment, consideration will turn to the possible use of genome editing to enhance the benefits of extensive cultivation of the crop—or to limit problematic effects—by improving key traits. For example, genome editing might be applied to traits that affect potential weediness or to enhance traits relevant to production or end usage. Therefore, the key questions of foresight assessment are: If there are both beneficial and problematic effects of widespread cultivation of the crop, can genome editing enhance benefits and reduce undesirable effects? Are these benefits sufficient to outweigh any concerns about using genome editing or about the new crop per se? If the answers to these questions are positive and endorsed under the governing rules of the network, it would then certify the new crop for further investment.

Conclusion

Given the explosive rate of innovation in biotechnologies, new approaches to governing their exploration and evaluation are urgently needed. Given past successes, a cooperative governance network is a promising vehicle for mobilizing exploration of crop genome editing and may avoid further escalation of polarizing conflict about this technology in civil society. We underscore that we do not view the network as a fixed or permanent institution, but rather an intervention to manage the current situation, in which applications of genome editing to crops are rapidly increasing without consensus on how these applications should be governed. This problem was recently emphasized in a report by the US National Academies of Science, Engineering and Medicine [10], which called for tiered approaches to fill the gap left by outdated statutory definitions.

Box 1: Further reading

Droppelmann KJ, Snapp SS, Waddington SR (2017) Sustainable intensification options for smallholder maize-based farming systems in sub-Saharan Africa. *Food Secur* **9**: 1–18
Cullis C, Kunert K (2017) Unlocking the potential of orphan legumes. *J Exp Bot* **68**: 1895–1903
Guston DH, Sarewitz D (2002) Real-time technology assessment. *Technol Soc* **24**: 93–109
Kearney S, Murray F, Nordan M (2014) A new vision for funding science. Available at https://ssir.org/articles/entry/a_new_vision_for_funding_science
Kuzma J, Kokotovich A (2011) Renegotiating GM crop regulation. *EMBO Rep* **12**: 883–888
Milder J, Newsom D (2015) SAN/Rainforest Alliance impacts report: evaluating the effects of the San/Rainforest Alliance certification system on farms, people, and the environment. New York, NY: SAN/RA
Østerberg J, Xiang W, Olsen L, Edenbrandt A, Vedel S, Christiansen A, Landes X, Andersen M, Pagh P, Sandøe P *et al* (2017) Accelerating the domestication of new crops: feasibility and approaches. *Trends Plant Sci* **22**: 373–384
Pew Initiative on Food and Biotechnology (2003) The stakeholder forum on agricultural biotechnology: an overview of the process. Available at http://www.pewtrusts.org/~/media/legacy/uploadedfiles/wwwpewtrustsorg/reports/food_and_biotechnology/pifbstakeholderforumprocesspdf.pdf
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Reinecke J, Manning S, Von Hagen, O (2012) The emergence of a standards market: multiplicity of sustainability standards in the global coffee industry. *Organ Stud* **33**: 789–812
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Snir R (2014) Trends in global nanotechnology regulation: the public-private interplay. *Vanderbilt J Entertain Technol Law* **17**: 107
Silva Dias JC (2015) Plant breeding for harmony between modern agriculture production and the environment. *Agric Sci* **6**: 87–116

A governance network could fill the earliest tier and enable the broader societal assessments suggested in the National Academies report. Of course, this approach is experimental, and it will have significant logistical challenges and costs. Implementation will require resources to convene potential participants and devise a modus operandi. However, experience with current GE crops shows that such costs must be weighed against legal, commercial, and reputational costs, and, perhaps, the suppression of agricultural innovation that would result if tension and conflict about crops produced by new agricultural biotechnologies are allowed to fester under current governance regimes. Moreover, we anticipate that successful operation of a governance network can broaden cooperation and compromise among investors, scientists, NGOs, companies, and retailers. Via network participation, these can begin to act as an "army of the willing", to identify situations where some types of GM crops may be broadly acceptable. In turn, we believe that this success could open the door to broader consideration of when and how gene editing and other emerging biotechnologies might be acceptable in food and agriculture, generally.

Conflict of interest

The authors declare that they have no conflict of interest.

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