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Perspective

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Are disruptive agricultural technologies compatible with agroecology?

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Helena Shilomboleni[1] ✉ & Matthew A. Schnurr[2]

Agroecology has emerged as a credible approach to achieving sustainable and resilient agrifood systems. But the role for disruptive agricultural technologies within agroecology remains contentious. This paper examines the potential congruence for technology-driven and agroecology-driven approaches to agricultural development. We examine two case studies from east Africa—one focused on user-centered digital technology in Ethiopia and the second on new breeding techniques in Uganda.

Agroecology has gained prominence as an approach to sustainable agriculture with potential to address food and nutrition security, support biodiversity, and build resilience to climate change, while simultaneously advancing goals of social equity and rights-based governance[1–3]. Various agricultural development organizations and agencies—including the UN's Food and Agriculture Organization's (FAO) High-Level Panel of Experts (HLPE)—support and promote the scaling of agroecology, particularly in low-income farming contexts of the Global South[4–6]. While no single definition of agroecology exists, the most comprehensive elaboration are the HLPE's thirteen principles of an agroecological approach to sustainable food systems, which are designed to achieve three operational principles of improving resource efficiency, strengthening resilience, and enhancing social equity[7].

The growing acceptance of agroecology by mainstream development actors has not been welcomed by all proponents[8–11], for instance, raise concerns about how mainstream spaces are being used to contain and co-opt the transformative potential of agroecology. These authors problematize the incorporation of agroecology into what they argue is a top-down "innovation-frame" focused on increasing yields and profits via technological modernization, which tends to overlook and diminish the agency of farming communities. Others warn that the institutional endorsement of agroecology by governments, development agencies, NGOs, and the private sector serves to bolster the monoculture model of industrial agriculture, dismissing such ventures as 'neoliberal agroecology', 'fake agroecology' or 'junk agroecology'[9,10].

A critical area of contention in this polarized debate surrounds the role of technology, including whether, how, and which types of technologies might be appropriate for advancing agroecological goals. Agricultural technologies encompass a broad suite of innovations that tend to be characterized as bottom-up or top-down. Bottom-up technologies primarily involve local innovations that rely on traditional knowledge and tend to be disseminated directly from farmer to farmer[12–14]. Top-down technologies are associated with conventional agriculture research and development and rely primarily on scientific knowledge to develop and transfer new innovations to farmers[15]. Agroecologists tend to embrace the former and dismiss the latter, arguing that top-down technologies weaken farmer autonomy and decision-making power[16,17], thus serving to undermine broader goals of food security and democratization[18].

This paper seeks to move beyond this binary framing by showcasing two case studies where the use of technologies that tend to be dismissed as top-down might align with the HLPE's three operational principles of sustainable food systems: improve resource efficiency, strengthen resilience, secure social equity (the HLPE's thirteen principles of agroecology are presented as subsets of these operational principles). Specifically, we focus on disruptive agricultural technologies (DATs), defined as digital and technical innovations that vault current best practices by substantively increasing productivity, efficiency, income, nutritional status, and climate resilience[19]. DATs comprise a wide range of innovations, including digital tools, robotics, remote sensing, and biotechnology[20]. Other scholars have explored similar questions regarding the conditions required for DATs to support agroecology in a more general sense[21–23] (See also[24–27] for similar debates pertaining to other forms of sustainable agriculture). In this paper, we drill down into specifics regarding the design, delivery, and structures to broaden understanding around how this subset of technologies might serve agroecological transitions. We mobilize two case studies—user-centered digital technologies in Ethiopia and new breeding techniques in Uganda—chosen because they highlight the challenges related to knowledge politics and program delivery that must be addressed to ensure alignment between a new technology and the agroecological system into which it is designed to succeed.

The role of disruptive agricultural technologies in agroecology

There is growing debate about the role of technology within a transition to agroecological-driven food systems[16,28,29]. Scholars who argue that disruptive

[1]School of Environment, Resources and Sustainability & Department of Geography and Environmental Management, University of Waterloo, 200 University Ave W, Waterloo, ON, N2L 3G1, Canada. [2]Department of International Development Studies, Dalhousie University, 6299 South St, Halifax, NS, B3H 4R2, Canada. ✉e-mail: hshilomb@uwaterloo.ca

agricultural technologies can be compatible with agroecology point to their potential to boost yields, offer timely and specific agronomic advice, and strengthen resilience and adaptation to climate change. These scholars have identified conditions needed to ensure congruence between technology and agroecology, including the need to facilitate participatory knowledge generation, ensure equitable access, and improve accountability and transparency within governance mechanisms[22,29,30]. Wittman et al. mobilize evidence from a collaborative partnership between North American Universities and farmer-based organizations working in southern Brazil, which co-developed an open-access digital tool for participatory monitoring and certification. This project was borne out of a community need to overcome cumbersome pen and paper methods of assessing their agroecological management practices, in favor of more accessible and cost-effective digital methodologies that could effectively measure the multidimensional outcomes of agroecology across a range of farm sizes and production systems[22]. Other collaborations comprising international agencies, NGOs, farmer organizations, private sector and government actors are similarly leveraging digital tools to connect large numbers of dispersed and heterogenous smallholder farmers to crucial farming services, such as user-driven digital extension services, at lower cost compared to traditional extension methods[31].

Critical scholars argue that DATs serve a neoliberal agenda that incorporates farmers into hierarchical structures of domination and control[10,11]. Critics have untangled the public-private partnerships promoting data-driven tools, exposing how these structures strip farmers of their agency and autonomy in decision-making[8]. Malik presents evidence from India showing that the use of disruptive technologies has intensified disenfranchisement by 'nudging' smallholder farmers toward market-oriented farming prescriptions that diminish community-level innovative capacity and agency[32]. As such, critics dismiss disruptive agricultural technologies not only as top-down but also as disempowering, as they serve to cement dependencies on external actors in ways that undermine farmer agency and control[17].

The skepticism expressed by critical scholars surrounding the co-optive potential of top-down technologies stems from historical experience. Colonial officials introduced technologies to accelerate their vision for export-oriented, monoculture production of agricultural commodities highly valued by European consumers[33]. The Green Revolution introduced high-yielding varieties alongside chemical fertilizers and pesticides that weakened soil health, caused water usage to spike, undermined the cultivation of traditional crops, and exacerbated farmer inequality based on land size and gender[34]. Critical agroecology scholars view DATs as a continuation of these legacies, in that they entrench farmer dependency on purchased inputs, justified based on moral imperatives to 'save the poor' and 'feed the world'[10]. While we share concerns about the potential for these technologies to extend the legacies of colonial and Green Revolution technology transfer, we believe a wholesale rejection of these technologies runs the risk of missing out on opportunities to accelerate the transition to sustainable food systems.

In East Africa, for instance, smallholder farmers rely on a suite of technologies and practices to increase or maintain yields in the face of variable agro-climatic environments and other pressures[35,36]. As we illustrate below, agricultural technologies that foster meaningful impact at scale for smallholder farmers tend to prioritize local fit, comprising multiple encounters and exchanges between different actors and are subject to the creative agency of farmers as technology practitioners[37]. Glover et al. explain that such models of technological change enable farmers and other relevant local stakeholders to adapt, creolize, hybridize and incorporate technologies into their local farming contexts[38]. A consideration of the specific conditions under which DATs might effectively serve local farming contexts offers crucial insights into the potential congruence between technology and agroecology. The next section showcases two case studies that have embraced innovative approaches to knowledge politics and program delivery to ensure that DATs reflect the priorities of the farming communities they are designed to serve.

Leveraging disruptive agricultural technologies for agroecology

User-centered digital technologies

Digital agriculture is an umbrella term for technologies used to enhance decision-making along the agricultural value chain. Sometimes referred to as 'smart farming', digital agriculture technologies include drones, sensors, robotics, mobile phones, satellites systems and modelling whose use is managed and enhanced by the application of big data. These technologies are lauded for their potential to improve both the efficiency and environmental sustainability agri-food systems[19,39,40], while concerns persist regarding data ownership and restrictions on control and access implemented by technology developers[41–43]. The uptake and impact of digital technologies in low-and-middle income countries remain both limited, with use currently confined to interactive Information Communication Technology (ICT) tools and platforms such as mobile phones (for voice calls, Short Message Services [SMSs], interactive voice response [IVR], social media (WhatsApp and Facebook and e-vouchers)[44–46].

Over the past few years, there has been a spike in agricultural development interventions working to improve the design and delivery of digital agriculture technologies to smallholder farmers in low-and-middle income countries. The most promising initiatives have sought to adopt a user-centered design to digital tools that responds to farmers needs in terms of useability, accessibility, and equitability[31,47,48]. The idea is that farmers will be able to access more up-to-date and specific information regarding weather and climate, pest and disease outbreaks, or market information to enhance their day-to-day decision-making[44].

In Ethiopia, the National Market Information System (NMIS) has utilized user-centered digital technologies to expand the coverage of market information in that country, reaching over 1.5 million smallholder farmer users over the past decade. As a collaborative partnership between Ethiopia's Ministry of Trade and Industry, Federal Cooperative Agency, the Agricultural Transformation Institute, and other stakeholders, NMIS emerged as a national digital agriculture platform to gather, validate and disseminate agricultural volume and price data for key food security crops (teff, wheat, maize, haricot bean and sesame) from 157 markets across the country[49]. This information is being delivered to farmers in their local language based on their preferred mode of communication. In this way, NMIS has embraced user-centered digital technologies as a means of addressing persistent challenges in Africa's smallholder agricultural markets, namely information asymmetries pertaining to price discovery, product quality, and transactions costs associated with the exchange of goods and services[50].

Beyond helping to overcome basic market constraints, digital agriculture tools and platforms could be used to expand or reinforce the marketing of agroecology products, connecting the channels and actors through which products flow[51]. In recent years, these channels have grown in range to include public procurement programs and participatory guarantee schemes that leverage digital tools to enhance farmer decision-making within the value chain[5]. Another promising stream is that of digital extension, which mobilizes site-specific data points to provide farmers with more timely and specific advice and transform what has traditionally been a one-way, top-down mode of communication into one that is more farmer-driven and dynamic. This ability to enrich the two-way flow of information with farmers seems supportive of the HLPE's three operational principles of improving resource efficiency, strengthening resilience, and securing social equity.

New breeding techniques

Genetic modification and genome editing are another suite of technologies that could be coupled with agroecology to help increase or maintain yield productivity and strengthen resilience and adaptation in the face of climate change and variability. We begin by noting that nearly 98% of all Genetically Modified (GM) crops in existence are focused on two traits (insect resistance and herbicide tolerance) across four commodity crops (cotton, soybean, canola, maize). Such innovations can in no way be called agroecological; these serve to exacerbate the type of large-scale, monoculture, inputdependent, Intellectual Property driven mode of agricultural production that is antithetical to all things agroecological[17].

But there are versions of new breeding techniques being developed in smallholder farming contexts seem capable avoiding what the HLPE identifies as ‘conflicts with core agroecological principles associated with ecology, democratic governance and sociocultural diversity’[7]. One example is that of cooking banana in Uganda, known locally as matooke. Coordinated through public-private partnerships—most of which are facilitated by third-party intermediaries funded by the Gates Foundation—Ugandan scientists employed at the National Agricultural Research Organization are breeding Genetically Modified forms of matooke resistant to some of the crop’s most pernicious pests and diseases. Once released, these GM varieties will be available license-free, allowing farmers to recycle, replant, and share planting materials as they would any conventionally bred variety[52]. Cassava that is genetically modified to resist cassava brown streak and cassava mosaic disease is another example of a new breeding technique designed to be compatible with agroecological practices including intercropping, reduced tillage, rotation crops, soil and water conservation, composting, and the use of natural pesticides[53]. It is worth noting that both banana and cassava reproduce clonally, making conventional breeding especially difficult and laboratory-based breeding options such as genetic modification even more critical.

Gene editing represents the next generation of breeding technologies, which allows scientists to manipulate a plant’s genome in situ. Many unknowns around the technology’s potential for smallholder agriculture remain, including claims regarding its precision, cost and speed[54]. Many of the experimental programs currently underway are focused on crops (such as sorghum, cassava, matooke banana) and traits (such as disease resistance, nutrition enhancement and stress tolerance) that have largely been ignored by investment and innovation[55,56]. But, as proponents of agroecology remind us, this gene edited future runs the risk of perpetuating anti-democratizing norms and technological lock-in[57]. While we agree with critics that it would be premature to endorse these gene edited possibilities as congruent with agroecology, it seems equally premature to dismiss them outright before farmers have had the opportunity to engage with these innovations for themselves.

Conclusion: broadening the scope of disruptive agricultural technologies within agroecology

Proponents of agroecology are right to be skeptical of the triumphalist narrative that buoys the introduction of disruptive agricultural technologies, which remains steeped in histories of colonial and Green Revolution thinking that prioritized the expertise of outsiders over those of farmers such interventions were ostensibly designed to help. There are also valid concerns around DATs exacerbating the loss of farmer knowledge and skills, including the political and economic structures accompanying some new innovations that can limit a farmer’s ability to modify it (as in the case of the rigid Intellectual Property that prevents the sharing, replanting or recycling of genetically modified seed). But to dismiss this new category of technologies outright is to miss the potential that some of these might be congruent with principles of agroecology. We believe that agroecology needs to be more pragmatic, and less paradigmatic, in assessing the potential benefits of DATs to ensure that possibilities are not preemptively foreclosed.

The two case-studies presented here reveal the nebulous but crucial importance of ‘fit’ between technology and farming system. In Ethiopia, NMIS leveraged user-centered digital technologies to provide over 1.5 million smallholders with timely and relevant market information in the language of their choosing. In Uganda, plant breeders are experimenting with techniques of genetic modification and gene editing to develop improved varieties of a staple crop (matooke banana) that are resistant to pests and diseases impacting smallholder farmers, a process which has proven nearly impossible to accomplish via conventional breeding. These examples showcase the possibilities for DATs to accelerate the transition to sustainable food systems.

Realizing this vision for a more technophilic than technophobic version of agroecology will require shifts in understanding, program delivery, and knowledge politics. First, we need to broaden our understanding of what counts as technology and innovation, moving beyond the unidirectional flow from experts to farmers that characterized technology transfer during colonial and Green Revolution eras. Restoring farmers’ role as chief innovators of their farming systems will require building pathways for technology transfer that flow from farmers to experts and not just the other way around. Second, we need to reimagine program delivery to emphasize user engagement at every step of the process, so that farmers are no longer positioned as passive recipients of discreet technological packages, but rather as agents of change who modify, improve, experiment, and ultimately make decisions on what works best for their farming systems. Contributions from the world of participatory design provide useful building blocks for how to reform planning processes to foster a more situated and inclusive form of innovation[31,58,59].

Third, we need to disrupt the agricultural technology pipeline by granting more agency and decision-making to downstream actors and investing in horizontal knowledge-sharing platforms such as farmer research networks, which empower end users to develop, design and assess a particular technology’s potential. Recent contributions in responsible innovation provide useful templates for creating a more inclusive and deliberative knowledge politics, such as collective foresighting[60], which seem likely to produce better alignment between technology design and farmer needs[61].

Data availability

No datasets were generated or analysed during the current study.

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Competing interests

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Additional information

Correspondence and requests for materials should be addressed to Helena Shilomboleni.