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Aligning digitalization with agroecological principles to support a transformation agenda

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Aligning digitalization with agroecological principles to support a transformation agenda

Policy Paper for the D4S-Network
November 17th 2022

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Abstract

In this paper, we, firstly, critique the current forms of digitalisation of industrial agriculture and its ICT (information and communication technology) tools implemented with promises of achieving efficiency gains and sustainability goals. In the second part, we explore how ICT tools could support the transformation of these industrial forms of agriculture into truly sustainable agroecological forms. For this, we summarized proposed principles that offer guidance for the integration of ICTs into context-based, farmer-centered transitions to agroecology as recently published by IFOAM (International Federation of Organic Agriculture Movements) and present examples for illustration from the East African country of Tanzania. While the examples we draw from are situated in a lower-middle-income country, the lessons learned and challenges identified may apply to other countries as well. Our main premise is that applying ICTs to support the transition toward agroecological food systems can be best achieved if ICT tools and platforms are developed according to principles that are in line with the key elements of agroecology as proposed by FAO (2018): 1) diversity, 2) co-creation and sharing of knowledge, 3) synergies, 4) efficiency, 5) recycling, 6) resilience, 7) human and social values, 8) culture and food traditions, 9) responsible governance, and 10) circular and solidarity economy, into the field of ICTs. However, the practical implementation of these principles for ICT for agroecology is a complex task that needs to carefully consider local environments and contexts at every step, as well as reconsidering the role of ICTs.

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TABLE OF CONTENTS

1 INTRODUCTION

As the role of industrial forms of agriculture and land use in the destabilization and degradation of global ecosystems has become increasingly documented, the pressure on politicians has grown to come up with solutions (e.g., Rockström et al., 2009a, b; Foley et al., 2011; Steffen et al., 2015; Barnard et al., 2021; IPCC 2019; Campbell, 2017; IPBES, 2018; Persson et al., 2022). Species extinction is rampant, with 1 million out of approximately 8.1 million species in danger extinction (e.g., IPBES, 2019). Simultaneously, animal populations are vanishing at a staggering rate: German insect biomass in protected areas has declined by nearly 80% in less than three decades (Hallmann et al., 2017), and the world's vertebrate populations by 68% in 50 years (WWF, 2020). These developments – as well as altered biogeochemical cycles (nitrogen and phosphate) caused by massive land-system change and climate disruption – are largely driven by conventional agricultural practices (Olsson et al., 2019). In fact, three-quarters of the world's land-based environment has been significantly altered by human actions. For example, more than a third of the world's land surface and nearly 75% of global freshwater resources are devoted to livestock or crop production (IPBES, 2019). Land degradation, habitat destruction and chemical pollution due to industrialized agricultural production methods have significantly contributed to pushing the planet towards a sixth mass species extinction and climate disruption, e.g., through the release of carbon stored in soils (IPCC, 2019). The International Panel on Climate Change (IPCC) states that limiting global heating to 1.5° C – thereby avoiding irreversible and abrupt climate change (Lenton et al., 2019; Steffen et al., 2018) – would require far-reaching and rapid "systems transitions [that] are unprecedented in terms of scale, but not necessarily in terms of speed" (IPCC, 2018, p.15). In other words, humanity's current use and treatment of natural resources and ecosystems – with industrial agriculture being a major contributor – poses existential threats not only to the biosphere but to humanity itself.

A series of expert consensus reports have been published over the past decades calling for a rapid transformation from input-intensive industrial agriculture, towards agroecological farming methods (e.g., Gliessmann, 2015, 2016; IAASTD, 2008; IAASTD+10, 2020; IPES, 2018; De Schutter, 2011; Wezel et al., 2009). Today, global debates have shifted towards solution-based approaches to the remediation of the largely undisputed global ecosystem degradation. Two competing proposals currently dominate the debate. On the one side, solution proposals have emerged from actors within the currently dominant industrial agriculture sector, namely large, oligopolistic agri-tech firms. These proposals rest on bringing about environmental improvements through digitalization of agro-food systems (Walter et al., 2017). Corporate actors in the agricultural sector – e.g., biotech and chemical transnationals such as Monsanto, Bayer (e.g., Bayer, 2020), and agricultural machinery manufacturers such as John Deere or Claas – are rapidly introducing digital packages building upon and expanding existing industrial structures. These initiatives are also bringing new players into the agricultural sector who have no relevant expertise in agriculture (e.g., mobile network providers such as Vodafone). In Box 1, we explain the various terminologies and concepts in use related to 'digital agriculture.'

Box 1: Various terminologies and underlying concepts for 'digital agriculture' (from Hilbeck et al., 2020)

Precision Farming or Precision Agriculture are the oldest terms in use, reaching as far back as the early 1990s, when GPS-signals became publicly available. Initially, Precision Farming focused on managing in-field variations more accurately, with the intention to treat each plant individually (Variable Rate Application, VRA), thus increasing the output while reducing inputs (CEMA, 2017).

'Smart' Farming encompasses Precision Farming/Agriculture but has a focus that goes beyond individual machines. It makes use of Farm Management Information Systems (FMIS) to optimize complex farming systems. While significant access barriers mirroring international, national, and local patterns of inequality continue to define what digital access means for farmers across the world, the access to, and use of smart devices are growing. Smart farming tools include devices and applications that provide real-time data about, among others, market prices, weather, soil conditions, or resource usage, which helps farmers make more informed decisions (Griepentrog, 2017).

'Farming 4.0' or **'Agriculture 4.0'** are terms that are often used interchangeably with 'Smart Farming' and relate to the concept of 'Industry 4.0.' Whereas Agriculture 1.0 was based around labor-intensive, (supposedly) low-productivity, peasant agro-food systems, Agriculture 2.0 marks the beginning of today's 'industrial,' input-oriented, entrepreneurial, agro-food systems. Using high yielding varieties bred in conjunction with synthetic pesticides, fertilizers and increasingly specialized machines, farmers were able to substantially increase yields, following the period widely known as "The Green Revolution." Agriculture 3.0 coincides with the emergence of Precision Farming in the 1990s and the gradual introduction of more advanced and mature Precision Farming technologies – mostly automation. Finally, around the early 2010s, the exponential increase of information and communication technology (ICT) used in farming has led some authors to argue that these developments constitute the next agricultural revolution (Finger et al., 2019). Thus, Agriculture 4.0 has been coined to describe a new boost in Precision Farming, based on several technologies, such as cheap and improved sensors, high bandwidth cellular communication, cloud-based ICT systems, and Big Data analysis (CEMA, 2017).

Digital Farming/Agriculture is probably the broadest term in use and is sometimes described to integrate both Precision Farming and 'Smart' Farming when applying digital technologies to agricultural management, marketing, production, and processing (Griepentrog, 2017). Its essence lies in 'creating value from data,' which can mean a variety of things, including a shift from a hardware- to a service-oriented corporations (e.g., enhancing vehicle performance via Big Data analysis) (CEMA, 2017), but also the emergence of new, potentially disruptive players such as Microsoft, Google, various insurance companies, or even retailers such as Amazon, who all make use of farming data in various ways.

Various stakeholders use the above-mentioned terms – as well as other vocabulary such as AgriTech, mobile agriculture, ICT4Ag, and e-agriculture - interchangeably or with different meanings attached. For example, the strategy consulting group Roland Berger (2015, 2019) conceives 'Precision Farming' to also include all the latest developments around Big Data and cloud-based ICT systems leading to platform-based, whole-system packages that vertically integrate (i.e., capture) entire food-systems on technology platforms. This includes not only the products of physical-electronical engineering processes equipped with wireless data transmission and high-speed computing capacities, but also the products of biotechnological and chemical engineering.

These solution proposals are predominantly underpinned by narratives of improving the sustainability of industrialized forms of agriculture. In fact, industrialized processes and operations are a prerequisite for many digital technology proposals developed by global corporations. This prerequisite also presents an inherent barrier to the uptake and adoption of corporate digital solution packages in farming systems that are not fully industrialized and require manual labor and artisanal skills and processes, which characterises many organic farming operations. Furthermore, these proposals also implicitly (rarely explicitly) acknowledge the destructive role of industrialized forms of agriculture, but only to the point where they have already developed and presented digital solution packages, without remediating or addressing the underlying causes and responsibilities (e.g., Walter et al., 2017, see Box 1 and references).

Another proposal of a solution package is agroecology – an agro-food systems approach that has gained traction over the past decade. Agroecology aims to remediate the causes of environmental destruction rather than mitigate its symptoms (e.g., Levidow et al., 2014; Pimbert, 2015; Wezel et al, 2020). Agroecological solution proposals are rooted in civil society movements and have long been positioned as counter proposals to the currently dominating industrial agro-food system (e.g., Altieri, 1995; De Schutter, 2011; Pimbert, 2015). Agroecology is the contextualized application of ecological principles to agriculture and builds on the identification and application of the best locally adapted practices in food production. In essence, agroecology works with nature, not against it, unlike many dominant forms of farming (e.g., Altieri 1987, 1995; HLPE, 2019; Pimbert, 2015; de Schutter, 2011; Wezel et al., 2020). Agroecology can be seen as the skillfull, situated, and sustainable art and science of agriculture.

These two different types of solution proposals for making agriculture more sustainable with digital means – 'greening' high input industrial agriculture through optimization primarily driven by digital means, or fundamentally transforming agriculture into agroecological systems where digital means take on more of a secondary, support role – are offered by very different actors, are difficult to reconcile, and are often understood as being mutually exclusive both conceptually and practically.

In this paper, we propose an approach in which digital tools can be carefully applied in the service of the agroecological transformation of agriculture. Agroecological production systems place farmers and communities at the center and operate without synthetic inputs (e.g., by following organic certification rules). We acknowledge that these operations take on different forms of intensification and industrialization in different global regions, which can also be the subject of controversy in some areas (e.g., Levidow et al., 2014). Furthermore, we focus on the role of digital tools that fall within the field of information and communication technologies (ICT) – not the robotics/mechanical engineering field that are driven and controlled by ICT. We argue that digitalization holds valuable potential for supporting agroecological food systems and the associated necessary transformation processes, while acknowledging that digital tools specifically developed for such farming operations are still virtually non-existent. Though the current market offers vast numbers of digital ICT tools for agriculture, many of which also claim to support meeting various sustainability goals, it is a key challenge, as we will explain below, to differentiate between ICT proposals that can support and foster agroecological and organic principles and ¬– by extension – support a transformation agenda, from those that undermine agroecological principles. We also argue that critically examining design principles and their ideologies in order to delineate ICT proposals that support and foster agroecological transformation from those that do not, is key to getting ahead of the curve and proactively shaping how ICT initiatives and digital tools for farmers can – and should – be developed from the onset and implemented to support agroecological transitions.

Thus, we firstly offer a brief historical introduction of ICT and a critique of the current forms of digitalization of industrial agriculture, including the various terminologies and concepts, followed by a critique of the underlying political economy and ideology in the technology. In the second part, we explore how digitalization could support a transformation of industrial forms of agriculture into truly sustainable agroecological forms. For this, we will summarize proposed principles that offer guidance for the integration of ICT into context-based, farmer-centered transitions to agroecology recently published by International Federation of Organic Agriculture Movements (IFOAM) (Hilbeck et al., 2020). Thirdly, we present examples for illustration from the East African country of Tanzania. While the examples we draw from are situated in a lower-middle-income country, the lessons learned and challenges identified may apply to other countries as well.

2 BRIEF HISTORY AND CRITIQUE OF THE INTRODUCTION OF ICT IN SUPPORT OF THE DIGITALIZATION OF AGRICULTURE

The potential contribution of ICT to agriculture in general was widely recognized early on in 2003, when the term e-agriculture was introduced at the first World Summit on the Information Society (WSIS, 2003). In the conference report, the aims of e-agriculture were stated to be the application of ICT to dynamically disseminate accessible, up-to-date information relevant to agriculture, particularly in (so-called) developing countries, and to increase food production (WSIS, 2003). More detailed potential contributions of ICT to agriculture were identified in subsequent studies by NGOs, ICT corporations, and scientific researchers (e.g., Vodafone & Accenture, 2011; Furuholt & Matotay, 2011). A general set of policy recommendations was formulated together with the original aims of e-agriculture: 1) building on existing systems, 2) determining who should pay for access to ICT, 3) ensuring equitable access, 4) promoting local content, 5) building capacities, 6) using realistic technologies, and 7) building knowledge partnerships (Chapman et al., 2003). As with the aims of e-agriculture, policy recommendations were also progressively refined over time (e.g., World Bank, 2017). However, despite incipient policy recommendations, the importance of ethical, social, and environmental principles for the design, development, and implementation of ICTs in agriculture has largely been by-passed. Instead, the development and implementation of result-oriented ICT platforms that tend to uncritically amplify unsustainable agro-food systems has been favored (Tisselli, 2016).

The application of ICTs within the agricultural sector in various countries and regions globally – under the umbrella term 'Digital Agriculture' – is complex and has more profound implications than simply thinking about it in terms of automation (Stone, 2022). Today, 'digital agriculture' applications include automation of repetitive and cumbersome processes such as ginning machines (e.g., for cotton), milking robots (for cows mainly), or harvester combines and electronic data collection via networked calculating machines (i.e., computers) for record keeping of quantitative data that can be captured by these machines (e.g., milk per cow and day, ton of harvested grain per area). Contemporary digitalization of agriculture encompasses all of the above, integrated by a technical engineering component of automated machinery, i.e., robotics, thus aiming to make automated robots entirely 'autonomous.' The extreme of this envisioned agricultural future consists of either entirely unmanned operations or those controlled remotely by joysticks or computers using either built-in cameras or camera equipped drones for surveillance. The most significant leap, however, has not occurred on-farm, but off-farm, as we will explain in the following.

2.1 Adding new dimensions of integration and path dependencies

The above described digitalization of agriculture has allowed for further optimization of farm operations at all levels by making human farm labourers and – by extension – farmers themselves increasingly obsolete. Most importantly, it has opened up novel business models that have brought completely new actors into the field who held no previous stake in, and only limited knowledge, if at all, of agriculture or food systems (e.g., Vodafone & Accenture, 2011). The data generated and exchanged between robots and remote controllers forms a new type of raw material that is combined and mined by algorithms and repurposed or repackaged into new protocols for what is presented as improved productivity, and traded by the licensing tech company or other sub-contracting companies. This data is often sold back to the farmer as a 'value-added service' or a necessary 'update' within the service packages with the promise for specifically tailored solutions to optimise agro-economic outcomes. Needless to say, this has created great opportunities for new business models to emerge and additional forms of lock-in to specific farming technologies and – by extension – neo-liberal market systems (Abdulai, 2022).

2.2 Adding new dimensions of capture and exploitation.

The last decades of the 20th century saw the horizontal capture (often one of the drivers of 'consolidations' or 'mergers & acquisitions') not only of specific input sectors such as the seed, pesticide, or fertiliser industries, but also among the buyers and sellers of agricultural commodities (e.g., Mooney, 2018; Howard 2009, 2015; Elsheikh and Ayazi, 2018). The first decades of the 21st century have seen the vertical convergence (or capture) of various sectors – from inputs, to cultivation, to selling and processing industries – into what is being called 'platform capitalism' made possible by digital means (e.g., Mooney, 2018; Hilbeck et al., 2020 and references therein). This vertical convergence or integration – made possible by exponentially growing computing and networking capacities – have contributed to the creation of complex platforms interconnecting inputs (chemicals and seeds) with cultivation, and harvested outputs with marketing, distribution, and transport. This is a scalable model that works at the local and global level. For example, at the country level in

Switzerland, barto is a farm management and information system based on 365FarmNet, Claas' Smart Farming platform, and is run jointly with the 'cooperative' Fenaco legally 'owned' by Swiss farmers, but operating as a for-profit enterprise and a de facto integrated Swiss monopoly[1]. Agri Gaia[2] and GeoBox[3] are other examples of (private and public) platforms bundling and mining farmers' data in Germany, and the Agri-food data portal[4] at the EU level, respectively. Bayer is currently the top performer of such a business model at the global level. After buying Monsanto and its prime assets in the digital sector such as the Climate Corporation and other IT companies, the newly formed mega corporation set out to digitally integrate all its products and created the ICT platform 'Fieldview.' Others are following suit. After the failed merger with Monsanto, prior to the Bayer-Monsanto deal[5], John Deere set out to develop its own platform: the 'John Deere Operations Center' TM[6] that now integrates with other data collecting and mining platforms such as 'Farmcommand' run by 'Farmersedge.'[7] All these platform providers only offer digital services for (semi-) autonomous precision cultivation techniques tailored specifically to the inputs (pesticides, fertilizers, and biotech-seeds), farming equipment, and protocols of its platform partners. Within this vision, valued farmers' 'knowledge' is the data generated by usage of licensed service packages which serves as a resource for extraction by mining algorithms. Other knowledge forms – tacit, intuitive, experiential, experimental, cultural, historical, etc. – that cannot be captured digitally are excluded by default.

2.3 The risk of 'junk agroecology'

In contrast, in agroecology, these various types of farmers' knowledge and generated evidence ideally form the foundation on which to build locally situated, resilient, and diverse food systems that need to be constantly nurtured, built upon, further developed, and adapted to changing situations by following generations. Furthermore, digital technologies used in the agricultural sector, including both hard- and software, come with environmental costs that are almost always overlooked. For one, this includes resources and energy demands and their associated emissions related to the production of digital devices such as sensors, robots, and drones (Hilty & Aebischer, 2015). In addition, the overall electricity consumption for both the operation of these devices and the ICT infrastructure used for the data transmission from, e.g., autonomous robots or video/image material is substantial. Although no precise data is yet available for the agricultural sector, estimates from other fields show that these additional environmental costs are non-negligible (IEA 4E, 2021).

To our knowledge, no digital innovation proposals exist that are specifically developed in support of agroecological or organic systems, or transitions to such systems, except our case example from Tanzania explained below. At best, regional digital technology providers advertise specific digital products as being 'also' applicable in organic systems, as a collateral benefit (e.g., fully automated digital chicken production facilities (Zinke, 2021). However, we expect that the big corporate players will eventually begin to advertise their digital technology proposals as 'also' suitable for organic systems where they embrace and comply with the requirements for industrial production and platform business models. This potential application of these platforms for organic agriculture is problematic, as only the technical requirements of organic certification schemes need to be met. Meanwhile, the platforms support the continuation or even exacerbation of industrial production standards into realms where they did not exist before (Alonso-Fradejas et al., 2020).

This approach towards the digitization of agroecological systems has been coined as 'junk agroecology' in a widely publicized report by Friends of the Earth International. They state:

> "[...] the main global agrifood corporations are seeking to redress their worst socio-ecological impacts through the adoption of a model of sustainable agricultural intensification with agroecological nuances. This model seeks merely to introduce some required reforms in order to safeguard the current agrifood and corporate and industrial natural resource use systems from itself. ... For the purposes of 'changing everything so that nothing changes,' transnational agrifood corporations find, in agroecology, a menu of extremely useful solutions that they have decided to selectively integrate into their agro-industrial model." (Alonso-Fradejas et al., 2020, p. 9)

2.4 Ideology written into technologies

We note that the current discourse on the digitalization of agriculture is highly technocratic and presented with a supposed neutrality. For instance, the above described digital agricultural 'solutions' promise to lead to greater food security and sustainability by improving precision and productivity in agriculture. However, as Castells (1999) has argued, technology is society, and social values are embedded in technologies. Technology is never neutral, and it is crucial to acknowledge that ideologies are written into technologies in three key ways (Kleine, 2009): Firstly, the explicitly intended (agricultural) futures are written into the design specifications. Secondly, the explicitly stated design specifications are turned into the design of systems, artefacts, and services. Thirdly, designers carry with them internalized and implicit conceptions – both epistemic and normative – which frequently differ from the internalized and implicit conceptions of the clients funding the intervention, as well as the internalized and implicit conceptions of the imagined users (in this case often farmers). Hence, the final technology often cannot be easily accessed and used in different contexts. However, the context of industrialized, high-input agricultural system and agroecological systems differs profoundly.

For example, different agricultural systems balance the four normative aims of short-term productivity, biodiversity, soil health, and respect for local, culturally specific farming practices in very different ways. Many current digital applications and other such tools are focused on (often short-term) productivity gains (see examples below), thus, choosing a particular normative direction. Related design specifications will reflect this and the resulting application will be further optimized to support short-term productivity, with relevant visual prompts and color-coding. Biodiversity, soil health and respect for local, culturally specific farming practices may then not appear at all, neither in the data being collected, the present situation being monitored, nor the recommendations for interventions and production configurated from these data. Consequently, the resulting digital tool may well reflect the normative judgements of the commissioning client which, in the global south, is often a donor or funder, and in the global north, is often a corporation or farmers' organization. However, this may or may not coincide with the normative judgement of the intended users – the farmers. As we will show, at least in our case examples, below, the tool either does not align or at best poorly aligns with agroecological farming goals.

In light of these shortcomings, we ask: How could, and should, digitalization in the realm of food production and agricultural land use be designed to fulfill its much needed supporting role? In the following sections, we offer our analysis and resulting recommendations drawn from a study situated in the East African country of Tanzania.

3 HOW DIGITALIZATION COULD SUPPORT THE TRANSFORMATION OF INDUSTRIAL AGRICULTURAL SYSTEMS INTO TRULY SUSTAINABLE AGROECOLOGICAL SYSTEMS

A key problem is the lack of principles for ICT applications in agriculture that seek to orient the integration of ICT towards supporting context-based, farmer-centered transitions to agroecology. This has been pointed out in a recent report published by IFOAM, where Tisselli and Hilbeck (2020) offer a set of guiding principles that were developed along the 'Ten Elements of Agroecology' proposed by Food and Agriculture Organization (FAO) (FAO, 2018). The 'Ten Elements of Agroecology' of the FAO are the result of a process that synthesized scientific studies with discussions held at FAO's multi-actor regional meetings (FAO, 2018). According to FAO, the 'Ten Elements of Agroecology' are interlinked and interdependent, and are intended to serve as an analytical tool that "can help countries operationalize agroecology" as well as a guide for "policymakers, practitioners, and stakeholders in planning, managing, and evaluating agroecological transitions" (FAO, 2018, 2). These ten elements served as starting point, and were translated into corresponding principles for what we coin 'ICTs for agroecology' (ICT4AE). These principles are proposed to serve as a guideline for actors involved in the design, development, implementation, and evaluation of ICT tools and platforms within agroecological programs.

In this paper, we use case examples from two long-term projects situated in Tanzania. The first project is an analysis of data collected within a mapping project of digital agriculture solutions (see Box 2 and Table 1) to discuss the practical application of digital agriculture in Tanzania from an agroecological perspective. The examples in Table 1 were selected with the objective to showcase the diversity of available applications (focus, technology used, implementing partners, etc.) in more detail, and a complete list of the 94 identified digital agriculture solutions is available in Box 2. The second project, the Ugunduzi application, serves as case example for how to implement the outlined ICT4AE principles to the design of an ICT application for use by smallholders in agroecological farming in Tanzania.

3.1 ICT for agriculture initiatives in Tanzania

The Global South is increasingly framed as an "untapped market" and touted as a lucrative business opportunity (Deloitte & Mastercard, 2017; GSMA, 2022a; GSMA 2022b). The digital agriculture sector in Africa alone was estimated to bring in a revenue of 2.3 to 5.3 billion

Euro in 2019 (Tsan et al., 2021) and has attracted the attention of both old and new players. The number of digital agriculture initiatives have proliferated globally and the Global South – and Africa in particular – hosts a crowded and rapidly growing landscape of digital agricultural services (Aker et al., 2016; ITU & FAO, 2022).

Tanzania has experienced a rapid mobile penetration and a parallel growth in investments in digital services, including within the agricultural sector, and is therefore an interesting case study. We have – through a related PhD project (McCarrick, in preparation) – identified and mapped 94 past, current, and planned digital agriculture projects, applications, companies, start-ups, services, and initiatives developed for the Tanzanian context (see Box 1). They were identified as part of research that took place from 2018-2022 which used qualitative interviews, focus group discussions, and ethnographically inspired participant observations with over 250 farmers in Kikwe Ward in Meru District and Ubiri Ward in Lushoto District. The research also conducted a three-week pilot project in northern Zanzibar, and carried out key informant interviews (e.g., digital agriculture practitioners, agricultural extension officers, and government officials) and desk research.

Box 2: Past, current, and planned digital agriculture projects in Tanzania

TAHA Kilimo App[8], TAHA Information System (TIS)[9], Mobile Kilimo (M-Kilimo)[10], WeFarm[11], LandPKS[12], Fertilizer Optimizer[13], Viamo Platform[14], UZA EAC[15], LandLinks/Mobile Application to Secure Tenure (MAST)[16], MkulimaHub[17], Plantvillage Nuru App[18], eHakiki/T-Hakiki (Harnessing Agricultural Know How for Inputs)[19], Ugunduzi, Kilimo Fresh Foods Africa Ltd.[20], Digital Inputs Financing Toolkit (DIFT)[21], Kilimo Smart[22], Akilimo[23], Ninayo[24], Kilimo Taarifa[25], Kilimo Utabili[26], Doctor Kilimo App[27], AfriScout[28], AfriFARM (Fall Armyworm Response Mechanism)[29], Kilimo Tanzania[30], Seaweed Farmer Project (Zantel), East Africa Fruits[31], GreenFingers Mobile[32], Pakacha[33], Kilimo na Ufugaji[34], eSoko[35], m-Kulima[36], MyAgro[37], Metajua[38], Upscaling Technologies in Agriculture through Knowledge Extension (UPTAKE)[39], Jembe Kilimo[40], Jembe[41], Porphyrio[42], Kigoma Joint Programme[43], weightCAPTURE[44], AgriManager/Agroforce/Virtual City[45], Dairy Farmers Information System (DFIS)[46], Yara Connect App[47] / Yara CheckIt[48], Seed Tracker[49], Tigo Korosho[50], KilimoGuide[51], mFarming[52], Ushauri[53], Knowledge Plus (K+)[54], Livestock Information Network Knowledge System (LINKS)[55], AgriTechs[56], AgroBot[57], MAMIS (Mviwata Agriculture Market Information System)[58], Nyanya ni Pesa (Tomatoes are Money)[59], COSITA/Farm Africa[60], Relationship Information Tracking System (RITS)[61], Z Kilimo[62], Ushauri Kilimo/M-FAIS/W-FAIS[63], Tigo Kilimo[64], Shamba Konnekt[65], Kilimo Fasta[66], Kilimobiashara[67], Tanga Fresh/MyPhoneExplorer[68], Ilovo Sugar[69], GeoFarmer[70], Agripath[71], AgriMark[72], Anzia Sokoni[73], mobileCHAPONA[74], mobile holistic climate service[75], Fertilizer app (University of Illinois)[76], Kuza One[77], Plantix[78], Agricultural Innovation Pilot Project[79], Alternative Exchange (trading platform) in Eastern and Southern Africa[80], E- License application for Exporters of Agri-products and Agricultural ERP[81], eKilimo[82], Food Processing Software[83], Iringa – Mitigation, Adaptation, Productivity for Climate Smart Agriculture (IMAP4CSA)[84], Jambo Maisha[85], Jumo[86], Keep an eye on Poultry Business[87], Kilimo Klub[88], Mobis[89], More Than Cashews[90], Mukuru App[91], NAAT APP (Netherlands Alumni Association of Tanzania App)[92], Obus[93], Robotech Lab[94], SAGCOT Integrated Knowledge and Information for Agriculture (SIKIA)[95], Smart Village Agri Hubs[96], SmartFarmer[97], Ubia Soko[98], iProcure[99], Farm Clinic[100], e-Sokoni tz . and Big Data analysis (CEMA, 2017).[101]

Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
Mobile Kilimo (M-Kilimo) Currently live. Initiated in 2015, pilot conducted in Dodoma in 2020, and launched later the same year.	• SMS and web-based service • Government run initiative to digitize agricultural extension services and provide a digital marketplace for farmers. Targets all farmers and extension workers in Tanzania • Farmers submit questions via SMS to extension workers, who respond via the online portal. The webpage also includes other functions such as a digital marketplace for agricultural produce. • Available in Swahili and English.	• Non-commercial government service for farmers and agricultural extension workers • Developed by the Ministry of Agriculture and Economic and Social Research Foundation (ESRF), implemented by Ministry of Agriculture and funded by United Nations Development Programme (UNDP).	5.544.421 Household heads had been registered. By January 2022, the system had handled a total of 17.906 consultations with farmers.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
WeFarm Recently closed down in Tanzania, now only available to online users in Kenya. Founded in 2015. Service available in Kenya. Used to be available also in Tanzania and Uganda.	• Until recently hosted a SMS based service. Has been replaced by an online platform which is initially only available in Kenya • Aimed at facilitating farmer-to-farmer knowledge exchange. Farmers were previously able to send questions via SMS and get answers from other farmers via crowdsourcing. • The agricultural focus was defined by the questions submitted by farmers. The service was focused on fulfilling farmers economic potential and to maximize agricultural productivity.	• Founded and run by the commercial company WeFarm, which is backed by various venture capitalists. • Aims to remain a free service for farmers. On their website they openly declare that they aim to earn income by selling data on agricultural trends based on the real-time data from all the questions and answers submitted by farmers.	2.4 million famers have used the SMS service, 37 million conversations have been held on the platform.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
Fertilizer Optimizer App Currently live. Project implementation phase in Tanzania 2013-2017, mobile application launched 2018. The application was developed for 13 countries, including Tanzania, Burkina Faso, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Uganda, Zambia.	• Android Application • Aimed at advising farmers on how to optimize their use of industrial fertilizers to increase their productivity and maximize their financial returns. • The application is built for 13 African countries, but is only available in three languages (English, French, Portuguese), of which none is a local African language, including Swahili.	• Carried out as part of the OFRA (Optimizing Fertilizer Recommendations in Africa) project with Centre for Agriculture and Bioscience International (CABI) as the main implementor. The local partner in Tanzania is Tanzania Agricultural Research Institute (TARI). • Funded by AGRA (Alliance for a Green Revolution in Africa) and GCRF (Global Challenges Research Fund).	No user statistics available. Low activity after launch of the service due to lack of funds for awareness raising and training.
T-Hakiki Status unconfirmed. Launched in Tanzania in 2018.	• Free Unstructured Supplementary Service Data (USSD) based system • Allows farmers to verify if their inputs (seeds and pesticides) are authentic or counterfeit by sending a unique serial number found on the input packages. • Available in Swahili.	• Government funded service, implemented by Tanzanian private company Quincewood.	No user statistics available. Aims to have 2.000.000 users by 2022.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
TAHA Information System (TIS) Currently being updated.	• SMS based service. • Market price information service for horticultural crops, freely available on all mobile networks in Tanzania. Can be used on any device and requires basic digital skills and literacy. • Aimed at horticultural farmers, includes market prices from local markets • Available in Swahili.	• Designed and funded by Tanzania Horticulture Association (TAHA), a private Tanzanian NGO financed through membership fees from farmers, agro-dealers and other players in the horticultural value chain.	No user statistics available.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
Akilimo Currently live. Implemented in Tanzania, Nigeria, DRC, Ghana and Kenya.	• Available through smartphone application, SMS, Telegram, Interactive Voice Response (IVR), or a printed leaflet. Multiple channels aimed to allow access to the service. regardless of ICT access, digital skills, or literacy • Digital decision-support tool for cassava farmers who can access pre-packaged information and agronomic advice through a variety of channels. • Focused on delivering practical advice on how farmers can choose, apply, and maximize the benefits of industrial fertilizers for cassava production, and increase their income. The smartphone app recommendations are based on the user's GPS location, the size of the plot(s), and prices. • Available in Swahili and English.	• Implemented by IITA as part of the African Cassava Agronomy Initiative (ACAI). • Funded by the Bill & Melinda Gates Foundation. • Implemented with Arifu and Viamo as partners.	No user statistics available.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
The Mobile Application to Secure Tenure (MAST) Currently live. Piloted in 2014-2016. Rolled-out in 2015-2019. Also implemented in Burkina Faso, Kenya, Namibia, and Zambia.	• Smartphone application • Focused on land rights and tenure administration. The app is used as a tool within a larger participatory, community-centered mapping methodology to obtain formal and transparent land rights with the involvement of multiple stakeholders • The application is compatible with the Government of Tanzania's land administration system.	• Not built on a commercial business model, donor funded as part of United States Agency for International Development's (USAID) Feed the Future initiative in Tanzania.	No user statistics availble.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
Yara CheckIt Currently live. Available for 69 countries, plus a global option for general information.	• Smartphone application. • Allows farmers to diagnose nutrient deficiencies, get advice, and input recommendations based on visual evidence. • The application is meant to be a decision-support tool for farmers to help them chose which of Yara´s products can help them prevent or treat a crop's nutrient deficiency. • Available in English (and a number of local languages for other countries, but not Swahili.	• Developed and owned by Yara International ASA, a Norwegian chemical company.	No user statistics available.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
Land Potential Knowledge System (Land PKS) Currently live. Initiated in 2013. Has a global focus, and has been piloted specifically in Tanzania (and five other countries). A new updated version of LandPKS is forthcoming.	· Open-source smartphone application and web-based service. · Decision-making tools that provide site-specific information for sustainable land management. · Farmers can record information about their farm (e.g., soil and vegetation) in writing and by submitting photos, and can access site-specific information about soil predictions and climate information. The website focuses on soil and ecological site information to support decision making, as well as vegetation monitoring and restoration. Data is aimed at supporting farmers in the improvement of soil health and productivity. · The service supports various approaches to land management including traditional, regenerative, and organic. · Available in Swahili, English, Spanish, and French.	· Developed by Agricultural Research Service of the United States Department of Agriculture (USDA-ARS) with funding from USAID, together with a range of partners · The service is available for free to all users. · Available in Swahili, English, Spanish, and French.	User statistics not available for Tanzania.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
The Viamo Platform (3-2-1 Service) Currently live. Available in a wide range of countries across Africa and Asia.	• IVR based service available on the Vodacom network. A few calls per month are free, subsequent calls are charged for. • Provides pre-packaged information on climate-smart agriculture, maize agriculture, and weather. • Designed to reach offline populations, avoids literacy challenges by being audio based. • Available in Swahili.	• Developed and run by private company Viamo (previously Human Network International), in partnership with local mobile network operator Vodacom.	User statistics not available.

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Table 1: Detailed overview of digital agriculture projects in Tanzania			
Name and status	**Description/Focus**	**Funding & Business Model**	**User Statistics**
Plantix – your plant doctor Currently live. Founded 2015 in Germany, launched 2017 in India.	• Through the smartphone application or WhatsApp, farmers take and submit pictures of their crops to get free crop diagnosis of infected plants. The app also gives advice on how to treat pests and diseases. • Submitted photos to the app are analyzed using machine learning and artificial intelligence algorithms. • The app includes a social network for farmers and a planning tool where farmers can get weekly action plans, a fertilizer calculator, and access best practices.	• Plantix is a commercial company. • Data from users of the free Plantix services are commodified and sold to paying users, e.g., Plantix Analytics, which sells access big data on pests and diseases. They also have Plantix Vision, where customers can pay to use and integrate Plantix´s image recognition technology in other Agricultural technology (AgTech) applications or services to customers.	More than 15 million downloads globally.

Our findings illustrate the crowded digital agriculture space in Tanzania. There is a lack of available, transparent, and easily accessible information about what digital agriculture work exists, its current status, and related specifications, which makes keeping up with the rapidly changing landscape challenging. Thus, there is a high probability that additional ICT work exists that we were unable to identify. These challenges can be exemplified by the fact that a recently published report by Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA, 2022) identified 27 agricultural innovations, while another recent paper (Mushi et al., 2022) only identified 8 ICT agriculture tools – in contrast to the 94 we have identified. This lack of transparency poses a challenge both for the imagined users of these services (e.g., lack of awareness among farmers about their existence and information on how to use them) and practitioners (limited awareness leading to lack of interoperability, duplication, and failure to build on lessons learned).

Our data shows that there are a large number of applications, services, and projects with a wide range of agricultural assets (e.g., crops or value chain specific) and technologies (e.g., drones, internet, SMS, USSD) for the agricultural sector, and that these are implemented by an equally diverse set of actors (e.g., start-ups, NGOs, technology companies, agricultural companies, mobile network operators, government, universities, etc.). Although the available information on the various identified solutions varies greatly, what is clear is that a majority – if not all – align partly or fully with conventional and industrial approaches to agriculture.

The extensive work on digital applications for agriculture that has been carried out in Tanzania and continues to be developed, should not be dismissed. Indeed, some of the identified solutions may fulfill some elements of agroecology, and could be useful and valuable, but only if applied within a larger agroecological strategy of transformation. For example, several organizations (e.g., Viamo Platform, Akilimo, TAHA Kilimo, LandPKS) have put significant effort into making their solution design and content farmer-centered and widely accessible, which aligns well with parts of the principles we present in this paper. At the same time, it is clear that the narratives, ideologies, and assumptions (which are embedded in the software, hardware, content, design, aims, and implementation) in digital agriculture in Tanzania predominantly align with conventional agriculture. Hence, implementation towards agroecological goals would be collateral and coincidental. A clear example is the focus on the use of industrial fertilizers – in itself incompatible with agroecology – which is directly or indirectly promoted by many services (e.g., Fertilizer Optimizer App, Akilimo). We therefore argue that digital tools for use in agriculture need to be developed which have, as a primary goal, strategies for agroecology and the transition to ecological systems embedded in their design and content – whether in the Global South or North. Agroecology cannot be adopted piecemeal (see Alonso-Fradejas et al., 2020 on 'junk agroecology'), but needs to be systemically embraced. While a strategy to enable this is still lacking, digital tools like ICT applications may play a role in supporting this transformative process across a range of contexts. In the following two sections, we hope to be able to illustrate how applying such principles to the development of ICT tools could more effectively support the transition to agroecological farming systems.

3.2 Application of ICT4AE principles to ICT applications for agriculture in Tanzania

In this section, we discuss each ICT4AE principle (along the 10 elements of agroecology) by applying them to the ICT applications from the above mapping project in Tanzania.

3.2.1 Diversity

The principle of diversity highlights the importance of integrating – as contextually appropriate – a range of locally relevant media and favoring interoperability. The context specific affordances and limitations of various ICTs must be examined to understand how ICTs are and are not used by different groups of people in the context(s) where the ICT4AE tool is imagined to be used. Diversity thereby entails the examination, and possible assimilation, of previously existing socio technical strategies in support of agroecology that may enhance or complement the implementation of a ICT4AE tool.

In Tanzania, available data clearly indicates that digital access is growing (GSMA, 2021; TCRA, 2022). However, measuring and understanding digital access, use, and ownership accurately and meaningfully is notoriously difficult in Global South contexts, such as Tanzania, due to common use practices such as multiple sim-cards and sharing of devices (e.g. de Lanerollo et al., 2017). We argue that digital access needs to be understood as a non-binary concept (Roberts & Hernandez, 2019) where multi-layered digital access barriers shape farmers' digital realities in ways which are difficult – if not impossible – to comprehend through subscriber statistics alone. In addition, the application of digital agriculture in Global South contexts has been found to have lacked a gendered lens (GSMA, 2022b).

In Tanzania, we found that the design and implementation of many digital agriculture initiatives are misaligned with farmers' digital realities and situated communicative ecologies. Farmers' digital access is shaped by multiple, and varying levels of access barriers, such as accessibility, affordability, awareness, abilities, and agency (Roberts & Hernandez, 2019), as well as socially formed, frequently gendered use of time and space (Kleine, 2013). These barriers shape farmers' ICT use and non-use patterns. Yet, an overwhelming majority of identified services in Tanzania require the farmer to access and use a smart device and the internet. Out of more than 90 initiatives, only a handful (e.g., M-Kilimo[102], WeFarm[103], Akilimo[104], T-Hakiki[105], Ushauri[106], and Viamo's 3-2-1 service[107]) have attempted to design digital agriculture accessible on basic mobile phones, which were the dominant handsets used by the more than 250 farmers in our study. By failing to accurately incorporate farmers' existing knowledge systems, and lacking an understanding of the context specific digital access barriers for different groups of farmers, ICT4AE is less likely to be useful, accessible, and used.

3.2.2 Co-creation and sharing of knowledge

The second principle emphasizes bottom-up, participatory approaches to the co-creation of knowledge (Altieri, 2002). ICT4AE should aim to create tools that combine top-down, bottom-up, and peer-to-peer modes of communication, with the overall aim to foster co-creation of situated agroecological knowledge. This stands in sharp contrast to the frequently top-down approaches that dominate conventional (digital and non-digital) agricultural extension programs (Rivera-Ferre, 2012). Farmers need to be recognized and valued as holders and creators of knowledge. In practice this means including farmers in meaningful ways at every step of a project life cycle. A failure to do so is by extension an act of epistemic injustice (Boogaard, 2021) as farmers' knowledge and existing multifaceted communication pathways are undermined and disregarded in the design and content of the tool.

To unpack co-creating digital development in practice, one needs to start by asking when and how inclusive, participatory, and co-creative processes are meaningful, and when they may be (fully or partly) performative. Our Tanzania case study illustrates a multiplicity of incentives as to why, when, and how imagined end-users and beneficiaries are invited or excluded during different phases of digital agriculture projects.

First, conventional digital agriculture initiatives tend to be designed to deliver pre-packaged solutions to farmers who are framed as passive information recipients (Tisselli, 2016).

Several identified Tanzanian digital agriculture services include end-users and/or content experts in the design process and/or use two-way communication (e.g., Ushauri, Viamo Platform, m-Kilimo). At the same time, pre-packaged top-down information services which – by their very design – frame farmers as passive information recipients are common. Among services which have been designed to accommodate two-way-communication – e.g., Mobile Kilimo – the predominant focus is transfer of knowledge from 'expert' to farmer. Such top-down approaches to information dissemination rest on assumptions that Tanzanian farmers need and want certain types information and knowledge, and that that knowledge is held and produced by external 'experts." By extension, we argue that this disregards and devalues farmer communities' ways of knowing and doing.[108] We also want to highlight examples of services which recognize and value farmers as holders and creators of agricultural knowledge, with the (now in Tanzania discontinued) WeFarm – which used to offer an SMS based platform where farmers answer each other's questions – being the most notable example.

Secondly, our findings highlight the importance of meaningful participation. An example from Tanzania is the Fertiliser Optimizer Application[109] – a smartphone-based decision-support tool to optimize fertilizer use in 13 African countries – which involved a local Tanzanian partner in selected stages of the project, but post-launch left the local implementing partner without resources to roll out the finished application or make post-launch content changes.

Finally, there is a need to critically look at who is and is not involved and invited into co-creative processes. Tanzania has a large and diverse population. The growing number of Tanzanian innovation hubs, start-ups, and local digital entrepreneurs does not by itself guarantee that digital agriculture is or will be better aligned with rural smallholder farmers' needs and interests. The lived experiences, priorities, needs, and interests of an urban digital entrepreneur and a rurally based farmer are very different, even if both of their nationalities are Tanzanian. Acknowledging that farmers themselves are in the best position to articulate their needs and interests, diverse groups of farmers must be directly involved at every stage of digital agriculture design, development, implementation, and evaluation. Below, we share a practical example of how principles of co-creation and participation can be successfully applied in the design process of a mobile phone application for smallholder farmers.

3.2.3 Synergies

The third principle relates to understanding ICTs as acting in synergy within broader sets of social, political, and economic actors that jointly seek to strengthen agroecological food systems. By approaching agroecology as a social movement seeking to build cohesion between its different stakeholders (Wezel et al, 2009), ICT4AE programs need to recognize and collaborate with other actors that operate and exist in this context.

We found that human elements of digital agriculture implementation are frequently disregarded and/or under budgeted for, leading to practical challenges but also missed opportunities to build synergies. Although ICTs do offer new spaces for collaboration, they must be considered as complementary and supporting tools with the potential to enhance – rather than replace – face-to-face communication and collaboration. Relationships of mutual trust are mainly built and maintained through physical interaction, rather than through 'smart' and remote modes of connectivity provided by ICT (Turkle, 2011; Kendall & Dearden, 2017).

In Tanzania, the implementation of M-Kilimo has been designed so that the extension workers – who are typically already overburdened with limited resources – are responsible for registering farmers to the service. In one of the author's multi-month ethnographic research in villages in Lushoto and Meru Districts, it was found that extension officers faced many challenges to do so, and the awareness and use of M-Kilimo amongst farmers remained low more than a year after registration had begun. While farmers can submit questions from any SMS enabled device, extension workers can only access and answer farmers questions if and when they have access to an internet-enabled and reliably connected smart device. This incentivizes extension workers to spend more working hours in areas with better connectivity (often offices, homes, and urban areas), which likely decreases the time spent on physical meetings with farmers who typically reside and farm in areas with multiple interlinked digital access barriers. A further unintended consequence is that it incentivizes spending more time with farmers who have the advantage of owning farms in areas with a better phone signal.

3.2.4 Efficiency

The fourth principle advocates for favoring energy-efficient technologies and renewable energy sources, and harnessing the full potential of ICTs – regardless of their level of sophistication. ICT4AE initiatives must identify and eventually integrate the most contextually accessible, efficient, and effective technologies available, regardless of their novelty. Simpler and more widely accessible and used technologies may prove to be the most effective and cost-efficient tools in helping to strengthen agroecological principles and practices.

ICT4AE presents an alternative to contextually detached visions of technological innovation, where new technologies are typically favored and pursued as a standalone business model branded as revolutionary or disruptive (Walter et al., 2017). Many of the digital agriculture services that have been launched in Tanzania imagine supporting farmers in doing tasks with, for example, smartphone applications that farmers that we worked with in Lushoto and Meru were already doing on their basic mobile phones without the 'help' of formal digital agriculture services. Our research in Lushoto and Meru Districts found that farmers creatively navigate contexts of multiple interlinked access barriers by using simple and more accessible digital technology – often basic mobile phones without internet features – in order to maximize their existing social networks and meet their agricultural interests and needs, such as market price information, agricultural knowledge exchange, and communication with buyers. We are not arguing that farmers do so without encountering problems, or that there is no room for improvement (which could or could not be through 'formal' digital agriculture applications). Rather we argue that these creative solutions illustrate the need to understand, value, strengthen, and build upon farmers existing digital practices, instead of replacing them with more 'sophisticated' technologies.

3.2.5 Recycling

The fifth principle highlights the importance of recycling, reusing, and repairing ICTs with the aim of extending their lifespan and usefulness. There are both economic and environmental incentives to limit waste and unnecessary expenditure of resources, such as technological artefacts or energy sources.

In the context of ICT4AE, this principle entails making use of ICTs that are already present and useful in a specific context, as well as repairing, reusing, and sharing devices during and after a project's lifecycle. We found that Tanzanian farmers value their mobile phones highly. Due to financial constraints, many of the farmers we worked with used phones which by many would be considered broken or useless. Unless a device is not functioning at all, resource constrained farmers typically find a way to repair (if they can afford it) or keep using a faulty device. However, to our knowledge there are no digital agriculture initiatives supporting or working with strengthening the repairing, up-cycling, and recycling of old and malfunctioning digital devices in Tanzania. We suspect this is the case anywhere else.

Although – as previously mentioned – the available information about various digital agriculture tools varies greatly, our analysis of available information about them found that it is uncommon to hand out devices to intended users of digital agriculture tools in Tanzania. For example, the nation-wide implementation of M-Kilimo does not provide agricultural extension officers with a device or funds to cover related costs such as purchasing a smart device and paying for mobile data and charging expenses. However, our research in Lushoto and Meru found that not all extension officers have a smartphone, and that use related to out-of-pocket expenses worked as a disincentive for extension workers to use the service regularly. This illustrates the need to understand and design for the various types of resources – including financial and time resources (Kleine, 2013) – which may be required by different categories of end-users to access and use an ICT4AE tool.

3.2.6 Resilience

The sixth principle encourages the design of resilient, sustainable digital agriculture solutions capable of adapting and thriving in challenging socio-technical and environmental settings, such as unreliable internet connectivity, limited resources (financial and other), adverse climate and weather, or limited possibilities to repair, replace, or recycle broken devices. ICT4AE initiatives seek to avoid creating or increasing farmers' dependency on pre-packaged information, monetized loops, and external inputs.

We found that the design of many digital services launched in Tanzania fails to account for the costs farmers must absorb as they learn about, try, use, and continue to use a specific digital service, even one advertised as 'free.' Our analysis used Kleine's (2013) Choice framework's list of resources: material, natural, social, cultural, educational, financial, geographical, psychological, as well as information, health, and time. Farmers' access and use of ICTs often depletes various resources, including time (e.g., walking long distances to buy vouchers, charge a device, find good connectivity; some – especially women – simply can't find the time to use a device) and financial resources (e.g., buying a device, vouchers, and bundles, charging and repairing). In sum, farmers' many needs and wants compete for limited sets of resources; ICT4AE needs to accommodate these to be resilient.

In addition, ICT4AE initiatives aim to encourage resilient agroecological practices, which may be achieved by enhancing participating farmers' abilities to acquire and share knowledge, carry out autonomous research, and strengthen their social networks.

3.2.7 Human and Social Values

The seventh principle highlights the importance of examining locally practised, ethical principles and cultural values and integrating them into the project's tools and methodologies as relevant. ICT4AE avoids socially and ecologically disruptive practices, such as the introduction of technologies and methodologies that disturb or contradict local ethical and cultural values. Here, we recognize that such values are not monolithic; farmers' values diverge. Examples of tools and methodologies which contradict this reality include digital surveillance of farmers' communication and activities, the monetization of farmers' data and metadata through non-consensual extraction, or the implementation of ICT programs with content that encourages decontextualized or poorly modelled practices that may result in the mismanagement of land, crops, or livestock. ICT4AE promotes farmers' full ownership of tools, methodologies, and data, by integrating and centering farmers' views, ideas, knowledge, and values at every step of the process.

In digital agriculture, farmers are frequently reduced to mere sources of data extraction to benefit commercial interests. This can be exemplified by Plantix[110] – a mobile application to which pictures are submitted by users, who are provided with relatively standard (i.e., not tailored) crop diagnosis and treatment advice. Plantix Analytics then commercializes these big data sets on agricultural pests and diseases to paying customers. We found that some digital agriculture services are open about their data management and privacy policies and ask farmers to approve them before beginning to use the application (e.g., LandPKS[111]). However, many services have no information about how user data will be used, or offer information that is difficult to find, access, and fully comprehend. Acknowledging that rural smallholders often have varying levels of literacy and digital literacy and may be most comfortable with oral communication in their (local) language(s), data management information not only has to be available, it must also be accessible and easily comprehensible for farmers' consent to be meaningful and ethical.

3.2.8 Culture and Food Traditions

The eighth principle emphasizes the importance of respecting, understanding, and integrating local culture, traditions, values, and norms. ICT4AE tools and methodologies should support locally relevant crops, foods, and methods of cultivation, preparation, and exchange. The most basic principle of digital development (or any type of intervention) should be to cause no harm. Whilst ICT4AE tools and technical interventions should accommodate local cultural norms, traditions, and beliefs, it is equally crucial to explore and understand who benefits from them, and who may be harmed by them. If existing patterns of inequalities are reproduced in the design and use of digital agriculture, this may exacerbate existing types of marginalization (e.g., if only those in more powerful positions in communities' benefit) or create new types of social, economic, and agricultural imbalances (e.g., if only certain groups adopt new agricultural practices as a result of using digital agricultural tools) (Abdulai, 2022). The goal should not be that everyone in a community uses a ICT4AE tool, but that everyone should have the choice and ability to do so if they want to in order to meet their needs and interests. This goal must include a consideration of how ICT4AE may support women's and men's practical and strategic interests and needs (Molyneux,1985; Buskens, 2015) and avoid reproducing or reinforcing harmful gendered norms and values. For example, recent work in Tanzania (McCarrick, in preparation) indicates that women have less time to use ICTs due to high workloads of productive and reproductive labor, have less disposable income they can put towards ICT related costs due to competing basic needs costs, and are more likely to only have access to a shared device.

3.2.9. Responsible Governance

The ninth principle relates to complementing ICT platforms with corresponding governance provisions that ensure their appropriate usage by integrating a wide range of local actors, organizations, and institutions. ICT4AE initiatives should include contextualized governance guidelines, workflows, and methodologies, which are co-designed and led by farmers and their representatives and provide frameworks for responsible, locally relevant, and accountable usage of ICT platforms. Additionally, ICT4AE governance frameworks should pursue alliances and partnerships with a wider range of local, regional, and global actors, including governments, organizations, and institutions.

It is hard to look at the crowded digital agriculture space in Tanzania without drawing parallels to the early 2010s, when discussions around "pilotitis" (a term coined to refer to resource heavy and unsustainable pilot projects implemented with little or no coordination and interoperability) in the digital health space in African countries was a hot topic in Information and Communications Technologies for Development (ICT4D) research and practice communities (Huang et al., 2017; Ndlovu et al., 2021). In Tanzania we found the sector to be characterized by fragmentation, duplication, lack of coordination and interoperability, and a frequent failure to learn from past and current digital agriculture work in and outside of Tanzania. We found that awareness of the vast array of digital agriculture services that had been launched in Tanzania was extremely low among farmers in rural communities in Meru and Lushoto, as well as among the community of practice (stakeholders that previously or currently coordinate, implement, and fund digital agriculture). It is unrealistic and inefficient to expect farmers who often have limited digital literacy and experience digital access barriers to have the incentives, skills, and resources to learn about, access, and use a wide variety of applications, of which many are narrowly focused on a certain topic or crop.

3.2.10 Circular and Solidarity Economy

This final principle emphasizes the importance of embedding the principles of the circular economy into the design of ICT4AE tools and methodologies. By implementing locally relevant and solidarity business models, minimizing technological resources and digital waste, and reusing and recycling ICTs, ICT4AE initiatives can integrate different economic principles, e.g., the circular economy. ICT4AE should seek to foster solidarity, understood as a reciprocal, non-competitive mode of communication and collaboration in which the well-being of farmers, communities, and ecosystems is always the overriding concern.

Digital agriculture applications in Tanzania are predominantly designed in a way that explicitly and/or implicitly reinforces and reproduces certain ideologies and narratives of conventional agriculture where there is little or no room for alternative futures such as the circular and solidarity economies. The focus on increasing yields, productivity, and profitability, which rests on western cultural values around individualization, is often in indirect or direct contradiction with the cultural values (and benefits) of collaboration and sharing found in Tanzania at the local level. In rural farmer communities, there are existing traditional ways and systems of reciprocity, sharing, collaboration, and support which are often very much in line with the concepts and principles of a solidarity and circular economy. These need to be recognized, valued, and considered as (part of) the solution, not as something that needs to be replaced.

Having critiqued the existing landscape of e-agriculture apps in Tanzania, we offer an attempt at the co-creation of a digital tool along agroecological principles, in a participatory action research project conducted by two of the authors.

3.3 Case example of a participatory ICT design project – the Ugunduzi app

At its core, the ICT4AE principles we developed along the FAO's 10 elements of agroecology comprise a toolbox that supports context-based, farmer-centered transitions to agroecology. What this looks like in practice is unique to each context. The following case example highlights how the participatory design of an application in support of farmer-led research resonates strongly with the agroecological principle of co-creation and sharing of knowledge, the second element of ICT4AE (see above). This principle encourages a dialogue between indigenous/traditional and scientific knowledge that can result in the development of locally relevant technologies or other innovations. Though this became a guiding principle behind the Ugunduzi app, its design was also inspired and informed by other principles of agroecology, such as the embedding of local social and cultural values in the development of new technologies.

On-farm experimentation with agroecological innovations requires on-farm data collection and record keeping by farmers, which remains low among smallholder farmers for reasons such as lack of training, or the volatility of both memory and paper notebooks. Therefore, within a larger research project on agroecology in Tanzania situated in three regions in Tanzania (Masasi, Morogoro, Bagamoyo), a mobile phone application was co-created with farmers that would facilitate and encourage smallholders' recording keeping and on-farm exploration. In the following, we briefly summarize the process of the co-creation of this application with reference to the guiding principles explained above. For a more detailed description of this process, we refer the reader to the respective chapter published by IFOAM (see Tisselli, 2020).

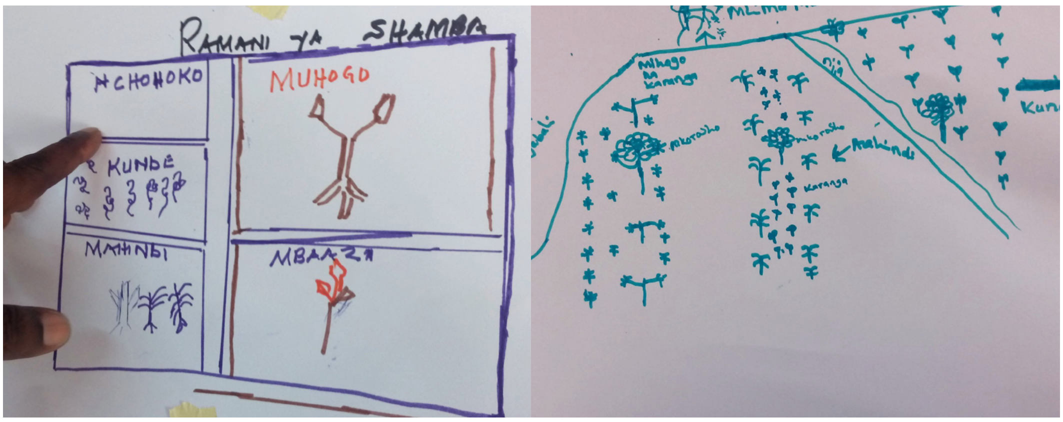
Ugunduzi is an ICT platform, consisting of a smartphone app supported by an online database, that aims to assist smallholder farmers in their record keeping and self-driven research tasks.

With a group of 30 farmers, a series of three co-design workshops were carried out over the period of two years. These were facilitated by one of the authors of this paper. The goal of the first series of workshops was to identify the concepts, elements, and tasks related to research and on-farm record keeping, according to the farmers' perspectives and actual experiences. The main research questions of this initial round were: How do farmers represent their farms visually? What is the farmers' understanding of research? Do they find research important? How, if at all, do they carry out research? What data elements, if any, do they record or would be interested in recording? What units of measurement do they use? Which crops do they grow and which agroecological treatments do they apply in their farms? The conceptual model derived from the answers to these questions was subsequently used to design and develop a first prototype of the platform which, at that time, had no name.

Firstly, farmers were asked to draw and map their farms, including the produced crops, agroecological treatments, and other relevant elements. This activity was inspired by rich pictures drawing, a technique associated with the practice of soft systems methodology, which introduces subjectivity in systems thinking and allows for the inclusion of different perspectives and ways of understanding a common issue. The rich pictures drawing technique is often used to produce subjective pictorial representations of a specific situation, including its various actors (i.e., people and things) (Lewis 1992). The technique allows for the formulation of questions in an open-ended manner.

In group discussions with farmers, topics of agroecology were raised which allowed us to determine the actual level of understanding and practical experience that the farmers had with techniques such as organic pest control, intercropping, and soil fertility management. Subsequently, the discussions addressed the question of research. The aim of these discussions was to explore the farmers' perspectives, without judging or steering their understanding towards more systematic research methodologies. In the spirit of the socially oriented principles of agroecology, the intention was to respect the farmers' ways of knowing. The hope was that discussions related to the what, why, and how of research might raise additional research questions related to record keeping and on-farm practices.

The drawing activity directly addressed the question of how farmers represented their farms visually. Two trends were detected: farms drawn with clearly differentiated and delimited plots, drawn as a grid, and farms drawn in a free style, with no clear delimitations (see Figure 1). Except for three farmers, all represented their farms as a grid.



a) b)

Figure 1: Drawing styles of farms. a) a farm drawn as a grid; b) a farm drawn in free style.

The farmers’ degrees of understanding and practice of agroecological techniques ranged from basic (i.e., notions) to intermediate (i.e., notions and practice). Among these farmers, the understanding of research was essentially a practical one. Farmers defined research as a way to solve problems, and practiced it through observation and the application of advice offered by peers or trainers. However, research was also defined as discovery, translated in Kiswahili as ugunduzi. Discovery thus became the name of the ICT platform.

This first series of workshops gave way to the phase of prototyping, a crucial element of design thinking. The first prototype of the Ugunduzi app for Android smartphones was developed using the Java programming language. The prototype included the following functionalities:

- → Creating a farm: Starting from an empty space, plots could be added, moved, and resized. Imitating the visual representations made by most farmers, plots were placed on the screen as a grid of up to 16 variably sized rectangles (see e.g., Figure 2).
- → Defining the contents of plots: Each plot could contain one or two (intercropped) crops, and one or two agroecological treatments, namely pest control and soil management, or none.
- → Entering plot records: Two types of records could be entered at the plot level: qualitative, consisting of a combination of a picture and a voice recording, or quantitative. Quantitative records were based on the different kinds of activities, processes, and transactions identified by farmers during the workshops (e.g., land preparation, planting, or the cost of seeds).
- → Reviewing previously entered records: Records for a specific plot or for the entire farm could be viewed in chronological order.

From the onset, Ugunduzi was designed to be easy to use, even for non-experts, and capable of functioning in environments with low or non-existent internet connectivity. The prototype assumed the literacy and numeracy of the farmers, which was confirmed during the workshops, and therefore featured a user interface in Kiswahili.

The main goal of the second workshop was to test the prototype of the Ugunduzi app. All participating farmers received a smartphone with a pre-installed version of the app. The aims were to learn: how farmers interacted with the app; what was missing or needed modification; and whether the farmers already kept records or conducted research – if they didn’t, they were asked to enter qualitative and quantitative records relative to crops, treatments, and other activities on their digitized farms for training.

In group discussions farmers provided feedback on the Ugunduzi application, identifying challenges and shortcomings of the prototype, as well as suggestions for improvements. For example, significant differences between the plot layouts and contents of the new drawings and the ones that the farmers had drawn in the previous workshop were detected.

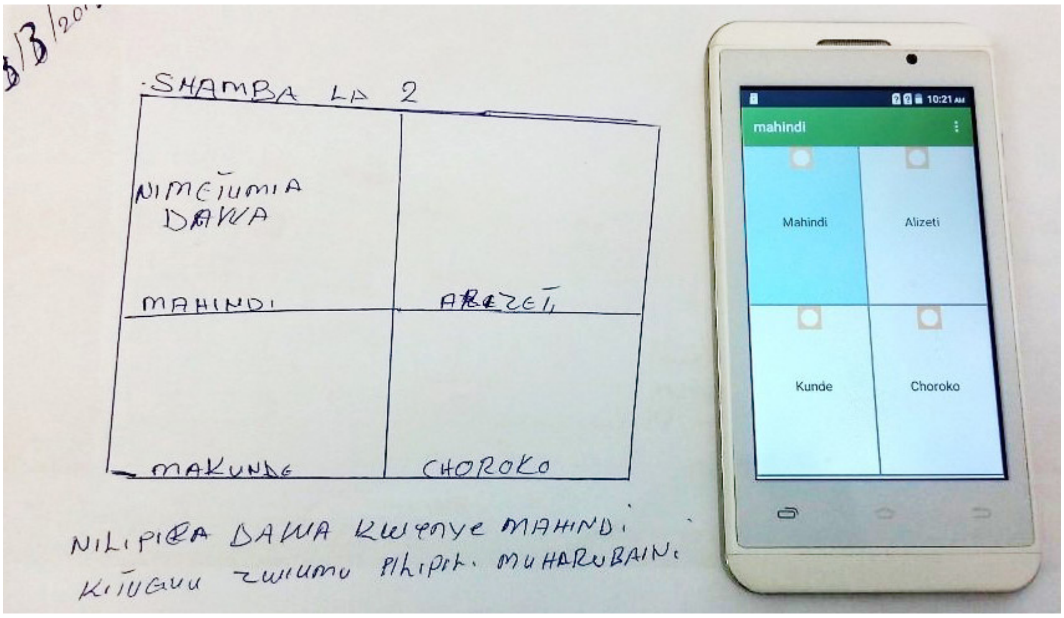
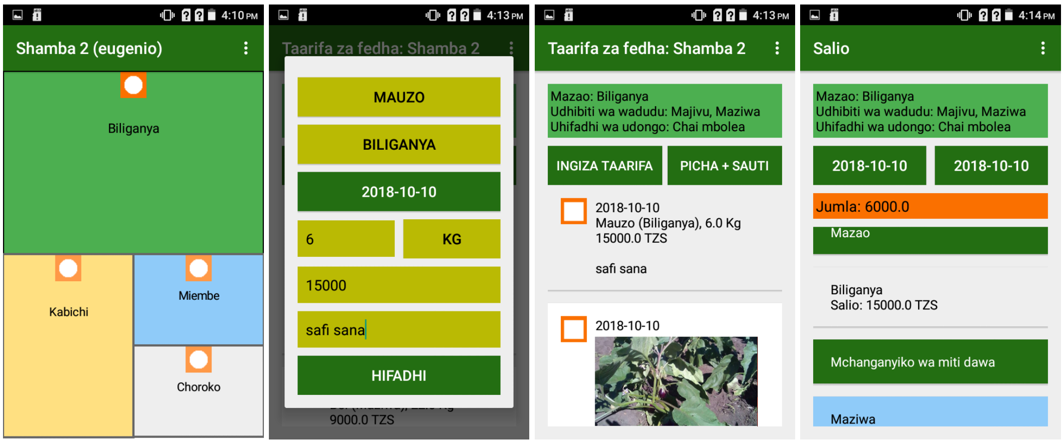


Fig. 2: A farm copied from paper to screen

Subsequently, additional changes to the Ugunduzi app were added. These changes were then tested again in third and final workshop. Training on the operation of the smartphones was repeated, and the new features of the Ugunduzi prototype were explained with the aid of a new version of its user's manual (see Figure 3). Farmers carried out a series of guided, sequential exercises: 1) copying the layout of the farm from paper to screen; 2) adding records to a plot; 3) reviewing the records and consulting the farm's financial balance; 4) modifying the layout of the farm; 5) backing up the farm's records online.



a) b) c) d)

Fig. 3: Screenshot of the Ugunduzi app: a) farm layout. Colors represent different types of agroecological treatments applied to plots; b) entering records for the selected plot; c) reviewing the records of the selected plot; d) reviewing the financial balance of the selected plot.

4 DISCUSSION AND REFLECTIONS

In agroecology, it is argued that farming knowledge is obtained through practice and reflection, while intimate knowledge of the land comes from trial and error and a familiarity with its history. Thus, knowledge is infused with local cultural context and shared in dialogue within the community of practice. This is not necessarily harmonious, as there will be diverging views both within and across generations of farmers, between cultures of production, and between genders. However, through practice, farmers become experts of their own land. Nevertheless, they benefit from further sources of information, examples of good practice, and innovation, while remaining autonomous as they balance different normative aims and different forms of knowledge. In this context, this paper examined the aims and objectives of various ICT interventions and mobile phone applications designed to facilitate best agroecological practice among smallholding farmers in Tanzania.

While we used examples of ICT proposals for agriculture situated in Tanzania as a case study, many aspects may apply in other countries as well. For example, in countries with dual agrarian structures, where highly industrialized agriculture systems exist side-by-side with smallholder farming systems such as those in Tanzania (e.g., South Africa, Brazil, Paraguay, Argentina, Bolivia, and others), there are numerous situations where our findings and conclusions apply. In countries such as the US or many European countries, we also see, alongside industrialized farming systems, highly diverse smallholder farming initiatives proliferating, mostly with the aim to support the agricultural transformation towards sustainability and explore alternative, ecological models of food production. Many of the aspects evaluated above apply in these countries as they do in Tanzania, one example being the principle of designing applications (or other tools) with farmers, while being respectful of their values. Thus, the above presented principles for ICT tools in support of agroecological farming systems and transitions apply everywhere to various extents, as do many of the identified shortcomings of current ICT initiatives on offer.

In another step, we described a vision of a design process that takes into account agroecological principles. The co-design workshops that led to the development of the Ugunduzi app were planned and executed as a series of incremental steps, which were guided by participatory principles and grounded on specific techniques of soft systems methodology and design thinking. The main challenge found throughout this process was striking a balance between the farmers' own understanding of research, based on practical problem-solving approaches, and the more systematic 'scientific' method. Indeed, one of the key findings of the workshops was that farmers had diverse perspectives on the nature, importance, and practice of research. Carrying out research according to scientific methods, such as the establishment of a test plot to compare the performance of crops or agroecological treatments to an untreated control, may yield a higher degree of certainty than ad-hoc problem-solving. However, throughout the workshops, it became clear that the different ways farmers do research needed to be accounted for, since they are embedded in the farmers' culture (i.e., oral exchange of information and advice). Therefore, the Ugunduzi app was designed in a way that allows farmers the choice between drawing control and test plots in order to systematically investigate the effectiveness of an agroecological treatment, or bypassing scientific research by drawing a map of unrelated plots and tracking their progress through basic record keeping over time. This way, Ugunduzi was designed to become just as much a self-reflexive application that may be integrated as part of the daily farm labor, through which farmers can keep track of the performance of their farms over time by looking at past records and using them as a basis for decision-making.

However, the platform could be criticized on the basis that it may potentially benefit only a select group of advanced farmers, while leaving behind others who are unable to advance their practice due to unfavorable socioeconomic conditions or lack of access to smartphones. It is true that Ugunduzi was co-designed with a small group of farmers who were regarded as leaders in their regions. The top-down technology transfer model in agriculture has been questioned precisely on the ground that, by concentrating on leaders and early adopters, it tends to leave out underserved and minority groups. It is also true that the rate of smartphone ownership among Tanzanian farmers is low, which is why devices had to be distributed during the co-design workshops. Nevertheless, the rate is increasing fast and the cost of subscription to mobile broadband has consistently decreased as cheaper devices, including smart phones, have become more widely available. Thus, it is realistic to expect that the Ugunduzi platform can be disseminated and adopted by a larger number of smallholder farmers in Tanzania using their personal smartphones.

Ugunduzi is currently in its pilot phase and is being tested against the real-life scenarios of the farms of the 30 participants. The actual levels of acceptance, usability, and usefulness of Ugunduzi are presently being monitored and evaluated by independent researchers. It is foreseen that, if monitoring and evaluation ultimately yield a positive outcome, the Ugunduzi platform may subsequently be made available to a wider user base in Tanzania, using the ICT4AE principles as a guide in the continued design and implementation work.

In conclusion, if digitalization is to support agroecological transitions, the development and creation of not only ICT interventions but also other digital tools, ranging from hardware to software, requires a centering of the normative choices of farmers themselves and the communities they live in. To respect farmers' autonomy and agency, they need to be actively involved in the design process. Similarly, out of respect for multiple forms of knowledge, different sources of knowledge need to be represented. A pretence of technology as being normatively neutral can lead to an imposition of 'scientific' top-down technological models that have not been produced in collaboration with local farmers and communities. Since these systems and applications are in reality carriers of epistemic and normative decisions, their imposition amounts to a form of epistemic violence. Instead, we propose a process of value-based co-design/creation which starts with local people, their epistemes, and their normative decisions.

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