



Article title: Supporting the capacities and knowledge of small-holder farmers in Kenya for sustainable agricultural futures: A Citizen Science pilot project

Authors: Matthew Davies[1], Muki Haklay[2], Timothy Kiprutto[3], Megan Laws[4], Jerome Lewis[5], Samuel Lunn-Rockliffe[6], Jaqueline McGlade[7], Marcos Moreu[8], Andrew Yano[9], Wilson Kipkorir[10]

Affiliations: McDonald Institute for Archaeological Research, University of Cambridge and Institute for Global Prosperity, University College London[1], Department of Geography, University College London[2], Prosperity Co-Lab Kenya and British Institute in Eastern Africa[3], Department of Anthropology, London School of Economics[4], Department of Anthropology, University College London[5], Independent Researcher[6], Institute for Global Prosperity, University College London[7], Prosperity Co-Lab Kenya[8], School of Natural Resource Management, Department of Forestry and Wood Science, University of Eldoret[9]

Orcid ids: 0000-0001-9740-0622[1]

Contact e-mail: md564@cam.ac.uk

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Supporting the capacities and knowledge of small-holder farmers in Kenya for sustainable agricultural futures: A Citizen Science pilot project

M.I. Davies¹, Haklay, M.² Kiprutto, T.K.³, Laws, M.⁴, Lewis, J.⁵, Lunn-Rockliffe, S.⁶, McGlade, J.M.⁷, Moreu, M.², Yano. A⁸ and Kipkorir, W⁹.

Covering Letter

This case study paper argues that current models of agricultural development in the Global South, and in Eastern Africa in particular, often marginalise small-holder farmers from the process of agricultural design. In so doing, we suggest that important agricultural knowledge and capacities are overlooked and the opportunity to engage farmers in process of innovation and experimentation are lost. Instead we report on a study that engaged farmers in Elgeyo-Marakwet County Kenya in a process of research co-design. Utilising the ExCites Citizen Science approach we worked with farmers to build an Android smartphone application using their own understandings that allowed them to record a variety of agricultural challenges. Pilot testing of the application generated a wealth of proof-of-concept data that speaks to multiple possibilities including further studies of farmer innovation and experimentation but also the potential to spatially and temporally track and respond to farmer challenges related to climate, crop disease and pests.

¹ McDonald Institute for Archaeological Research, University of Cambridge and Institute for Global Prosperity, University College London

² Department of Geography, University College London

³ Prosperity Co-Lab Kenya and British Institute in Eastern Africa

⁴ Department of Anthropology, London School of Economics

⁵ Department of Anthropology, University College London

⁶ Independent Researcher

⁷ Institute for Global Prosperity, University College London

⁸ Prosperity Co-Lab Kenya

⁹ School of Natural Resource Management, Department of Forestry and Wood Science, University of Eldoret

Abstract (up to 250 words).

Sub-Saharan Africa is often presented as the continent most vulnerable to climatic change with major repercussions for food systems. Coupled with high rates of population growth and existing nutritional deficiencies, the need to enhance food production across the continent is thus seen as a major global imperative. We argue here, however, that current models of agricultural development in Eastern Africa often marginalise critical small-holder knowledge from the process of future agricultural design due to a lack of a methodological tools for engagement. This paper addresses this by outlining a potential means to capture and share locally produced agronomic information on a large scale. We report on a 'Citizen Science' pilot study that worked with smallholder farmers in Elgeyo-Marakwet County, western Kenya, to co-design a mobile application using the well-developed *Sapelli* platform that easily allows farmers to identify, record and geolocate cropping patterns and challenges at multiple stages in the agricultural calendar using their own understandings. The pilot project demonstrated the technical and epistemological benefits of co-design, the abilities of smallholder farmers to co-design and use smartphone applications, and the potential for such technology to produce and share valuable agricultural and ecological knowledge in real time. Proof-of-concept data illustrates opportunities to spatially and temporally track and respond to challenges related to climate, crop disease and pests. Such work expounds how smallholder farmers are a source of largely untapped ecological and agronomic expert knowledge that can, and should, be harnessed to address issues of future agricultural resilience and food system sustainability.

Keywords: Citizen Science, *Sapelli*, smartphone, co-design, trans-disciplinary, farmer, agriculture, sustainability, Kenya, Africa.

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Introduction

Sub-Saharan Africa is often presented as the continent most vulnerable to climatic change with major repercussions for agriculture and food systems (Toulmin 2009; Niang *et al* 2014; Carabine *et al.* 2014). Coupled with high projected rates of population growth and existing major nutritional deficiencies, the need to enhance and secure food production across the continent is thus seen as a major global imperative. Contrasting approaches to this challenge tend to emphasise either externally driven technological innovation and ‘Green Revolution’ policies (Otsuka and Larson 2013, Juma 2015; Bergius and Buseth 2019) or prioritise agroecology principles and practices and food sovereignty movements (Altieri and Nicholls 2012; Altieri *et al.* 2015; Hathaway 2016). However, Green Revolution frameworks are often critiqued for promoting unsustainable industrial production processes and chemical inputs whilst simultaneously ignoring the unjust politics of food production and distribution (Holt-Giménez and Altieri 2013; Rhodes 2017; Spann 2017). Conversely, agroecological approaches are subject to criticism for being highly labour intensive and lacking scalability on a level that can meet Africa’s growing food demands (McMichaels and Schneider 2011; Mugwani 2019). More nuanced work emphasises the importance of co-production with farmers, viewing them as potentially pivotal actors within innovation systems (Sanginga *et al.* 2009; Dawson *et al.* 2016; Dolinska and d’Aquino 2016; FAO 2018). Yet, whilst there is much potential for harnessing farmers innovative capacities, there are few methodologies to support such an approach and there remains a dearth of detailed information of the sophistication and complexity of farmers’ knowledge and experimental activities.

This paper addresses this lack of methodology and detailed knowledge by outlining a potential means to capture and share locally produced agronomic information on a large scale. In what follows, we report on a ‘Citizen Science’ pilot study that worked with smallholder farmers in Elgeyo-Marakwet County, western Kenya, to co-design a mobile application using the well-developed *Sapelli* platform that easily allows farmers to identify, record and geolocate cropping patterns and challenges at multiple stages in the agricultural calendar. The pilot project demonstrated the technical and epistemological benefits of co-designing such applications, the abilities of smallholder farmers to co-design and use smartphone applications, and the potential for such technology to enable the production and sharing of valuable agricultural and ecological knowledge in real time. Such work seeks to expound how smallholder farmers are a source of largely untapped ecological and agronomic expert knowledge that can, and should, be harnessed to address issues of future agricultural resilience and food system sustainability.

Background

Smallholder farmers in sub-Saharan Africa are often presented as relatively static, resistant to change and lacking the capacities to innovate in the face of population growth, food insecurity and climate extremes. Such stereotypes fuel calls for external interventions that can all too easily by-pass existing sustainable farmer knowledge and practice and, in the process, fail to understand how external innovations are not simply adopted passively by recipient farmers, but rather creatively incorporated into existing bodies of knowledge and practice (e.g. Davies and Moore 2016). Consequently, many agricultural interventions have either fostered unwanted outcomes or outright failed in their attempts to increase livelihood wellbeing and address issues of food insecurity (Fergusson 1994; Kipkorir *et al.* 1983; Dawson *et al.* 2016).

We propose that a fundamentally different approach is needed that places farmers at the centre of design processes in order to harness local knowledge and practice and collaboratively build sustainable socially and culturally appropriate agricultural futures (Lunn-Rockcliffe *et al.* 2020). In doing so, we advocate for a framework that aligns itself not only with calls for agricultural production rooted in localised 'food sovereignty' movements (Altieri and Nicholls 2012; Holt-Giménez and Altieri 2013), but with research trends that allow farmers to take-back a central role in the design, experimentation and validation process of agronomic knowledge creation (e.g. Waters-Bayer *et al.* 2015; Kerr *et al.* 2019).

The foundations for this argument build from an extensive but often poorly known body of literature that has explored the deeper histories and ethnographies of the long-term sustainability of intensive and highly productive agricultural practice across many regions of Eastern and Southern Africa (Widgren and Sutton 2004; Stump 2013; Davies 2015; Davies *et al.* 2016). This body of work, alongside more recent research on farming innovation within the research regionⁱ, collectively illustrates how farmers in the study region continually engage in creative processes of innovation, selective valuation and intelligent adoption of old and new technologies on a daily, weekly, monthly and seasonal basis.

Importantly for this project, smallholder farmers in the study region and across Eastern Africa are technologically savvy. In Kenya, for example, the term 'digital farmers' constitutes a Facebook group with over 400,000 active members engaging in dynamic forms of information sharing and knowledge exchange. Digital engagement is also evident throughout a plethora of smartphone applications already targeted at African farmers, such as iCow and WeFarm. Whilst no doubt useful tools for many farmers, such applications and digital platforms are often externally designed technologies that offer farmers products or services (finance, marketplaces) that tie them into certain kinds of market relations in ways that can undervalue the abilities, knowledge, and networks of farmers themselves.

As we explore below, we advocate for alternative approaches that build upon farmers' knowledge of smartphone and mobile internet technologies in ways that more readily facilitate the co-design of tools that enhance their own agricultural capacities. At the same time, this project was embedded in longer-term research that seeks to understand the history,

contemporary practice and potential of farmer-led agricultural innovation in Elgeyo-Marakwet, thus providing an effective context in which to undertake such pilot research.

Harnessing small-holder farmer's capacities: A Citizen Science Approach

Citizen Science has multiple distinct approaches, phases and degrees of citizen engagement (Vohland *et al.* 2021; Haklay 2013; Bonney *et al.* 2009). In recent years, the core of Citizen Science work has aimed to empower communities to build, design and then utilise their own research potential. As explored elsewhere (Moustard *et al.* 2021), a majority of Citizen Science projects have focussed on a highly specific problem or issue identified by outside 'experts'. The gathering of data is then used to build an evidential base for or against a certain course of action – such as noise pollution, illegal logging, community rights to land, or similar (Bishop 2021 *et al.* 2021; Senabre Hidalgo *et al.* 2021). Mostly, these problems are identified and projects designed by scientists and researchers who then ask the public to join in by carrying out research tasks that can range from carrying out experiments, collecting data, or analysing images. Less common are Citizen Science approaches designed to broadly capture the knowledge and practices of a community as well their own understanding of the challenges or issues that they currently face.

In 2019, this pilot study worked with a small community of smallholder farmers in Elgeyo-Marakwet County, Kenya, to apply the Extreme Citizen Science approach (Fryer-Moreira and Lewis 2021; see <https://uclexcites.blog>) and trial a process of Citizen Science research co-design. Working with *Sapelli Collector*, a highly customisable mobile data collection application designed to facilitate more inclusive Citizen Science, we used a series of focus groups with n=15 farmers to explore cropping practices and challenges faced at each step in the annual cultivation cycle. Information gleaned from initial focus group discussions was then used to co-design a *Sapelli* Project with the participants. A *Sapelli* Project defines the user and pictorial interfaces that are displayed through the *Sapelli Collector* mobile app (see below for more detail). From the original 15 farmers, a sub-group of six individuals were given a smartphone and trained to use the interface of the *Sapelli* project. With airtime and technical support for a period of four months, the farmers had the opportunity to test the data collection process and to feedback on the application design for subsequent refinement.

After the pilot period, we ran focus groups where the advantages and disadvantages of the application were discussed in detail, allowing us to adjust for future use. This review particularly focussed on the changes that might be required to scale up the use of the application by farmers and to enhance its usefulness to these users. In the section that follows, we further elaborate on this co-design process and on the structure and function of the resulting *Sapelli* application. Following this, we report the results of the pilot data collected and explore the potential analyses and uses that these data might facilitate. In the final section we reflect on the pilot project to date, report on the feedback from farmers and outline future steps for Citizen Science approaches to agricultural sustainability in Kenya with potential applications to other locations in Africa and elsewhere.

Engagement and Participatory Design

The co-design process for the *Sapelli* Project followed that outlined in Moustard *et al.* (2021) and was built on the core principle of Free Prior and Informed Consent (FPIC) and the development of a community protocol to govern the collaboration. This not only involved providing participants with all of the information on the proposed project, but also the active collaborative exploration between researchers and community members to understand potential positive and negative impacts of the project's outcomes. The first phase of work focused on engaging with farmers and agricultural extension officers in order to identify what farmers want to report and map. It was here that the first paper prototype was developed during a participatory design session (Figure 1). Following this, a further session was organised with a small group of farmers and agricultural extension officers to refine the paper prototype and create the pictograms and images that represent the crops and farming issues as identified and classified by the farmers themselves. While *Sapelli* is designed to be inclusive for people without literacy, the use of pictograms and images can be mixed with text where it is appropriate, thereby increasing accessibility for people with medium to higher levels of literacy. In this project the farmers chose to combine easily recognisable pictograms with *Kiswahili* words.

Participatory design is a process that requires multiple paper and digital iterations and real time coding and field testing. While the process often faces time and resource constraints, the well-established *Sapelli* co-design process allows a working prototype for extensive field-testing to be designed in a matter of days. Nevertheless, due to time constraints, the appropriateness of the pictorial interfaces and the navigation flow was tested and discussed with only a few farmers and improvements were based on these few farmers' feedback and the knowledge of the extension officers. Plenary focus groups suggested that the interfaces and navigational flow worked well with only minor alterations suggested.

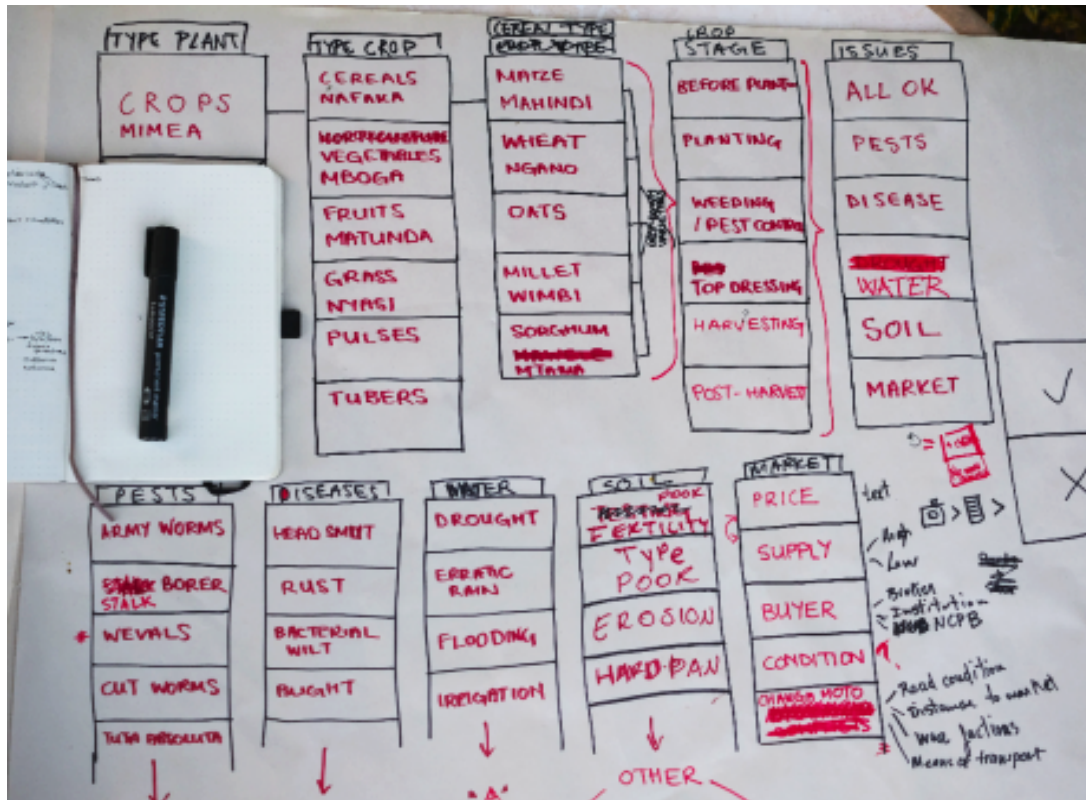


Figure 1. Draft of the co-created paper prototype, which is later on converted into a Sapelli Project.

The Sapelli Project Structure

The technological output of the participatory design process is the *Sapelli* Project that defines which pictograms will be used, how they are displayed in the *Sapelli Collector* mobile app, and what data are stored and transmitted to the database management platform GeoKey (<https://geokey.org.uk/>). This latter is designed to support participatory mapping and visualisation in the Community Maps' user-friendly interface (<https://communitymaps.org.uk/>). The *Sapelli* Project was co-designed to collect and share information about crop type, stage and farming issue. The 33 crops/plants identified were grouped into 6 categories (cereals, vegetables, fruits, grass, tubers and pulses) by the farmers. After the crop/plant is selected, the user is then prompted to select the stage of the cropping cycle (before planting, planting, wedding/pest control, top dressing, harvesting or post-harvesting), and then the type and specificities of any issue (pests, disease, water, soil, market or equipment) currently being faced. The next screens allow the users to provide additional information using text, audio recording or by taking a picture. When the user reaches the last screen, the location is recorded and the user can either record another issue or store and send the data (the data is automatically sent when online and the region was well covered by 3G/4G). Figure 2 shows the work-flow as co-designed and illustrating the visual interface supplemented by written terms in Kiswahili. Figure 3 shows an example of project data and location, with the attribute information of the contribution selected in the map shown in the panel on the left.

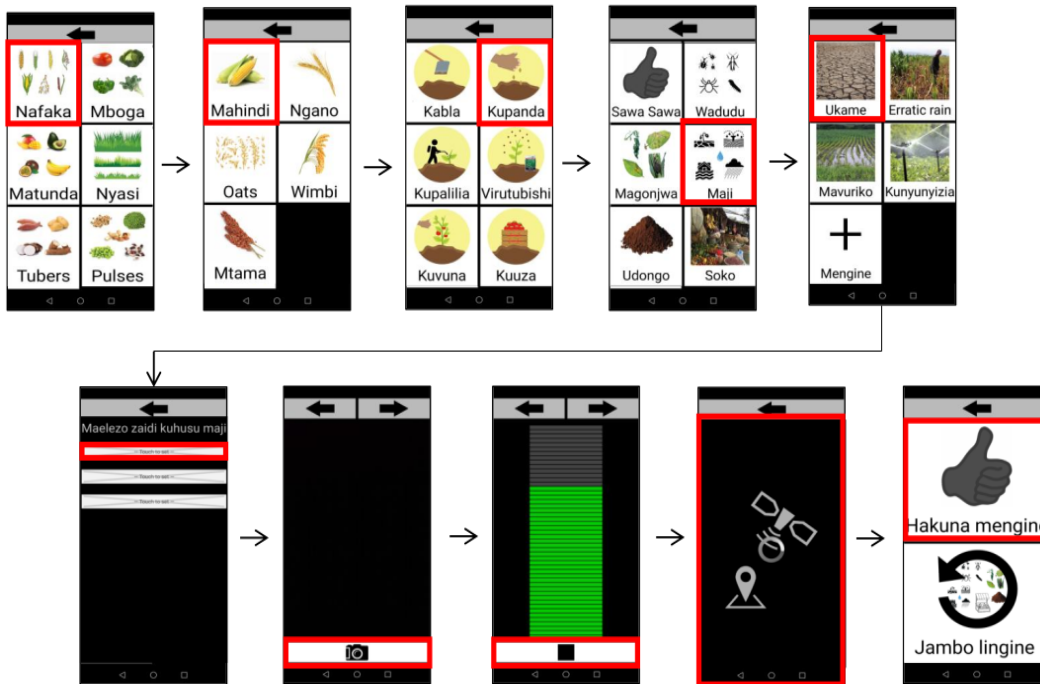


Figure 2. The Sapelli co-designed Project, showing the workflow and pictograms (with captions in Swahili) displayed when cereals and water issues are selected, cereals> maize> water problems> drought> additional text> photograph>voice recording> geolocation> finish/another issue.

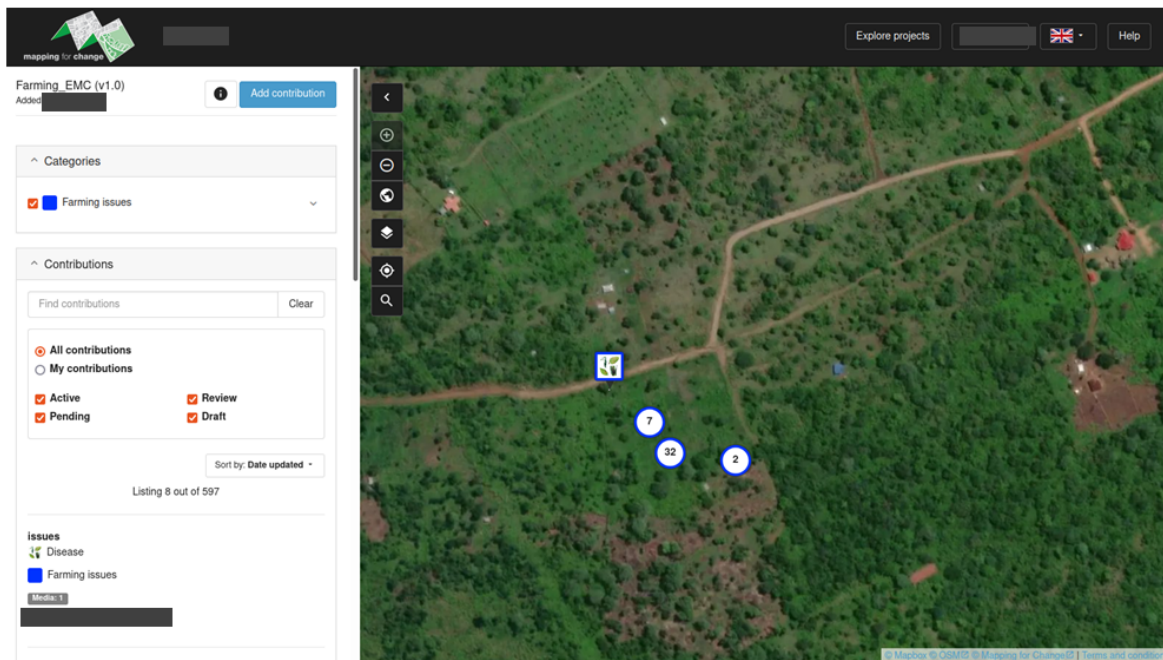


Figure 3. Screenshot of Community Maps showing some of the data points collected by farmers to report farming issues.

Data collection: Results and Preliminary Analysis

Data collection was undertaken by six farmers (F1-6) from April to August 2019 in and around Elgeyo-Marakwet County (Figure 4). All data points collected by farmers were geolocated, but in order to preserve anonymity, locations of research activities are presented here at a low resolution by clustered points according to Device ID (i.e. the smartphone being used by one farmer). Spatial documentation within the context of this project is particularly interesting given that farming practices can vary greatly across the County. This variation is due to the altitudinally contingent ecological and climatic diversity of the region, where the acacia scrubland environment of the semi-arid Kerio Valley (c. 1000 masl) is on average hotter and drier than the forest environments of the highlands (c. 2500 masl).

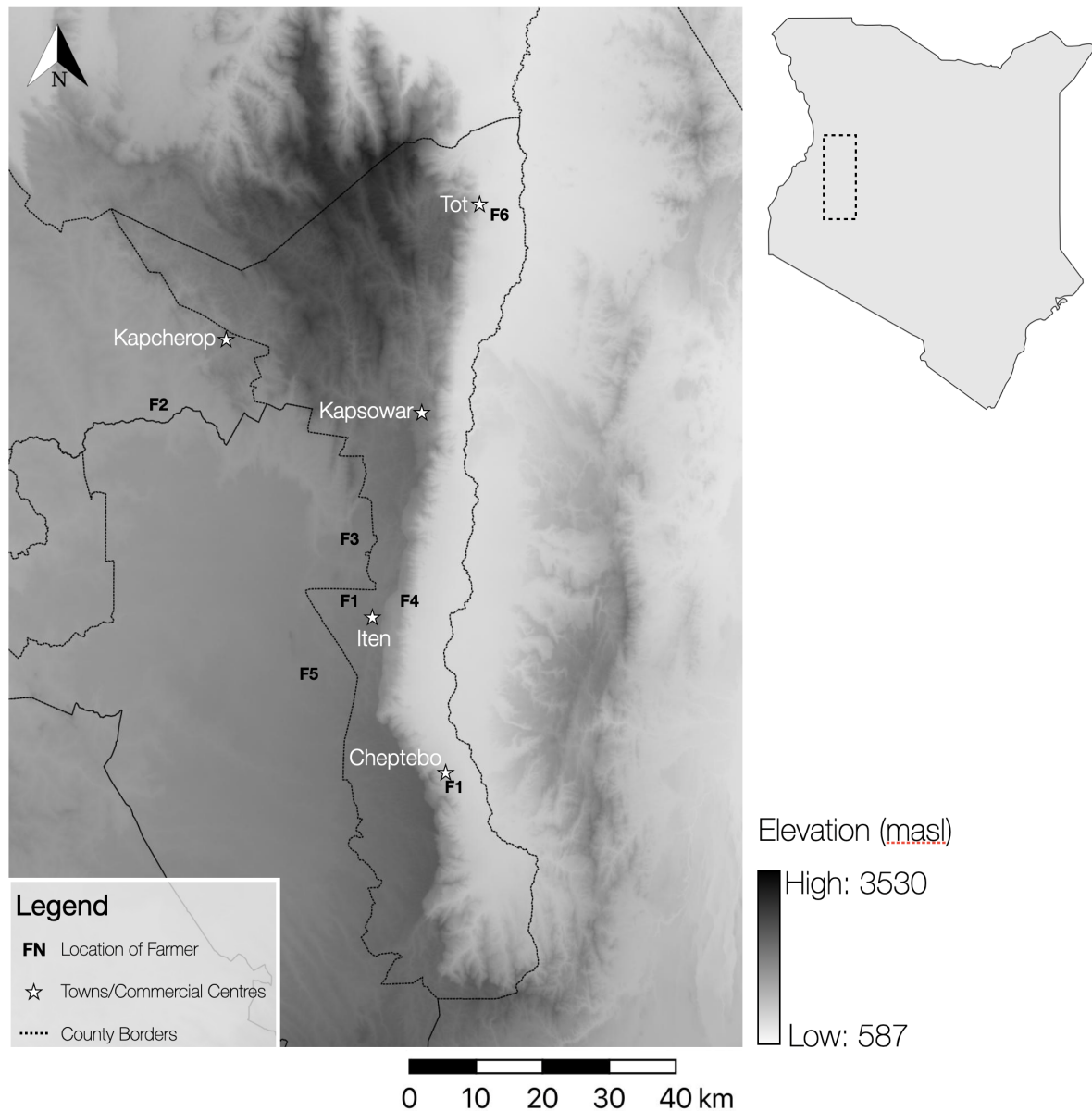


Figure 4. Location of Farmer Activities in and around Elgeyo-Marakwet County

Farmers 2, 3, 4 and 5 undertook work in the highland areas between c. 2000 and 2300 masl, and Farmer 6 collected data in the Kerio Valley in Tot-Sibou village (c. 1000-1200 masl; Figure 4). Farmer 1 recorded data from two plots of land, one in the highlands and one in the valley. A total of 534 data points were taken across the devices, with a mean average of 89 points per device. Across all locations, a total of 31 different foodstuffs were documented (Figure 5), with each farmer recording a mean average 17 different foodstuffs. Of the total amount of crops grown, 39.9% were exclusive to the highlands. All foodstuffs that were grown in the valley were also grown in the highlands, albeit it in much smaller proportions (e.g. mango trees accounted for 21.4% of crops grown in the valley and only 0.7% of those grown in the highlands).

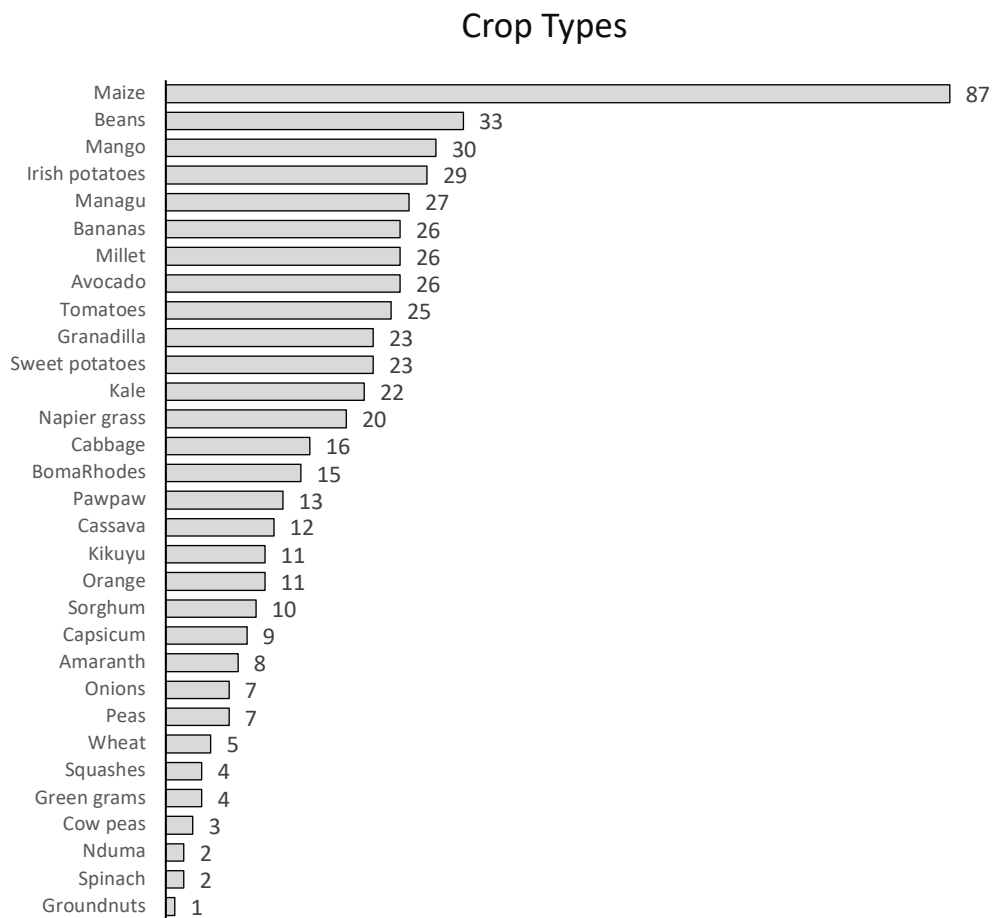


Figure 5. Total number of data points for different foodstuffs collected by the six farmers.

The data captured clearly demonstrate the potential for better understanding and exploring farmers highly resolved micro-ecological knowledge, by illustrating the differing combinations and ratios of crops grown at varying altitudes. For example, as shown in Figure 6, Farmer 1 grows 22 different crops in combination, with the top 5 recorded being (mango 20, sweet potato 16, managu (African nightshade) 11, Avocado 13 and kale 4). Farmer 4 grows 28 different crops, but the top 5 recordings are quite different (Maize 36, tomatoes 16, potato 13, beans 17 and bananas 17). Similar diversity is found across the other farmers, including surprising diversity within

ecological/altitudinal zones. This provides a powerful example of the diversity of farmer practice and farmer-led experimentation recorded in previous smaller-scale and qualitative research (Davies and Moore 2016). These data further speak to opportunities for targeted support with different crop species and the sharing of effective botanic ecological knowledge among farmers in different zones and regions. When collected and analysed longitudinally, such data would also offer potential to understand longer-term changes to cropping patterns, markets and changing ecological and climatic conditions.

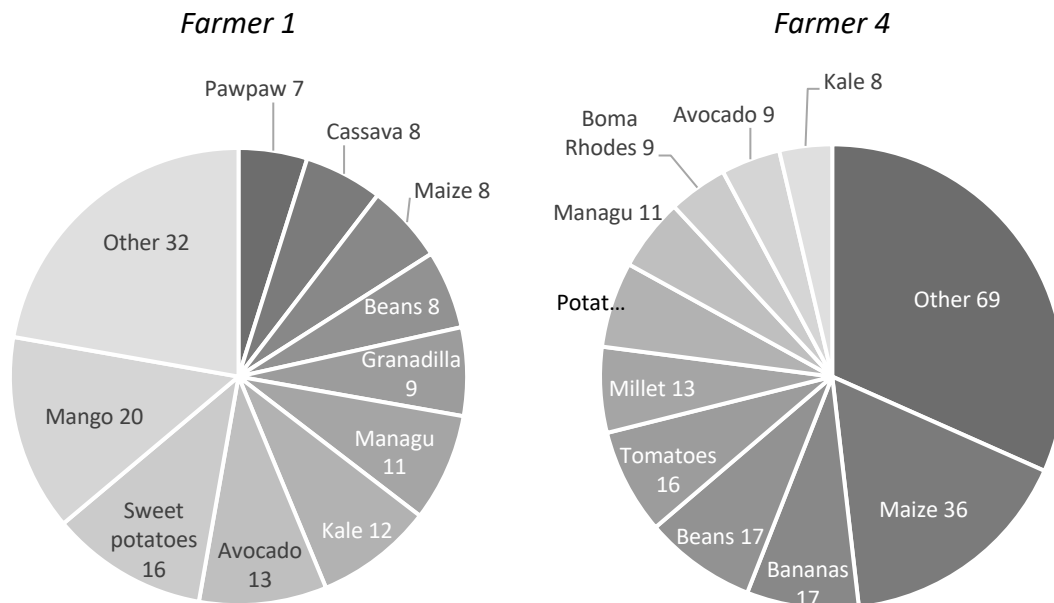


Figure 6. Recorded crops grown by Farmer 1 and Farmer 4 (see figure 4 for location).

Data points for each crop also captured the stage of planting and any associated challenges with considerable potential for real time mapping of the distribution of disease, pests and climatic events such as drought or flooding and the linking of these to critical moments in the cultivation cycle. The greatest percentage of data points were taken at the stages of Weeding/Pest Control (35%) and Top Dressing (33%), followed by Planting (11%), Harvesting (11%), Post-Market (7%) and Before Planting (3%). Issues and challenges documented suggest that 95% of recorded data points had at least one associated issue, of which 31% were related to disease (167 instances of blight, rust, bacterial wilt, head smut or unidentified pathogens). Challenges related to water, including flooding, erratic rain, drought or irrigation, accounted for 29% of the issues encountered. Problems associated with market access and price (14%) were greater than those associated with pests (9%), soil conditions (9%) or equipment (1.5%).

Whilst correlations between crops grown, stages of production and issues encountered remain tentative, it is possible to pick out some relationships from the pilot data. For example, certain crops present distinct challenges, with approximately 60% of mango trees displaying issues with disease in comparison to 22% of Maize crops (Figure 7).

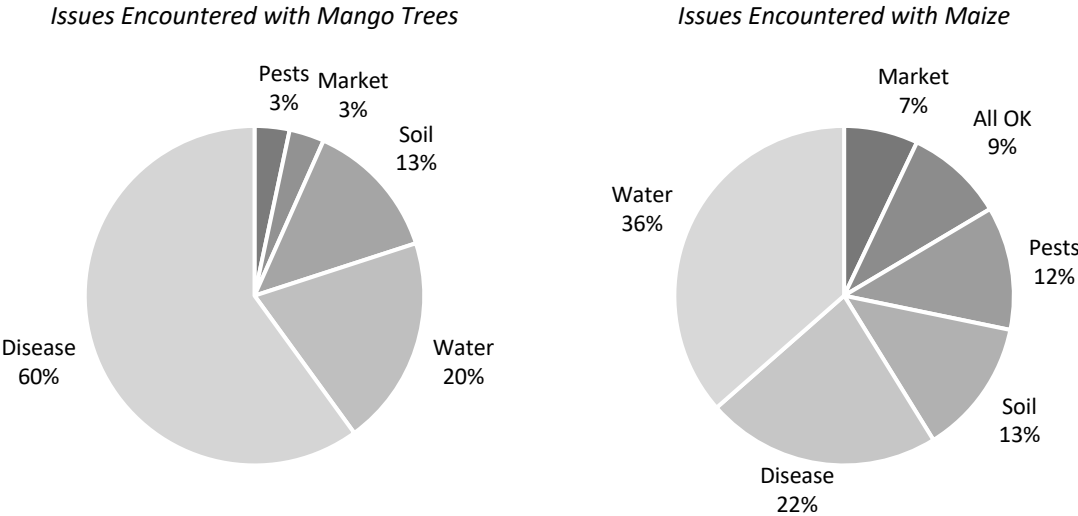


Figure 7. Comparison between challenges associated with Mango Trees and Maize.

Similarly, there are clear differences in the problems being encountered by farmers at the different phases of the cropping cycle, where the challenges associated with poor soil conditions at the planting phase (29%) are far more prevalent than at the top-dressing phase (6%) where disease is more common (Figure 8).

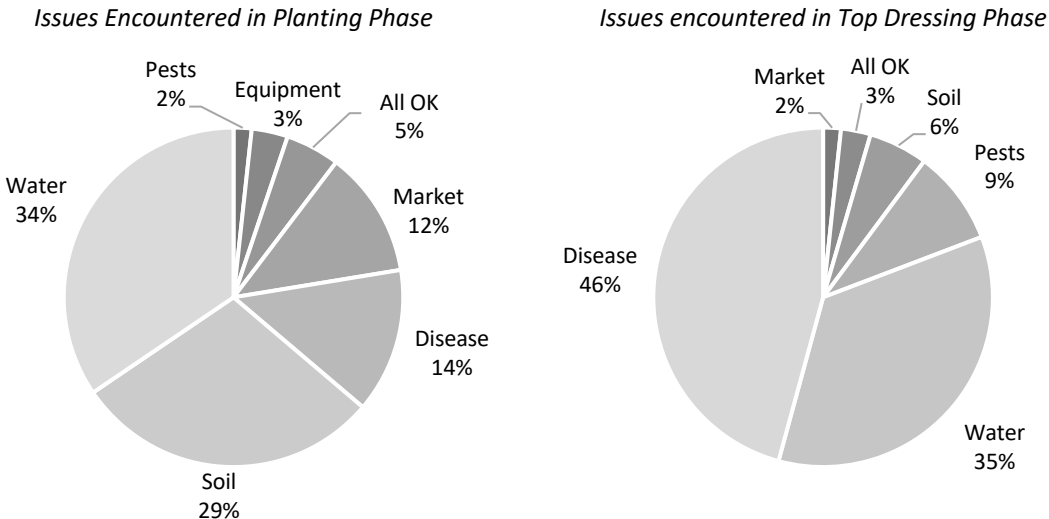


Figure 8. Comparison between cropping challenges at different phases of the cropping cycle.

The spatial distribution of issues encountered by farmers in different locations can also be observed from the data (Figure 9). The greatest issue encountered at lower elevations was with disease, accounting for 41.3% of the challenges of valley-grown foodstuffs, followed by water (28.6%) and soil (16.7%). The greatest challenges in the highlands were water-related (29.3%), followed by disease (28%) and market access (17.8%). As discussed further below, such data clearly lend themselves towards spatially targeted interventions and support.

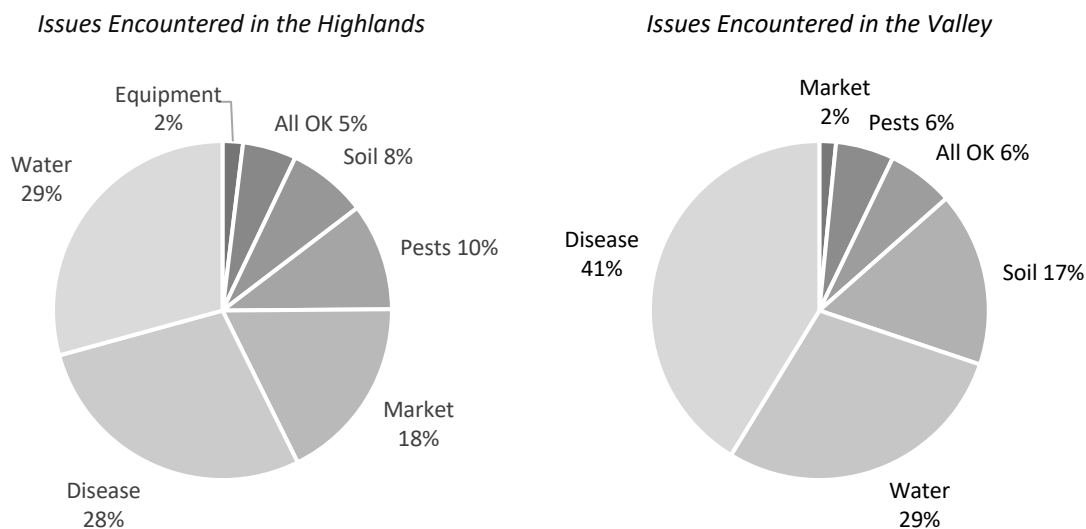


Figure 9. Comparison between cropping challenges encountered in the Highlands vs the Kerio Valley

These preliminary results demonstrate that farmers are planting a huge diversity of crops in interesting and complex ways and have a clear understanding of the problems related to the health of farm produce and market infrastructures. Before we discuss the implications of these data, it is important to point out that preliminary correlations from this analysis between location, crop types and issues encountered must be treated with caution. Indeed, these are not the results of a replicable large-scale technical study with strict controls for measuring specific variables. Rather, data should be seen as proof of concept for harnessing farmer-led data collection procedures and producing an emergent dataset that captures the ways in which smallholders observe and address multiple issues across time and space.

Discussion

The results from this pilot study demonstrate the vast potential behind citizen-led data collection. In the first instance, it allows for the large-scale mapping of farming innovation and experimentation in response to multiple challenges and issues being encountered on a daily, monthly and seasonal basis. With this kind of information being gathered via *Sapelli Collector*, real time data may be shared and knowledge exchanged between farmers, extension officers and

other practitioners within wider agricultural value chains. Participant farmer feedback suggested that the integration of such technologies into messaging (text, images, audio and maps) services for both farmer-to-farmer and extension officer knowledge transfer can help to provide live updates to the challenges and solutions of farmers from across the region (and beyond). If integrated into novel knowledge networks (messaging, open access forums), such technologies may both support immediate livelihoods and stimulate new farmer-led innovations. While user focus group sessions emphasised the need for better knowledge sharing across the project, for better provision for access to airtime and data, and a refined interface for managing data synchronisation, the feedback was highly positive as to the effectiveness and ease of use of the interface and the potential of the project for knowledge sharing and advocacy.

More urgently, equipping farmers with the ability to upload real time challenges may help to capture the changes and impacts associated with climatic events and the movement of disease and pests at multiple spatial (regional, national, international) and temporal scales (hours, days, weeks, months). A concrete example of this can be seen with the early warning systems for monitoring locust swarms that are available on the Locust Hub (<https://locust-hub-hqfao.hub.arcgis.com>). The data for this is collected on the ground by trained field staff using specialist software and hardware, notably the FAO developed eLocust3 monitoring system that offers near-real time data validation and tracking of locust swarms (<http://www.fao.org/3/i6058e/i6058e.pdf>). Whilst perhaps effective for planning and implementing control operations, using eLocust3's technical software and hardware requires multiple training and refresher sessions. As such, the scale at which locust swarm monitoring can be implemented and shared is compromised, thus reducing the spatiotemporal resolution of locust activity that may otherwise be invaluable for the preparedness of everyday farmers.

By contrast, the existence of pests such as locusts was easily coded into the *Sapelli* project and would allow farmers to record their presence as part of wider data gathering on agricultural practice and challenges, and using a simple smartphone interface rather than specialist equipment. With enough participation, real time farmer generated data on desert locust behaviour and movement may be able to provide more fine-grained live information on the time, location and direction of movement of locust swarms or hopper bands. This concept need not only be applied to desert locust swarms, but also the monitoring of pest or disease breakouts such as fall armyworm or blight, as well as the sharing of information on how farmers innovate and experiment to build on-farm resilience and prepare for future challengesⁱⁱ.

The broader point here is that existing systems that monitor ecological and socioeconomic change often lack the ease of use, number of users and granularity of data needed for meaningful local and regional policy making both over the long-term and in emergency or crisis situations. Often policies are based on syntheses that make poorly articulated assumptions about local effects, impacts and mitigation. At best these fail to harness the knowledge potential of farmers and at worst can stand at odds with the perceptions, experiences and aspirations of the communities they aim to assist. With the advent of affordable smartphones and mobile broadband (4G and 5G) across Eastern Africa, it is now possible to work closely with rural communities to collect information on a wide number of ecological and social issues, even where

numeracy/literacy levels are low. Working with policy makers to build farmer-led live information systems may prove incredibly important for enhancing and empowering farmer knowledge and circulating this knowledge to increase preparedness for multiple challenges.

Conclusion

The IAPS project demonstrates the significant potential behind the co-design of Citizen Science data collection. Whilst the results from the pilot work presented are tentative, the value of this project has been to provide a novel example of how processes of co-design and principles of collaboration are integral for foregrounding local knowledge and practice. The genuine engagement of farmers and extension offices throughout the process helps to not only create an accessible and appropriate user interface for a mobile technology, but also starts with farmer priorities, wants and needs rather than imposing a research agenda upon them. We see this as a necessary step in empowering farmers to design their own futures (Lunn-Rockliffe et al. 2020) and towards advocating for better informed policy making and crisis management. Whilst still in its infancy, we envisage these methods of co-design and data collection will continue to be refined and scaled (see <https://uclexcites.blog>), and for appropriate technical upgrades to be implemented to enhance the knowledge sharing potential of this and similar *Sapelli* projects.

Notes

ⁱ See <https://seriouslydifferent.org/igp-stories/reconceptualising-innovation-for-agricultural-futures-in-africa-part-i> and <https://seriouslydifferent.org/igp-stories/reconceptualising-innovation-for-agricultural-futures-in-africa-part-ii>

ⁱⁱ Alternatively, separate *Sapelli* projects for various forms of pest monitoring might easily be co-designed.

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Authorship Contribution

All authors contributed equally to the research design, implementation and writing of this article.

Data availability statement (see below).

Sapelli collector is fully open source and can be downloaded freely and used via the [Google Play Store](#) or [GitHub](#) repository. *Sapelli* packager is available via [GitHub](#). The proof-of-concept data collected under this project includes personal spatial data and is currently not publicly available.

Conflicts of interest

There are no conflicts of interest or competing interests.

Ethics and Research approval

Project data was collected under UCL Ethical approval 16863/001 and under authorisation from the Kenyan National Commission for Science, Technology and Innovation NACOSTI/P/19/3137.

Consent for publication

No identifiable personal information is presented in this article. Data collected by Citizen science research teams is presented anonymously and with the Full Prior informed Consent (FPIC) of the participants.

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