Participatory assessment and Adaptation for Resilience to Climate Change

Topic 6. Climate Change Adaptation and Resilience Building in Agriculture

Sixth Annual International Conference on Sustainable Development (ICSD)

Dr. John Michael Humphries Choptiany (The Palladium Group), Benjamin Ernst Graeub (Ricolab Ltd.), Sinan Hatik (George Washington University), and Prof. Samuel Thomas Ledermann (George Washington University)[1]

Corresponding author
Dr John Michael Humphries Choptiany
Jchoptiany@gmail.com
+447752581142
31 Sandall House, Daling Way, E35ND, London, UK.

Keywords:

Adaptation, Resilience, Climate change, Agriculture, Participatory, Assessment

Abstract

Climate change and its effects on agriculture present a major global challenge to livelihoods. Agricultural adaptation and resilience to climate change are still poorly understood in the context of economic development, in part due to their complexity and paucity of data. Within the aim of achieving Agenda 2030 (United Nations 2015), resilience and adaptation to shocks and stresses have gained importance. However, measuring and providing meaningful, action-oriented and empowering recommendations remains difficult, given the context-dependent nature of agriculture and subsequent high demands on data availability and quality.

Traditional monitoring and evaluation tools are often costly and are not well placed to assess complex, multi-dimensional dynamic livelihood attributes, such as resilience. While these approaches may be accurate in measurement, they often fail to empower respondents to take action. Approaches that have been developed recently range from econometric assessments using few quantitative indicators (e.g. RIMA (FAO 2018a)) to fully participatory approaches (e.g. UNDP 2018 for participatory resilience analysis; Chambers 1994 for participatory rural appraisals). Other approaches attempt to incorporate both quantitative assessments of resilience with a participatory approach that asks the interviewee for their own opinions and assessments of resilience (e.g. SHARP, which two of the authors co-developed; FAO 2018b).

While these approaches have merits, their drawbacks include a requirement for a large amount of information, a significant time to administer the surveys and data analysis burdens (Schipper and Langston 2015, 19; COP 2016). They also need a baseline and endline to assess change. They typically fail to capture how farmers are actively addressing specific shocks and stresses or what lessons can be learned. Given these limitations, an opportunity exists to review alternative approaches and develop alternative tools.

Our approach and tool, PARCC – Participatory assessment and Adaptation for Resilience to Climate Change - attempts to build on lessons learned from developing and implementing these tools. Rather than looking at the user as lacking agency in a challenging environment,

[1] We acknowledge funding received from the World Food System Center at ETH, Mercator Foundation Switzerland and Mercator Foundation Germany for the Google Venture-inspired Design Sprint carried out.

PARCC helps users make conscious decisions to adapt and withstand specific shocks and stresses such as floods, drought and conflict, which can require contradicting coping strategies. We aim to then further connect knowledge-holders whose farms have similar agro-ecological conditions and challenges, to better target knowledge-sharing between food producers, ultimately improving learning and resilience. This allows for the connection of the power of artificial intelligence and big data with (traditional) knowledge and competences already being used by farmers to identify potential actions to improve resilience. This is enabled by advances in technology (sensors, voice recognition, mobile phone availability, as well as computational agroecology), which offer new opportunities to more easily and cheaply collect data (e.g. soil quality through sensors) as well giving access to marginalized groups' (e.g. illiterate people) views and knowledge (e.g. Raghavan et al. 2016).

Here we present our innovative approach to assessing and improving climate resilience through the PARCC tool. The methodology is presented with an emphasis on the unique approach to overcome existing assessment challenges.

1. Introduction

Climate change and its effects on agriculture present a major global challenge to sustainable livelihoods. Agricultural adaptation and resilience to climate change are still poorly understood in the context of economic development, in part due to their complexity and paucity of data. Within the aim of achieving Agenda 2030 (United Nations 2015), resilience and adaptation to shocks and stresses have gained importance. However, measuring and providing meaningful, action-oriented and empowering recommendations remains difficult (Choptiany et al. 2017). This difficulty is due in part to recommendations needing significant amounts of data and to be context-specific, to be practical and actionable for people to become more resilient and the diverse and multidimensional aspects that make up resilience (Altieri et al. 2015; Darnhofer et al. 2016).

Many of the current approaches used to measure resilience are frameworks rather than tools that can be used to measure resilience on their own, lacking the qualitative (self-assessment) and quantitative (academic) parts needed to assess the complex attributes of resilience (Choptiany et al. 2015). A few tools, such as SHARP (FAO 2018b), are participatory, including both *insider* (self-assessment) and *outsider* (academic) assessment of resilience. Others, like RIMA (FAO 2018a), have a strong econometric basis, whereas others like UNDP's Community Based Resilience Analysis (CoBRA) provide an approach to working with communities to discuss resilience (UNDP 2018). All of these types of tools however fail to provide farmers with a set of recommendations, lacking a significant step towards improving resilience at the farm-level. The 'one-off' snapshot of resilience produced by existing tools gives a picture of resilience but requires outsiders (often a development project or organization) to support changes following from the assessment. Additionally, efforts to measure resilience are often based on the need to monitor or evaluate development projects, rather than empowering local communities to adapt or mitigate climate change. They are thus top down and focus on the needs of development projects and practitioners.

Given the challenges climate change will be increasingly posing, however, traditional development projects will not be adequate due to limited funding and capacity. Approaches focusing on sustainably empowering local populations directly have a higher potential for success and sustainability. To be successful, such approaches should harness the knowledge of local actors, be sensitive to the political, economic, and environmental factors, as well as build upon advances in research.

Based on these considerations we are proposing a novel approach described in the remainder of this article. The structure of our article is as follows: we first outline the objective, followed by a description of the methods and an illustrative case study of a section of the tool. We subsequently review the challenges and our proposed way forward before concluding.

2. Objective

Our objective is to empower farmers and pastoralists[2] in developing and emerging countries to measure and improve their resilience. We believe that technological and economic developments are increasingly aligning for such an approach to become viable outside of developed countries. Our technology-based approach features knowledge- or labor-intensive solutions that are expected to not only improve resilience in the long-run, but currently also are lacking financial investments due to their nature of being a public good (and by definition not patentable) (e.g. Vanloqueren and Barret 2009).

With the rise of increased computing power (both localized and server-based), higher mobile (smartphone) penetration rates even in rural areas in sub-Saharan Africa (GSMA 2018; World Bank 2016; QELP 2018; Deloitte 2016[3]), and improved literacy rates (UNESCO 2017), a market is emerging for mobile app-based technologies operating on Android and iOS systems in developing countries. Increased availability of spatial data at the global level (e.g. open-source remote sensing data for assessing Normalized Difference Vegetation Index [NDVI][4]) or local level (e.g. sensor data from farm equipment or small weather stations used in precision agriculture (Walter et al. 2017)) is supporting the viability for using data-intensive approaches for farm-level assessments also in emerging developing countries.[5]

We argue that this increasing access to data, if paired with additional relevant information on farm-level resilience through surveys (similar to the approach of the SHARP tool) (Choptiany et al. 2017), could serve to better measure resilience on the farm level in sub-Saharan Africa at a large scale. This approach becomes feasible, as in parallel to better assessment approaches and data sources, a growing evidence base of effective solutions to improve farming practices is being documented and becoming available online (Aker 2011).

While existing tools are using individual segments of these approaches, the timing is ripe for an attempt at integrating them for a comprehensive and holistic farm-level assessment, recommendations for improvement of resilience using locally and globally sourced solutions database.

3. Methods and Material

Below we describe five key parts of our novel approach, outline how we marry machine-learning approaches with rapid prototyping, and highlight the schematics of our farmer-centric approach. We conclude the section with an illustration of a hypothetical case of a smallholder farmer in Kenya.

3.1. Novel methods

Based on these observations, we have developed a prototype of an action-oriented tool that takes this approach further by measuring resilience in a participatory manner, providing five crucial improvements:

[2] For legibility sake only, we have subsequently dropped pastoralists in our papers, albeit they are an integral part of our tool.
[3] Rural smartphone penetration rates in selected SS-African countries in rural areas are: 30% in Kenya, 83% in South Africa, 27% in Uganda, 82% in Nigeria, 37% in Zimbabwe (Deloitte 2016).
[4] See e.g. SwissRe's Opti Crop, ND.
[5] These approaches are already being successfully used in many developed countries through business models like the Farmers' Business Network (https://www.farmersbusinessnetwork.com).

First, it is a user-friendly mobile and offline[6] tool accessible to anyone with a smartphone.

Second, the tool breaks from past conventions of a dependency on development actors by using a farmer-centric approach where the farmer is the primary user and entry point for the tool and implementing solutions (see Section 3.3 below); while development actors may find value in PARCC to better understand and support farmers, the tool has been explicitly designed to be implemented and used directly by farmers[7]. This empowers farmers to work without external support to improve their resilience.

Third, this break from a dependency on outside support is manifested by disaggregating a person's livelihood into distinct resilience attributes to assess what specific shocks and stresses have impacted them in the past, allowing for a better understanding of how the person has adapted in the past through a self-assessment of their effectiveness.[8]

Fourth, by harnessing external data sources as foundational layers to build a unique profile of each farmer (e.g. land-use maps, climate projections, demographic data) combined with public, scientifically-verified databases of proven approaches to improve resilience (e.g. at the level of sustainable land management (WOCAT 2018); at the level of sustainable crop production (CABI 2018)), we aim to combine farmers' knowledge with a database of existing adaptation and coping mechanisms that have been shown to be effective at improving resilience or adapting to specific shocks and stresses. Connecting this external data with the participatory resilience survey subsequently provides us with a set of individualized, resilience-improving recommendations.

Fifth, the tool will ultimately provide actionable advice and access to information on how to adopt these practices, including an ability for users to interact and learn from each other (e.g. by identifying and visiting (virtually or physically) nearby farmer using the tool to witness a specific technology adopted), closing the farmer-to-farmer feedback loop. This will be done in a user-friendly way (i.e. using paired down text and visual descriptions where possible), recognizing the differing capacity levels of farmers in developing countries.

3.2. From Machine-learning to rapid prototyping

We will deploy a machine-learning tool (e.g. the open-source *TensorFlow*), including a recommender system, to ensure that recommendations for farmers are tailored specifically to their context and preferences and consistently improving based on the feedback received from users (e.g. via adoption rates, solutions shared and user ratings of solutions of past and current approaches)[9]. By drawing on externally, scientifically-verified, proven technologies documented based on farmers' implementations, our machine-learning approach will be strengthened through the continuous evidence-based feedback integrated from the farmers themselves (including the option for them to report and share their own solution set from past interventions).

Based on experience from developing and implementing SHARP and reviewing existing resilience measurement and monitoring and evaluating tools, we have identified the above gaps and opportunities, for which we used the Google Venture Design Sprint Method to build an initial prototype between July 23rd to 27th 2018. It included interviews of seven thought leaders across various domains (development practitioners, entrepreneurs, survey implementors etc.) acting as outside experts and advisors during the week. We also started

[6] While the assessment of resilience and prioritising aspect of PARCC works offline and provides a score, matching to solutions and providing resources to implement them does require a cellular or wireless connection.
[7] We have designed the tool to work in multiple languages and accessible to people with low literacy
[8] The tool furthermore allows for the self-reporting of these (traditional) solutions to be added into the database used for improving the recommender system's machine learning mechanism.
[9] We are investing different gamification approaches that provide rapid feedback on solutions but do not over burden farmers with too many options and questions.

(re)engaging with practitioners who work in resilience building, M&E and programme management to understand their successes and challenges to help tailor the approach.

This method offers a stark contrast from following the traditional development model using project cycles – within which we hold extensive experience – which uses a lengthy period of project development and annual or bi-annual cycles for monitoring and evaluating. By drawing on inspirations from lean start-up, (Ries 2011; HBR 2013) design-thinking (Brown 2009) and human-centered design approaches (Brown 2009), we aim to work fast and directly with potential customers – commercial smallholders in loose and tight value chains (USAID et al. 2016) – to rapidly prototype the tool through several iterations in a build-measure-learn loop (Ries 2011).

3.3. Farmer-centric approach

Inspired by *Doing Development Differently (2014)*, we aim to work with local stakeholders to develop country-versioning of a localized mobile application to train the learning mechanism to the local context (on the high-tech side), and also draw on local cartoonists and user-interface designers to illustrate and test the application (on the low-tech side). The trade-off of our chosen approach will be delayed indicators on the results from adoption of technologies, in favor of ensuring the potential of the tool itself, its usability, uptake and scalability. By starting out with an approach that has farmers as clients, we aim to provide a turnkey solution that has a reduced dependency on donor funding or development partner support (see also later section).

The farmer-centric approach is furthermore emphasized by allowing the user to set their own priorities and importance of what resilience gaps they would like to address on their farm and what resilience risks they would like to have strengthened.

The farmer profile represents the input side of the system. It is compiled based on the PARCC survey alongside outside data sources. The solutions section is the output of the tool with our custom recommender system matching the farmer profile alongside priorities to provide tailored resilience building solutions. The steps and components of the tool are outlined in Figure 1 below.

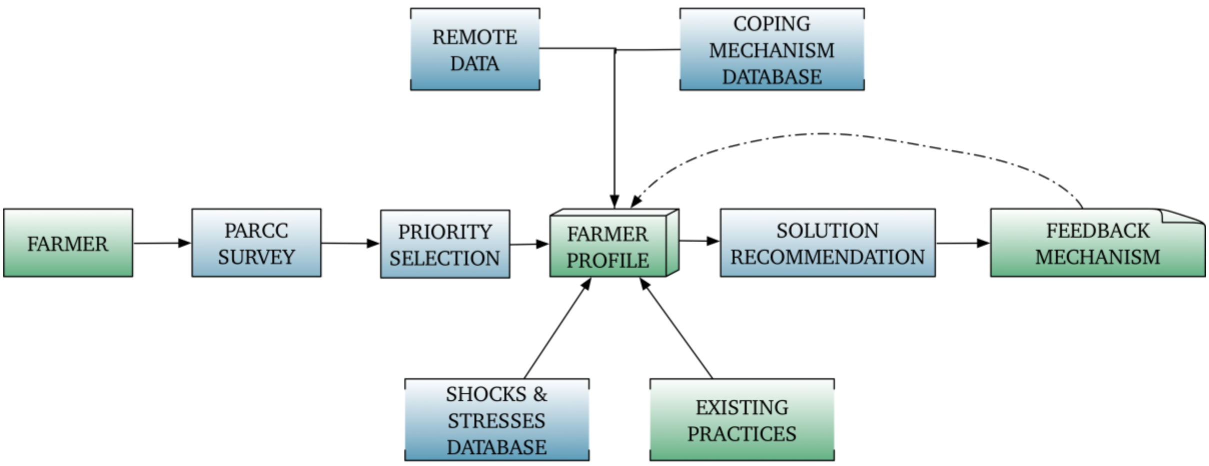

Figure 1: FLOWCHART DEPICTING FARMER-CENTRIC TOOL

3.4. Illustration of Farmer-Centric Tool

Here we use the example of a fictional farmer, Anah, based in Muranga, Kenya, to illustrate how segments of the farmer-centric tool could work. What follows are four key steps visualized.

The first visualization of the application (Figure 2) is showing resilience building priorities. As the PARCC tool captures substantial amounts of data, only some of the key attributes are summarized here:

- Location: Muranga, in the lowland area of Kenya
- Soil type: black cotton clay soils (suitable for maize)
- Crop production types: maize

Shocks and stresses

- Flooding: fields flood once every two years
- Fire: never experienced a fire
- Drought: has not severely impacted the area

Figure2. Screenshot of sample resilience improvement priorities selected by the farmer Anah.

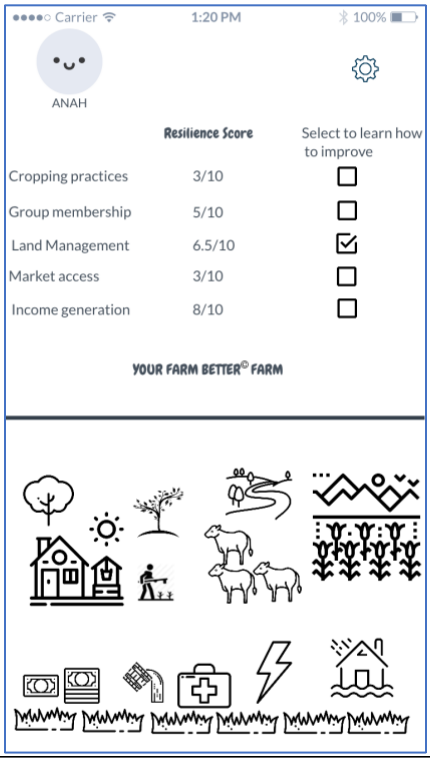

Figure 3. The resilience score from the PARCC survey above a graphical representation of her farm illustrating some of the farm attributes as well as shocks and stresses experienced.

The results of the PARCC resilience assessment tool, alongside external data sources are shown in Figure 3. This represents the farmer profile that is then matched to potential resilience building solutions.

In this example, we have used the WOCAT Sustainable Land Management practices database to identify three potential solutions to present to Anah. Solutions (practices) have been labeled as having: decreasing, having no effect, or increasing (e.g. – 0 +) on the following seven attributes: Labor requirements; crop yields; soil erosion; crop or animal water use; biodiversity; flood risk; and fire risk.

Three sample technologies identified are: 1: Low-cost drip Irrigation[10] (an example from Nepal), which has the attributes of labor (-), yields (+), erosion (-), water use (-), biodiversity (0), flood Risk (0), and fire risk (0); 2: Zero tillage farming,[11] which has the following attributes of Labor (-), Yields (+), Erosion (-), Water use (-), Biodiversity (+), Flood Risk (0), Fire Risk (0); and 3: Crop rotation maize with legumes[12] which has the following attributes of Labor (0), Yields (+), Erosion (-), Water use (0), Biodiversity (+), Flood Risk (0) and Fire Risk (0).

Finally, Figure 4 outlines the solutions page of the tool showing a broad overview of what Sustainable Land Management is, followed by the potential solutions. These solutions can be selected for more general information as well as step-by-step guides on how to implement the approaches.

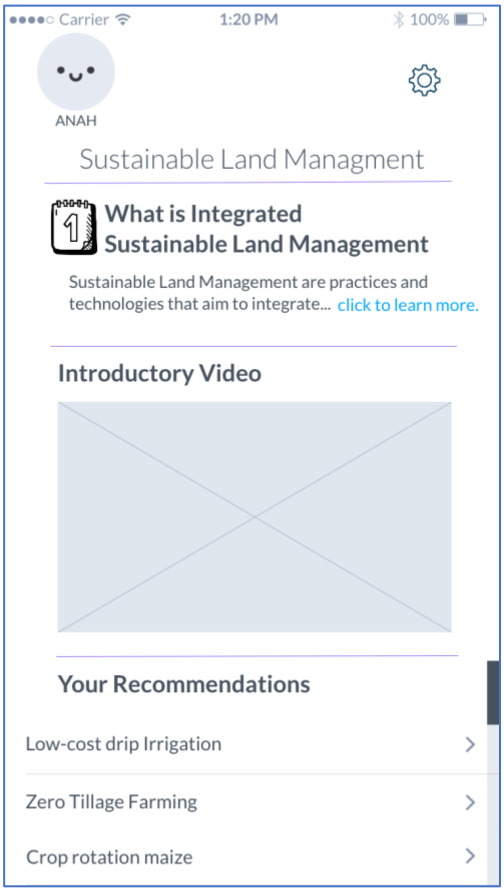

Figure 4. Sample recommendations for Anah based on her unique farmer profile, preferences and potential resilience improvement solutions.

10 https://qcat.wocat.net/en/wocat/technologies/view/technologies_1501/
11 https://qcat.wocat.net/en/wocat/list/?type=wocat&q=zero%20tillage
12 https://qcat.wocat.net/en/wocat/technologies/view/technologies_1326/

Challenges

Given the novel nature of the tool developed, we have identified the following set of five key challenges. They range from challenges at the side of programming, to implementation, adoption and financial viability.

On the computer programming side, a first key challenge is the development of a recommender system, which integrates machine learning. While there will be a human curation aspect of the system, filtering through a number of diverse and non-uniform datasets will be computationally intensive and hence calculations will need to be undertaken on a server in the cloud rather than directly on a device. The data being filtered includes publicly available datasets serving as knowledge banks (e.g. sustainable land management datasets); data gathered from farmers' input into the app, such as the geolocation of farmers (e.g. matching with global agroecological surveys); and their agroecosystem, their soil use, and land use. Tagging and sorting the recommendations database to allow matching filters to search for the solutions with these key agroecological variables represents the most significant investment of upfront time.

A second key challenge is to not only capture existing knowledge available in databases, but also surfacing existing innovations at the farm-level that have taken place outside the purview of development practitioners. Beyond the participatory self-assessment of the current resilience state of a farm, it will be essential (yet challenging) to capture similarly any successful adaptations that have taken place to build and complement these existing databases. From a farmer's point of view, it is unfortunate that current databases – reflecting the existing reporting bias in development practice - will only contain successful implementations, with failures, lessons learned, or adaptations (which would provide a pertinent field of learning) usually missing from existing databases.

Regarding adoption, a third challenge is to ensure that the tool will build successfully upon the development field's improved understanding of successful adoption pathways to build resilience and improve livelihoods. For example, while radio has been proven to serve as a successful pathway for advertising (ultimately creating interest or awareness for a tool or agricultural method), translating it into a decision and subsequent action to adopt needs to move beyond that approach and is much more challenging. Based on the literature, the approach needs to involve the ability for farmer-to-farmer learning, including visits to demonstration, trial or implementation sites (see e.g. findings from adoption of a knowledge-intensive technology in Kenya; Murage et al. 2011, 2012; Amudavi et al. 2009). Hence, we aim to avoid the technocentric pitfalls of a singular focus on the tool and its sole ability at transformation into a positive change in livelihoods, by potentially embedding the deployment of the tool in group settings (e.g. among farmer cooperatives) and facilitating the ability to connect with other farmers (both virtually and physically) through the tool so that they can share experiences, ask questions and learn from each other. This information for providing feedback through the adaptation (or possible dis-adoption) of a technology option is key to continuously reflecting the changing agroecological environment under pressure from (climate) shocks and stresses.

We are furthermore breaking the pattern of donor dependency by creating a system whereby farmers are empowered themselves to enter the adoption cycle by autonomously – i.e. without interference from scientists or outside extension agents (though they may also find use in implementing this application in their work) who have traditionally operated in a top down fashion – considering from a larger pool of information their adoption options.

A fourth key challenge with this approach is the need to make the tool financially viable and ultimately scalable, as the reduced dependency of donor flows also reduces the risk of becoming hostage to ebbs and flows in donor financing. The conscious decision to not use the tool for promoting sales of agricultural goods (unlike e.g. MFarm) but rather focus on diffusion of public knowledge, poses an additional challenge to create a viable business model. This challenge will be explored during the piloting phase of the tool to see under which conditions there is sufficient demand and willingness to pay from farmers to make the application financially viable.

With the increasing awareness by development practitioners that “development is a fundamentally political process” (Thinking and Working Politically Community of Practice, 2018), drawing on these insights from the community of practice around *Thinking and working politically (TWP)* will be a fifth key challenge for any application aiming to break through numerous political economic layers to directly reach farmers effectively. Based on our past experience, the Agricultural Technology sector especially has historically operated with the premise that the landscape is an apolitical space. In this context, we draw upon our own additional expertise in advocacy work (both at the level of the UN and the scaling out of ecological agricultural practices) to ensure that our farmer-centric intervention is embedded not only within the immediate value chain of farmers, but also their political economy. This involves not ignoring, but rather building upon existing networks of farmer groups (at local levels) or institutional support by governments (e.g. through extension officers), as well as engaging both local and national stakeholders in an eventual nation-wide launch of the tool and allowing for similar feedback mechanisms.

Areas of future work

Based on the methods and challenges outlined above, we have identified the following three areas of future work.

First, the task of creating an all-in-one tool to assess and improve the resilience of farms is substantial and challenging. For our future work, we have decided to forgo designing and programming the final application. Rather, we plan on building a so-called Minimum Viable Product (MVP) as a first step, to validate whether a (business) potential exists. This will mean not developing all potential features at the beginning, but only building a basic version of the tool at first. In an early test with farmers – possibly in different countries – we are hoping to gain information on the market demand and the usefulness of such a tool to farmers themselves. Based on this we plan to either further develop the MVP into a full-fledged application, pivot to a new approach, or halt work altogether.

Second, we aim to document for the larger development community and academics the data and information that this process and eventually the tool could provide for the mitigation of and adaptation to climate change. This will necessitate in the mid-term a research project to ensure that the data gathered can help to adequately address them.

Third, we aim to establish a farmer-practitioner-academic network for collaboration to address a scalable tool that is not dependent on volatilities in donor funding. Shocks and stresses, exacerbated by climate change, are also not static and therefore the responses recommended to build resilience to them will need to improve and adapt. This network, alongside machine learning from farmer feedback will be used to continually improve the recommendations given from a growing database of solutions.

Conclusions

Climate Change is one of the major challenges of our time, especially for farmers in developing and emerging countries. The trends of increasing populations will only further exacerbate the pressure of climate change.

While resilience is still an emerging concept and as such not clearly defined, development and research work on resilience has been growing and approaches to measure resilience in agriculture have been developed and are being use. The main disadvantages of existing approaches are that they are often focused on needs of development actors and stop at measuring resilience. What is needed, given the scale of the challenge, however, is to empower farmers themselves to improve their resilience to climate change.

With our approach, PARCC, we ultimately hope to better equip farmers for an uncertain future by bringing together the best of (traditional) knowledge and technology, thus offering a unique approach that leverages local knowledge with academic research in a simple IT package to assess and improve their resilience to specific shocks and stresses.

References

Aker, Jenny C. *Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries*. 42: 6. 631-647. (2011). https://doi.org/10.1111/j.1574-0862.2011.00545.x.

Altieri Miguel A., Clara I. Nicholls, Alejandro Henao, Marcos A. Lana. *Agroecology and the design of climate change-resilient farming systems. Agron Sustain Dev* 35(3). (2015):869–890.

Amudavi, D.M., Z.R. Khan, J.M. Wanyama, C.a.O. Midega, J. Pittchar, I.M. Nyangau, A. Hassanali, and J.A. Pickett. *Assessment of Technical Efficiency of Farmer Teachers in the Uptake and Dissemination of Push–Pull Technology in Western Kenya. Crop Protection* 28 (2009) (11): 987–96. https://doi.org/10.1016/j.cropro.2009.04.010.

Brown, Tim. *Change by Design: how design thinking transforms organizations and inspires innovation.* New York City: HarperCollins. 2009.

CABI. 2018. *CABI Plantwise Factsheet Library App.* 2018.

Chambers, R. *The origins and practice of participatory rural appraisal. World Development 22* (7) (1994): 953-969. https://doi.org/10.1016/0305-750X(94)90141-4

Choptiany, John M.H., Benjamin Graub, Suzanne Phillips, David Colozza, and Jami Dixon. *Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists*. 2015. www.fao.org/3/a-i4495e.pdf.

Choptiany, John M.H., Suzanne Phillips, Benjamin E. Graeub, David Colozza, William Settle, Barbara Herren and Caterina Batello. *SHARP: integrating a traditional survey with participatory self-evaluation and learning for climate change resilience assessment*, Climate and Development, 2017 9:6, 505-517, DOI: 10.1080/17565529.2016.1174661.

CoP. *Analysis of Resilience Measurement Frameworks and Approaches.* 2016. Available at: www.fsnnetwork.org/sites/default/files/analysis_of_resilience_measurement_frameworks_and_approaches.pdf

Darnhofer, Ika, C. Lamine, A. Strauss and M. Navarrete. *The resilience of family farms: Towards a relational approach*. Journal of Rural Studies. 44. 2016 111-122. 10.1016/j.jrurstud.2016.01.013.

Deloitte. *Game of Phones: Deloitte's Mobile Consumer Survey. The Africa Cut 2015/2016.* 2016. https://www2.deloitte.com/content/dam/Deloitte/ng/Documents/technology-media-telecommunications/ng_Deloitte-Game-of-Phones-Sep16.pdf.

Doing Development Differently. *A workshop on Doing Development Differently.* Harvard Kennedy School, Cambridge, MA. October 22-23, 2014. https://bsc.cid.harvard.edu/doing-development-differently.

FAO. *Resilience Index Measurement and Analysis (RIMA).* 2018a. Available at: www.fao.org/resilience/background/tools/rima/en/.

FAO. *Self-evaluation and Holistic Assessment of climate Resilience of farmers and Pastoralists.* 2018b. Available at: www.fao.org/in-action/sharp/en/.

GSMA. *The mobile economy 2018.* 2018. www.gsma.com/mobileeconomy/wp-content/uploads/2018/05/The-Mobile-Economy-2018.pdf.

HBR. *Why the Lean Start-Up Changes Everything.* Steve Blank. 2013. https://hbr.org/2013/05/why-the-lean-start-up-changes-everything.

Murage, Alice. W., D.M. Amudavi, J. Chianu, C.a.O. Midega, J.A. Pickett, and Z.R. Khan. *Determining Smallholder Farmers' Preferences for Technology Dissemination Pathways: The Case of 'Push-Pull' Technology in the Control of Stemborer and Striga Weeds in Kenya. International Journal of Pest Management. (2011).* 57 (2). 133- 145. https://doi.org/10.1080/09670874.2010.539715.

Murage, Alice W. G Obare, Jonas, N. Chianu, J A Pickett, and Z R Khan. *Effectiveness of Dissemination Pathways on Adoption of 'Push-Pull' Technology in Western Kenya. Quarterly Journal of International Agriculture* 51 (2012) (1): 51–71.

QELP. *Africa smartphone penetration at tipping point*. 2018. www.qelp.com/insights/africa-smartphone-penetration-at-tipping-point/.

Raghavan, B Barath, Bonnie Nardi., Sarah T. Lovell., Juliet Norton., Bill Tomlinson., & Donald J. Patterson. *Computational agroecology: Sustainable food ecosystem design.* In CHI EA 2016: #chi4good - Extended Abstracts, 34th Annual CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery. (2016). 07. 423-435. DOI: 10.1145/2851581.2892577.

Ries, S. *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses.* Crown Publishing Group. 337 pages. 2011.

Schipper, E. Lisa. F. and Lara Langston. *A comparative overview of resilience measurement frameworks*. ODI Working Paper 422. 2015. www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9754.pdf.

SwissRe. Nd. *Opti Crop.* https://swissre-a1b1zg0.opti-crop.com/map/ndvi/0,0/2/d/s

TensorFlow. *An open source machine learning framework for everyone.* (2018). www.tensorflow.org/.

Thinking and Working Politically Community of Practice. *Thinking and Working Politically.* (2018). https://twpcommunity.org.

UNDP. *Community-Based Resilience Analysis (CoBRA) Conceptual Framework and Methodology*. 2018. Available at: http://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_land_management/CoBRA/cobra-conceptual-framework.html

UNESCO. 2017. Literacy Rates Continue to Rise from One Generation to the Next. Fact Sheet No. 45 September 2017. FS/2017/LIT/45 http://uis.unesco.org/sites/default/files/documents/fs45-literacy-rates-continue-rise-generation-to-next-en-2017_0.pdf.

United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development. 2015. www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E.

USAID, The MasterCard Foundation, Global Development Incubator, Dalberg. *Inflection Point: Unlocking growth in the era of farmer finance.* 2016.

Vanloqueren, Gaëtan, and Philippe V. Baret. *How Agricultural Research Systems Shape a Technological Regime That Develops Genetic Engineering but Locks out Agroecological Innovations. Research Policy* 38 2009. (6): 971–83. https://doi.org/10.1016/j.respol.2009.02.008.

Walter, Achim, Robert Finger, Robert Huber, and Nina Buchmann. *Opinion: Smart Farming Is Key to Developing Sustainable Agriculture. Proceedings of the National Academy of Sciences* 114 2017. (24): 6148–50. https://doi.org/10.1073/pnas.1707462114.

WOCAT. *Sustainable Land Management Database.* 2018. www.wocat.net/en/.

World Bank. *World Development Report 2016: Digital Dividends.* 2016. www.worldbank.org/en/publication/wdr2016.