Innovative Solutions for Climate-Change Impacts on Food Systems

Innovation Technical Summary

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Executive Summary

According to the United Nations, agricultural development is important in preventing hunger through sustainable food systems, poverty prevention, and increasing the ecosystem's health (United Nations Industrial Development Organization and United Nations Inter-Agency Task Team on Science, 2022). Meanwhile, food systems are affected by many challenges, including rapid population growth, degradation of land and water resources within ecosystems, and climate change (Mirzabaev et al., 2023; Sixt, 2020). The impact of degradation of the ecosystems on agriculture has further led to limited arable lands and loss of biodiversity (Wang et al., 2022). Severe impacts of climate change, including drought, floods, and heat waves, have also led to crop/food disease outbreaks during the production, storage, and transport of food.

To forestall these significant challenges, some of the proposed innovative solutions include crop modelling using existing models such as the Decision Support System for Agrotechnology Transfer (DSSAT), AquaCrop, Agricultural Production Systems sIMulator (APSIM), or modified crop models and crop disease models such as APSIM-DYMEX (Whish et al., 2015) and APSIM-Eyespot Disease (Al-Azri, 2015), among others.

Crop/crop disease models such as these have been used in the design of innovative mobile applications (apps). These apps are effective in giving guidance regarding the best planting seasons for different crops in order to minimise the negative impacts of bad weather, pests, and diseases and, in so doing, have increased crop yields.

This innovation technical summary focuses on mobile crop-model apps (e.g., AgriCloud, Fapp, CROPMON, and Sat4Business), push-pull technology, and agrivoltaic farming. These innovations hold great promise for expansion, including for providing information on specific underutilised crops – such as Bambara groundnut, teff, baobab, moringa, and amaranth – and on effective marketing of such crops. These models and innovations have a broad target audience that includes farmers, extension practitioners, agribusiness companies, agrometeorologists, policy makers, and climate and renewable energy practitioners.

Some of these innovations may be quite resource-intensive initially, so government funding and other funding models – including communal and cooperative funding – should be encouraged. Furthermore, organisations with better facilities and equipment to drive innovations and enhance scalability should partner with those that have more limited capacity, such as NGOs and government departments/projects.

These innovations could be very effective in preventing and/or reducing crop-yield losses and the carbon footprint caused by agricultural activities; in this way, food production is increased and progress can be made towards achieving Sustainable Development Goals (SDG) 2 – Zero Hunger.

Introduction

The complexity of global challenges requires integrated transdisciplinary and innovative approaches to address them. This is why the 2030 Agenda for Sustainable Development, unanimously adopted at the United Nations Sustainable Development Summit in September 2015, positioned science, technology, and innovation (STI) as one of the seven key action areas for achieving the Sustainable Development Goals (SDGs). According to the United Nations Industrial Development Organization and the United Nations Inter-Agency Task Team on Science, Technology, and Innovation for the SDGs (2022), STI is key to achieving the SDGs – particularly for targets related to human well-being, such as health, clean water and sanitation, climate change, clean energy, decent work, and responsible production.

Innovation involves a new way of producing, delivering, or using goods and services based on new technology, new business models, or new economic or social organisation methods. New technologies, models, and methods can provide solutions that address existing challenges – particularly complex problems such as those currently faced in the areas of climate, land, agriculture, and biodiversity.

The Climate, Land, Agriculture, and Biodiversity (CLAB-Africa) project is a Future Africa (University of Pretoria) initiative hosted under the African Research Universities Alliance (ARUA) Centre of Excellence in Sustainable Food Systems (ARUA-SFS). CLAB-Africa aims to provide a platform for Africa's scientific community to contribute to the developmental work of African governments and development institutions in the form of science-based, actionable recommendations – including those related to innovation – within four identified clusters: (i) climate impact on food systems, (ii) land restoration and biodiversity, (iii) people-animal-ecosystems health and well-being, and (iv) land-water-energy resources use.

The **climate impact on food systems** theme aims to develop recommendations for applying climate change science to improve food systems, aid food security, and reduce poverty. Furthermore, the theme delves into how renewable energy can serve as a climate-sensitive food solution and how Africa's plant diversity can improve crop yield and nutrition.

The **land restoration and biodiversity** theme focuses on land restoration recommendations to improve biodiversity in farming landscapes, thereby achieving agricultural resilience and neutrality for land degradation. Land degradation is one of the most pressing ecological challenges, impacting most of the land worldwide. It affects an estimated 3.2 billion people dependent on degraded land for food, water, and other essential ecosystem services (Brondízio et al., 2019).

The **land, water, and energy resources use** theme aims to develop recommendations for optimal resource use to improve food production, reduce the emission of greenhouse gases (GHGs), and preserve the environment's ecological balance.

The **people, animal, and ecosystem health and well-being** theme aims to develop recommendations for improving human health through interventions in ecosystems and animal health. The theme tackles the challenges that impact the health and well-being of people, animals, and the environment and strives to develop sustainable solutions to improve quality of life.

This innovation technical summary assesses the innovations available in the context of the *impact of climate change on food systems*. In addition to identifying innovative solutions in this CLAB-Africa thematic area, this technical summary highlights these innovations' sustainability, effectiveness, scalability, adaptability, and economic viability. Key recommendations and the potential impact of the innovations will also be presented.

Overview of Current Climate-Change Challenges in Agriculture and Proposed Innovations to Address These

Global food systems face many challenges, including climate change, insufficient arable land, loss of biodiversity, and reduced investment in agriculture (Saghir, 2014; The World Bank, 2023). Many food systems processes have been affected by climate change both directly and indirectly (Hasegawa et al., 2022). Future climate change is projected to cause a temperature increase of 1.5°C by the end of the century, the impact of which is exacerbated by GHG emissions and shifts in rainfall patterns (Climate Change, 2022). Agriculture relies heavily on climate and weather conditions, so these extreme weather events devastate soil health and fertility and, invariably, food production and systems. For example, maize, one of the most consumed cereals, is predicted to experience a 24% decline in yield by the end of the century (Gray, 2021). Limited availability of arable lands and use of conventional agricultural practices have led to agricultural menaces such as soil erosion, desertification, and salinity. The decline in arable land worldwide, especially in Africa (the Food and Agriculture Organisation (FAO, 2011), is increasing the pressure on food systems through loss of biological diversity. The negative impacts of biodiversity loss are already felt in human lives and diets. For example, in Gambia, loss of wild foods has increased the intake of processed foods.

Although agriculture and food systems are central to human existence and impact all sectors – including health, education, and economic – investment in agriculture and food systems is not being prioritised in many nations (Fanzo et al., 2022). Furthermore, as climate change increases the occurrence of severe weather events such as floods and droughts, there is a decline in crop yields, negative impact on livelihoods, and delayed profit and financial returns (Pettinger, 2016).

Within this context, it becomes clear that the agriculture sector is in need of innovation that leads to transformation in order to prevent continued exacerbation of global hunger. Some of the innovation strategies currently available to enable such transformation include the use of crop models to predict planting seasons so as to help maximise benefits derived from rainfall patterns and reduce the impact of pests and diseases. Other innovations make use of climate-resilient crops that can still produce high yields despite harsh weather conditions. The use of climate-smart agriculture to maximise land use and increase energy generation with reduced emission is also being utilised.

This innovation technical summary aims to increase awareness around crop-model apps to provide continuous, timely advice to farmers and around the use of other climate-smart technologies to increase food production while reducing GHG emissions.

The **objectives** of this technical summary include:

- Identify innovative solutions that are being used to reduce the negative impact of climate change on food systems.
- Analyse the use of app-based innovations and solar-powered technology based on prescribed evaluation criteria.

Target audiences for these innovations include farmers, extension practitioners, agribusiness companies, the Department of Agriculture and Rural Development, local municipalities, and the Department of Environmental Affairs. Other target audiences include climate practitioners, renewable energy experts, policy makers, academics and agrometeorologists.

Context and Problem Statement: Climate-Change Impacts on Food Systems

The impacts of climate change on food systems and vice versa are complex because these impacts vary across locations and regions. For example, in Africa, where farming is mostly rainfed and subsistence in nature, shifts in rainfall greatly affect agricultural activities, resulting in low crop yields, reduced household incomes, and limited access to healthy foods (Climate Change, 2022). Furthermore, this has leads to acute food insecurity and nutrition, with many people needing humanitarian aid, especially in East and North Africa (Gebremeskel et al., 2022). Climate change is also creates an environment condusive to increased growth of weeds, pests, and crop diseases, which all exacerbate negative impacts on the food systems (Deutsch et al., 2018). Conversely, unsustainable agriculture practices exacerbate climate change.

With this context in mind, the transformation of food systems through innovative adaptation of agricultural practices is crucial for counteracting and mitigating the impacts of climate change. Examples include the production of climate-resilient crops identified via research – for example, Bambara groundnut and other underutilised crops indigenous to Africa. Alternatively, shifting locations where specific crops are produced according to the availability of fertile soils and shifting climate zones. This can also be done by aligning agricultural production areas to changing agroecosystems using crop models to forecast and predict crop yields based on the soil and climate data and by adapting farming practices at specific locations. Also, use of solar-powered technology for food production, preservation, and distribution can help reduce the food system's carbon footprint. Prediction and detection of crop pests and diseases to reduce crop loss will also become more important since natural predators might not be present or plants may become more susceptible to certain diseases as production areas shift.

Innovative Solutions

Food systems need transformative, innovative solutions in order to ensure that they are well adapted to cope with climate change and also to increase productivity.

Crop-model mobile app technology

There are several crop models used in smartphone apps, including AgriCloud (South Africa), Fapp (Uganda), CROPMON (Kenya), and Sat4Business (Ghana). These apps utilise real-time data to forecast crop yields and best production practices according to the expected weather during a particular season. Thus, when combined with apps to detect crop pests and diseases and predict outbreaks according to the current prevailing weather conditions, they can assist farmers to stabilise their crop productivity despite the changing climate. This will reduce crop losses and increase crop yields, thus addressing food insecurity, alleviating hunger, and reducing the carbon footprint due to wastage.

The building of the AgriCloud app in South Africa started with needs assessment meetings held with both small-scale farmers and extension practitioners about the weather information farmers need. Assessment of the available weather forecasts revealed that, together with evidence-based knowledge databases, an advisory app could be developed to assist farmers with on-farm decision making. Accordingly, the AgriCloud app was developed to allow farmers and extension officers to access information updated on a daily basis – including guidelines for timing of crop planting and occurrence of crop pests/diseases. Weather forecast information is obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF), South African Weather Service, Agricultural Research Council, and HydroNet to provide predictions for the upcoming 14 days on a grid (consisting of 8-15km^2 blocks) across the whole of South Africa. Programming of the available weather and crop-model information is done using Python script output for each of the grid cells, which is generated daily across South Africa. This generated information is then transferred to the HydroNet platform, from which the AgriCloud mobile app obtains location-specific information to deliver to users (Walker, 2020). So far, scalability and partnership are some of the challenges experienced by this project.

An additional innovation that was added to this platform was the development of a virtual market for farmers and buyers by connecting them via crowdsourcing. This functionality can be used as an add-on to other apps similar to AgriCloud or on its own so that it can be of use throughout the value chain and not just on the production end.

Promoting climate-resilient, indigenous crops

Bambara groundnut, amaranth, teff, moringa, and baobab are examples of neglected and underutilised African crops. Ongoing research has revealed that they can play a key role as foods of the future, given their resilience against climate change, contribution to dietary diversity, and medicinal properties (Ajilogba et al., 2022; Mabhaudhi et al., 2017; Tadele & Hibistu, 2021; Tan et al., 2020). One of the key barriers to moving research on these crops through the implementation and development stages is having a market for the product (Boulay et al., 2021; Tan et al., 2020). Increasing the value-addition opportunities for these crops along the value chain is vital, and this is where app-based notifications about supply and demand can prove particularly useful. This would assist in creating a market for farmers' produce and connecting them with the buyers who will process these crops into a variety of products such as infant formulas, snacks, livestock feed, pharmaceutical products, or other non-food uses. Although different regions in Africa are using value-addition techniques for some of these crops, national policies to promote such value addition will increase their importance and impact as food-security agents in mitigating the impact of climate change on food systems.

Push-pull technology

Push-pull technology is a more recent climate-smart agriculture strategy developed to protect farmers against crop pests and diseases using a climate-resilient biocontrol method with zero emissions. This technology makes use of a mixed-cropping strategy, where a companion crop (e.g., Desmodium) is intercropped with a food crop (e.g., maize). The companion ("push") crop repels weeds and pests from the food crop by producing repellent chemicals while forage plants (e.g., Sudan grass) is planted used as a border around the farm to attract ("pull") pests away from the food crop. This innovation has been utilised in the "Scaling Up Bio Control Innovations in Africa" project, funded by the Global Challenges Research Fund (UKRI, 2022). Furthermore, it has been push-pull technology has been upscaled by means of the PUSH-PULL App, available for download on popular platforms

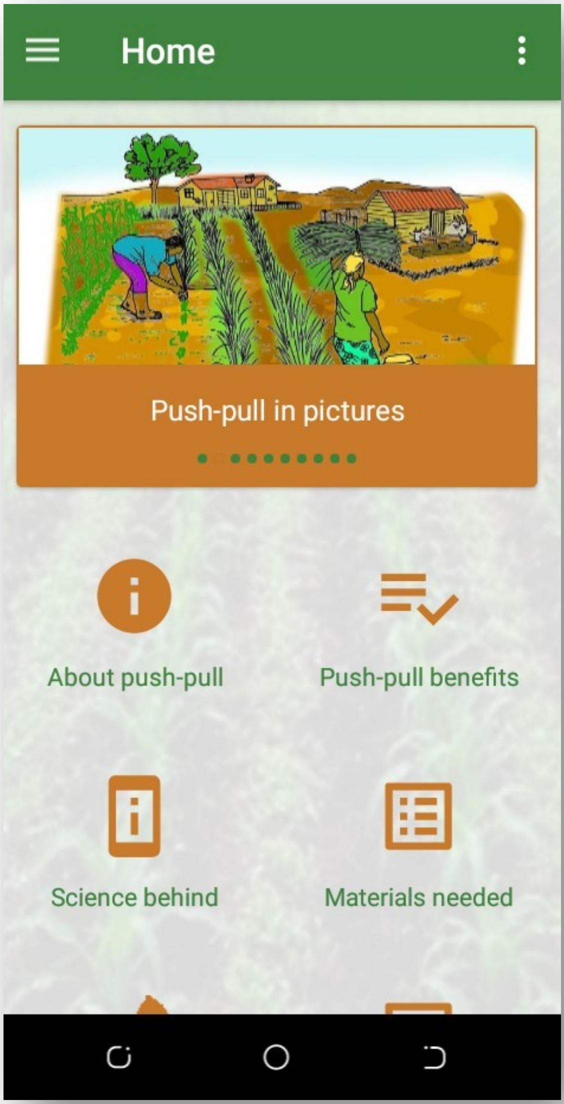

Figure 1: : Home page of the push-pull technology app
Source: Mugisha Paul[1]

such as Google Play.[1] This app is free and can be used offline, which means that internet connectivity will not affect the app's functionality – a particularly useful feature for rural areas that often have poor or no internet connection. Some shortcomings of this innovation include the cost of establishment, limited acceptance of the concept, and inadequate access to information and inputs (Adesina et al., 2023).

Agrivoltaic farming

Agrivoltaics is the practice of simultaneously growing crops underneath solar panels while generating electricity with these photovoltaic panels. This practice encourages land-use efficiency by making use of the same plot where the solar panels are mounted several metres off the ground for planting vegetables. In this way, the crops are shielded from heat stress and evaporation while the electricity needed to power the farm is generated in a renewable way. This innovation helps solve the problem of food insecurity and reduces GHG emissions at the same time by generating electricity from solar energy.

Figure 2: *: Mounted solar panels shade crops growing underneath them*

Source: Chloride Exide Ltd[2]

Evaluation of Innovations

Crop-model mobile app technology

Apps such as AgriCloud have the potential to expand to include a range of practical interventions that support farmers' on-farm decision making under changing and variable weather conditions. Some of the information used to build this particular app was collected during community engagements, which led to the inclusion of a crowdsourcing functionality in the app, which emphasises the value of community involvement (Walker, 2020). Furthermore, the platform encourages community engagement and participation, increasing its acceptability and viability. Its long-term economic viability can significantly increase when large-scale commercial farmers as well as the companies who purchase from them begin to make use of it. The more farmers use it, the more viable and attractive it becomes. Such an app is very effective, as it gives real-time solutions to farmers and is adaptable to different crops – although maize is the only crop currently on the app. There is potential for expansion to include other crops and to allow for use of the online market functionality by both farmers and buyers. Given the continued availability of consistent information for the model, this innovation can be sustained be means of paid subscriptions.

Climate-resilient indigenous crop promotion

Value addition is an innovation that brings to the fore the results of most research on neglected and underutilised crops to create viable products for the food and feed market. These crops (e.g., Bambara groundnut, amaranth, teff, baobab, and moringa) have been found to be drought tolerant and well adapted to marginal agricultural lands. They grow under adverse environmental conditions, which shows their resilience. The production and promotion of these crops have been ongoing in different African nations like Burkina Faso, South Africa, Cameroon, Ghana,

[1] https://play.google.com/store/apps/details?id=com.pushpull.tech&hl=en_GB&gl=US&pli=1

[2] https://www.theguardian.com/global-development/2022/feb/22/kenya-to-use-solar-panels-to-boost-crops-by-harvesting-the-sun-twice

Nigeria, Ethiopia, and other parts of the world such as Malaysia, Indonesia, and Thailand. This shows their adaptability to the climates of different parts of the world as well as their scalability, as they are originally indigenous to sub-Saharan Africa (Stadlmayr et al., 2020; Tadele & Hibistu, 2021; Tafesse et al., 2020). The adoption of this innovation in different countries has come with different challenges; however, the excellent value-addition opportunities offered by neglected and underutilised crop species provide a convincing case for launching pilot projects in communities which can then be expanded to large-scale projects at provincial level.

Push-pull technology

Push-pull technologies have already been scaled up to provision of advice and information to farmers. It is a sustainable strategy, as it is a technology that the farmers can use all the time without the need for extension workers. The resource efficiency is excellent because it does not generate any emissions. It is resilient against climate-change variables and very effective. Push-pull technology aligns with policies on reducing chemicals and fertilisers used in the soil, as utilising certain companion crops can be beneficial to soil health (e.g., the nitrogen-fixing benefits of legumes) (Olagoke et al., 2021; Pickett et al., 2014).

The PUSH-PULL app[1] gives guidance to farmers around detection and management of crop pests and diseases. It is a biocontrol strategy used to detect and control fall army worms, striga weed, and stalk borers in maize and sorghum. The app has step-by-step instructions on setting up push-pull technology for one's garden or farm. Use of this app was found to increase maize yield by 25–30% where stem-borer is the only farm challenge.

Agrivoltaic farming

Agrivoltaic farming is a climate-smart and solar-powered technology that is highly scalable and adaptable, and it has been successfully practised both in Africa and other parts of the world. Its sustainability, resource efficiency, and resilience are obvious as it enables use of the same plot of land for both renewable energy generation, water efficiency, and food production. Agrivoltaics has been successfully implemented in South Korea, France, the USA, Germany, and Kenya. The positive impacts of this approach that have been observed include more sustainable land use, increased soil water retention and stability, promotion of biodiversity, and carbon sequestration. Crops have been observed to be bigger, fresher, and healthier than control plots. This innovation thus constitutes a sustainable and economically viable innovation (Bingwa, 2023; Edmond, 2022).

Innovation	Crop-model mobile app technology: AgriCloud	Climate-resilient indigenous crop promotion	Push-pull technology	Agrivoltaic farming
Sustainability	High	High	High	High
Effectiveness	High	High	High	High
Scalability	High	High	High	High
Adaptability	High	High	High	High
Resilience	High	High	High	High
Community engagement	High	High	High	High
Resource efficiency	Moderate	Moderate	High	Moderate
Technological integration	High	High	High	High

Policy alignment	Moderate	Moderate	Moderate	High
Economic viability	Moderate	Moderate	Moderate	High

Challenges and Mitigations

Some of the potential challenges in implementing these innovations includes the timely availability of weather forecasts across different African countries, limited smart phone ownership in some parts of Africa, and the need for development of alternative/expanded knowledge databases, more extensive documentation of crop pest and disease monitoring information, and generation of accurate weather data for larger areas.

Some countries, like South Africa, have established institutions that have provided accurate daily weather forecasts for many years. However, even though global info from climate centres is usually available for free, it is also available on a larger scale. Detailed information for the 8-15km^2 blocks that are normally used for the AgriCloud app is not always available and can lead to more challenges in the project development. This means it might be difficult for nations without reliable weather-forecasting institutions to implement this innovation. Capacitating weather service institutions within the African Union so as to ensure that the weather services in African countries are effective is an important strategy to combat this challenge. International weather agencies such as the ECMWF can also partner in such initiatives.

The inability of farmers to afford a smart android phone limits their ability to make use of app-based technologies. Furthermore, some African countries have communities that cannot be located on the mapping grid, which makes it difficult to access accurate weather information specifically for farming communities in those locations. Partnerships among neighbouring farmers where a few have smart android phones can be initiated with the help of extension workers.

Alternative knowledge databases will need to be developed for a wide range of crops that farmers across Africa are growing. The crop models (such as AquaCrop) that are calibrated for underutilised crops can assist in creating a baseline dataset that can be used along with the indigenous knowledge about planting and harvesting times, local farming practices, etc.

Most of pest and disease monitoring information is not being well documented to reflect the influence of climate variables; this information will thus need to be expanded for integration into the knowledge databases required to generate early warnings for conditions conducive to crop infection and infestation.

Future Outlook and Recommendations

While agriculture is heavily compromised by the climate crisis, the sector is also one of the main contributors to global warming. In fact, agriculture contributes almost one-third to global anthropogenic GHG emissions – a compelling basis for prioritising the expansion of alternative, more sustainable agricultural practices.

Partnerships with established weather service institutions will enable the up-scaling of apps such as AgriCloud in other African countries. The PUSH-PULL App can serve as a model for similar technologies to be developed for use as information-sharing platforms among farmers that will enhance their productivity. Furthermore, the inclusion of climate-resilient crops such as Bambara groundnut into this type of app will encourage further research and development to improve the marketability and expand the use of underutilised African crops. The farmer-buyer online market will make it easier for farmers to connect with purchasing agents for their products. This will reduce the risk of spoilage and enable more efficient transportation – two factors that often hinders farmers from selling all their products and doing so on time. Furthermore, buyers can get a consistent supply of raw materials for their processed products, thereby boosting the economy and ensuring timely product supply for the general population.

Recommendations for Further Research, Development, and Implementation

Further expansion on the innovations discussed in this technical summary would require inclusion of more indigenous crops and also vegetables. Pest and disease forecasts for these different crops for specific countries and areas/communities within each country would be useful as add-ons for existing apps. Having apps available in different African languages would make them more accessible. More initiatives should be launched to support adoption of agrivoltaic farming, especially given the worldwide emphasis on renewable energy and the abundance of potential solar energy in African countries.

Conclusion

The use of crop models to build innovative apps and add-ons for existing apps to predict crop yields for a specific area for the current season or to predict favourable planting dates is an innovation that has been used in some African countries. Furthermore, such crop models have also been integrated into apps to predict and/or detect crop diseases and pests. However, there is much potential for this technology to be expanded to a wider variety of crops and upscaled to more areas across Africa.

Use of crop models built into apps holds great potential for addressing the global challenge of climate change negatively impacting food systems. If developed further, these apps can provide farmers across Africa with personalised, weather-based farming advice for their exact location and in their own language.

Climate-resilient indigenous African crops that have an archive of evidence-based research results about their quality, availability, accessibility, and nutritional properties should move from the research domain to implementation and development of the value chain, including value addition. Policy-backed initiatives that support such developments can be piloted first at community level and then expanded to district, provincial, and regional levels across African nations and beyond.

Online marketing functionality should be added to existing apps or developed as an app on its own so that farmers can showcase their products and negotiate with prospective buyers in real time. This could greatly reduce post-harvest losses and food wastage. Such functionality in apps could play a role in mitigating and adapting to climate change.

The use of agrivoltaic farming for both renewable energy and crop production is a resource-efficient innovation that can help reduce GHG emissions while increasing crop production at the same time – a win-win situation.

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