UNITED NATIONS DEVELOPMENT PROGRAMME

cultiv@te
Innovation for Sustainable Agriculture

UNDP

FOSTERING AGRITECH INNOVATION

LEARNINGS FROM CULTIV@TE: UNDP'S GLOBAL INNOVATION INITIATIVE FOR SUSTAINABLE AGRICULTURE

Acknowledgements

Cultiv@te was launched in November 2019 as UNDP's global innovative initiative for sustainable agriculture and was made possible through generous financial support from the Ministry of Sustainability and the Environment, Singapore and DSM. Cultiv@te was implemented by the UNDP Global Centre for Technology, Innovation and Sustainable Development, Singapore.

Following a global call for applications, submissions were received from over 200 startups and R&D teams around the world, through the Agorize SaaS platform. Finalists of Cultiv@te were selected after careful evaluation by a panel of evaluators consisting of UNDP staff from the Global Centre and participating Country Offices (Armenia, Bhutan, Ecuador, Ethiopia, Gabon, Indonesia, Kenya, the Philippines, Uruguay, and Uzbekistan) as well as agri-food experts from Cultiv@te partners – Singapore Food Agency, AgFunder, GROW, and Big Idea Ventures.

Virtual workshops on topics including various technologies, business models, and branding were delivered as part of a webinar series for the Finalists by experts from Cultiv@te partners – Microsoft and PALO IT. SWITCH (Singapore Week of Innovation and Technology) provided outreach to the initiative as well as a platform to showcase solutions from Cultiv@te Finalists.

Finally, a number of government partners at the national and local levels supported the piloting of selected Finalist solutions. These included the Singapore Food Agency (SFA); Ecuadorian Ministries of Environment, Water and Ecological Transition (MAATE) and Agriculture and Livestock (MAG); Ethiopian Biotechnology Institute (EBTi); Kenya Agricultural and Livestock Research Organization (KALRO); Agricultural and Forestry Research Institute (IRAF), Gabon; Municipality B, Montevideo, Uruguay; and Uzbekistani Ministries of Innovation and Agricultural Resources and State Committees for Veterinary and Livestock Development and on Ecology and Environmental Protection.

We express our sincere thanks to our donors, partners, and all participants of Cultiv@te for their continued support and engagement through the last two years.

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Cultiv@te at a Glance

202 submissions

from teams around the world, representing

114 nationalities

11 Country Challenges

across **Asia**, **Africa**, and **Latin America**

31 Finalists

across **3** Categories

- Urban Agriculture
- Rainfed Agriculture
- Livestock Farming and Aquaculture

25+ **partnerships** and **engagements**

*with **public** and **private** sector organisations*

2 knowledge products developed

1000+ downloads

(as of May 2022)

Foreword

Riad Meddeb
Director a.i.
UNDP Global Centre for Technology, Innovation and Sustainable Development
Singapore

COVID-19 has disrupted lives and livelihoods across the world, slowing down progress on the Sustainable Development Goals (SDGs) and even reversing it in several contexts. Through the loss of agricultural and allied livelihoods, disruptions in global food supply chains, increased food prices, and a rise in global hunger, the pandemic has shone a spotlight on the fragility of our agri-food systems and the various systemic issues facing them.

The first ever United Nations Food Systems Summit was held in 2021 in this context with the aim of transforming agri-food systems. It emphasised the centrality of agri-food systems in achieving all the SDGs, highlighting the complex interlinkages between issues of poverty, hunger, gender inequality, climate change, and biodiversity loss. The Summit also drew attention to the role of innovation as a crucial lever of change with the potential to deliver wide-ranging positive change.

Foreseeing the growing importance and relevance of technology and innovation for transforming agri-food systems, Cultiv@te was launched in November 2019, with support from the Ministry of Sustainability and the Environment, Government of Singapore. It drew inspiration from Singapore's pioneering efforts to leverage technology to boost local food production and foster an agri-food innovation ecosystem to address its food security challenges, as part of the '30 by 30' goal. Cultiv@te aimed at surfacing radical and transformative technologies to help address the toughest development challenges in the agri-food sector. Over the last two years, despite the pandemic, it has managed to bring together creative minds and passionate people to co-design innovative solutions and helped forge value-driven partnerships in countries across Asia, Latin America, and Africa.

Agritech has witnessed a massive boom in recent years, with the space attracting record-breaking investments from the private as well as public sectors. Yet, despite the promise of technology in addressing the various agri-food sustainability challenges, solutions have often failed to scale. Among several reasons, a key one is the lack of user-centricity of solutions. Agritech solutions—often technology-driven rather than being problem-driven—fail to pinpoint and address the 'real' needs of their intended users. These are often smallholder farmers lacking access to the required skills and resources to make the best use of available technology. Cultiv@te adequately highlighted these mismatches between technology and the ground realities of users. It allowed us to experiment with innovative solutions for bridging these gaps—generating valuable insights for a variety of stakeholders including innovators, investors, public sector officials, and development professionals.

This report shares the achievements over the two years since the launch of the global innovation initiative, summarises the key trends in the use of technology for advancing sustainable agriculture, and captures our learnings with regards to 'what works' for fostering innovation in the agri-food sector—from the importance of human-centred design to stakeholder engagement strategies.

We would like to take this opportunity to thank all partners of Cultiv@te for their tireless efforts and collaboration. To materialise its Strategic Plan 2022-2025, UNDP is invested in developing integrated solutions—with strategic innovation and digitalisation as key enablers—towards structural and inclusive transformation of agri-food systems. We look forward to working with existing and new partners in this endeavour.

Image: UNDP Peru

INTRODUCTION

THE WORLD'S POPULATION IS ESTIMATED TO INCREASE TO 9.7 BILLION BY 2050. FEEDING IT—CONSIDERING CHANGING GLOBAL DIET PATTERNS—WILL REQUIRE INCREASING CURRENT FOOD PRODUCTION BY UP TO 70 PERCENT.[1]

This will not be easy, especially given the increasingly adverse impacts of climate change on agriculture and depleting natural resources.

Agriculture is indivisibly linked to the lives and livelihoods of billions across the globe. From the food we eat to the clothes we wear—it impacts each one of us. Looking at agriculture as a 'system', it involves aspects of growing, aggregation, processing, distribution, and consumption.

A fair and sustainable 'agri-food system' rests on having enough for everybody's needs, ensuring that food isn't wasted, that farming methods and eating habits protect and nurture the soil, and that those who work the land are treated and paid fairly. Agri-food systems thus have a critical role to play in achieving all 17 Sustainable Development Goals (SDGs); But they need transformation.

1 Michiel van Dijk, Tom Morley, Marie Luise Rau, and Yashar Saghai, "A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050," *Nature Food* 2 (2021), 494–501.

Technology and innovation are playing a crucial role in enabling and accelerating this systemic transformation. The trends abundantly confirm this; Agritech and foodtech startups raised over $51.7 billion in 2021—a 85 percent increase over the previous year[2]—notwithstanding the disruptive impacts of COVID-19 on agri-food systems across the globe. However, the gains of technological innovation in the agri-food sector remain largely concentrated in the Global North.

Cultiv@te was launched in 2019, with generous support from the Ministry of Sustainability and the Environment, Singapore[3], and with the realisation that meaningful transformation of agri-food systems will require developing countries having access to knowledge, technology, and resources to foster innovation locally. It aimed to bring innovation and technology where it is most needed, combining globally leading innovation with local knowledge, expertise, and market insights. Most importantly, the initiative aimed to empower UNDP's partners at the national and local levels—with a special emphasis on leveraging South-South and Triangular Cooperation (SSTC)[4]—to explore, identify, test, and scale technological innovations.

Cultiv@te also drew inspiration from the Government of Singapore's concerted efforts towards tackling the country's food security challenges, leveraging technology and innovation to boost local food production. Singapore currently imports 90 percent of its food. The government has announced an ambitious '30 by 30' goal of producing 30 percent of Singapore's nutritional needs locally and sustainably by 2030. Guided and fostered by enabling policies, incentives, and regulations, Singapore is emerging as a global hub for agritech and foodtech innovation.

Through early 2020, we worked with 10 UNDP Country Offices[5] and respective national government agencies to identify 11 challenge statements in alignment with their national developmental priorities.

FOLLOWING OUR GLOBAL CALL FOR APPLICATIONS, WE RECEIVED OVER 200 SUBMISSIONS FROM STARTUPS AND R&D TEAMS FROM OVER 50 COUNTRIES AND REPRESENTING 114 NATIONALITIES.

In collaboration with UNDP experts and external partners,[6] we identified 31 promising solutions with potential for wide scale impact across areas of rainfed agriculture, urban agriculture, and livestock farming and aquaculture.

Through 2020 and 2021, we provided mentorship and catalytic funding to a few of the most promising Cultiv@te Finalists, supporting the piloting and/or prototyping of their proposed solutions and forging value-driven multi-stakeholder partnerships at the national level along the way. The visibility and recognition through Cultiv@te has helped multiple Finalists raise additional funding and build partnerships. The experience and insights from Cultiv@te have also helped shape the UNDP Global Centre Singapore's research and knowledge generation efforts in the use of digital technologies to promote sustainable agriculture. This has culminated in two UNDP publications—Precision Agriculture for Smallholder Farmers and Blockchain for Agri-Food Traceability—strengthening the Global Centre's position as a hub of knowledge and policy relating to sustainable development.

The remainder of this report aims to encapsulate the global agritech innovation landscape, feature some of the innovations supported through Cultiv@te, and share our learnings with regards to 'what works' in fostering innovation in agritech.

2 AgFunder, 2022 AgFunder AgriFoodTech Investment Report (2022).
3 The erstwhile Ministry of Environment and Water Resources (MEWR) was renamed to the Ministry of Sustainability and the Environment (MSE) in 2020.
4 South-South cooperation is a broad framework of collaboration among countries of the South in the political, economic, social, cultural, environmental, and technical domains. Triangular cooperation is collaboration in which traditional donor countries and multilateral organisations facilitate South-South initiatives through the provision of funding, training, management, and technological systems as well as other forms of support. Read more at https://www.unsouthsouth.org/about/about-sstc/.
5 UNDP Country Offices who participated in Cultiv@te: Armenia, Bhutan, Ecuador, Ethiopia, Gabon, Indonesia, Kenya, the Philippines, Uruguay, and Uzbekistan. The nodal organisation for Singapore's challenge statement was the Singapore Food Agency.
6 These included experts from participating UNDP Countries Offices, the Singapore Food Agency, AgFunder, GROW, and Big Idea Ventures.

Farmers testing ‘Soil Pal’—a low-cost soil sensor developed by Ujuzikilimo, a Cultiv@te Finalist.
Image: Ujuzikilimo

cultivate

Innovation for Sustainable Agriculture

We worked with 10 UNDP Country Offices across Asia, Africa, and Latin America and the Singapore Food Agency to pilot innovative technological solutions for sustainable agriculture.

Ecuador

How might we increase the productivity of livestock and dairy sectors, and improve the quality of its final products, in a forested area?

Gabon

How might we increase agricultural productivity to meet food security targets while ensuring net zero deforestation in Gabon?

Uruguay

How might we integrate urban agriculture into public housing programmes?

Map not to scale.

Image: L. Sharma/Marchmont Communications

THE AGRITECH INNOVATION LANDSCAPE

AGRI-FOOD SYSTEMS ARE COMPLEX, AND SO ARE THE DEVELOPMENT CHALLENGES ASSOCIATED WITH THEM. SEVERAL OF THESE CHALLENGES ARISE AT THE FIRST MILE ITSELF—CLOSER TO AGRICULTURAL PRODUCTION.

These include issues such as deforestation; low productivity and yields; unfair compensation to farmers; gender inequalities in access to knowledge, technology, and capital; and the increasingly severe impacts of climate change. Beyond the production stage, close to a third of the food produced globally also gets lost or wasted as it moves along supply chains.

Technology is emerging as a crucial enabler for addressing these challenges. The agritech landscape is vast, with solutions leveraging a wide range of technologies—from the now-ubiquitous mobile phone to artificial intelligence, blockchain, remote sensing, and biotechnology.

Given the diversity of technologies and the overlaps in their application, categorising agritech solutions is not an easy task. A helpful approach is to map solutions to the problems they seek to address across different stages of the agricultural value chain—from farm to table.

The Cultiv@te call for applications sought innovative solutions across three broad categories: urban agriculture; rainfed agriculture; and livestock farming and aquaculture. Cultiv@te aimed at finding inclusive solutions to address various developmental challenges associated with agriculture, with an emphasis on benefiting the most marginalised stakeholders such as smallholder farmers. Unsurprisingly, a majority of the submissions received were 'upstream', aiming to tackle sustainability challenges closer to production. These ranged from biotechnological solutions and agribusiness marketplaces to farm management software and novel farming systems.

Leveraging the diversity and wide range of Cultiv@te Finalists, the remainder of this section provides an overview of different kinds of agritech solutions aiming to address various sustainability challenges relating to agriculture.

AGRICULTURAL BIOTECHNOLOGY

The United States Department of Agriculture (USDA) defines agricultural biotechnology as "a range of tools, including traditional breeding techniques, that alter living organisms, or parts of organisms, to make or modify products; improve plants or animals; or develop microorganisms for specific agricultural uses."[7] Biotechnology enables a range of agricultural applications such as improving crop yields, increasing tolerance against pesticides and weedicides, reducing the need for synthetic fertilisers, and increasing resilience against climate threats.

Cultiv@te Finalist The Sustainable Nitrogen Foundation, for instance, has developed an agricultural biotechnology solution that uses a naturally occurring bacterium found in sugarcane that fixes up to 80 percent of plants' nitrogen requirements, providing an alternative to environment-harming synthetic nitrogen fertilisers. Whereas The Toothpick Project has developed a solution using a naturally occurring fungus to increase resilience of cereal crops against infestation by *Striga* (commonly known as 'witchweed') —a major threat to food security in Sub-Saharan Africa.

7 USDA, "Biotechnology FAQs".

Scientists from the Ethiopian Biotechnology Institute (EBTi) during their exposure visit to the Kenya Agricultural and Livestock Research Organization (KALRO), facilitated by UNDP through Cultiv@te. Image: The Toothpick Project

AGRICULTURAL E-MARKETPLACES

Lack of access to relevant information is an issue faced by almost all agri-food value chain actors. This is particularly the case in fragmented markets dominated by smallholder agriculture. Digital platforms are connecting agri-food value chain actors—from credit and insurance providers, input suppliers, and farmers to wholesale buyers and end-consumers—and helping reduce various inefficiencies in the exchange of goods, services, and information.[8]

Smallholder farmers often lack access to formal credit. This limits their capacity to invest in the technologies and inputs required to increase farm yields and incomes. CROWDE and iGrow are peer-to-peer lending platforms that allow private and institutional investors to invest in farming projects in Indonesia, providing farmers with access to much-needed capital.

The sharing economy—enabled by digital platforms—holds great potential for agriculture. It allows the sharing of technological resources which would traditionally be expensive and unviable for individual smallholder farmers to own and use. Hello Tractor enables the sharing of farm mechanisation equipment such as tractors, while Liquidstar allows sharing of electric batteries for farming-related tasks such as irrigation.

FARM MANAGEMENT AND DECISION MAKING

Digital technologies are transforming agriculture by enabling the easy collection, storage, and processing of digital data as well as the sharing of information derived from it. Moreover, this can be done at scale with near-zero marginal costs. Perhaps the most common example of the use of digital technology in agriculture is the growing use of mobile phones by farmers and other actors for communication and accessing knowledge resources. Farmz2U, for example, leverages open as well as proprietary information sources to provide tailored advisories to farmers based on their farming location, soil type, and market demand.

One of the biggest benefits of digital technologies is in unlocking the potential of agricultural data. Agricultural data can take many forms, ranging from agronomic data (e.g., production advice, pests and diseases), environment and natural resource related data (e.g., meteorological, hydrological, soil) to socio-economic data (e.g., market, prices, infrastructure) and administrative data (e.g., legal, financial, official records).[9]

Information and insights generated from these can guide decision-making by various agri-food stakeholders, starting with farmers. OneSoil, for example, leverages satellite imagery and machine learning to provide and actionable information to farmers. Their solution allows automatic field and crop detection, remote plant monitoring, and generating field maps for variable rate fertiliser application based on intra-farm variability in crop conditions.

Digitisation of farm-level data allows its easy sharing beyond farms to different actors in the value chain to guide their decision making. Agritask, CropIn, and Digi Agri—all digital platforms—provide a variety of data-driven services to different stakeholders. These include remote monitoring of farms, supply chain traceability, and inventory and process management for agribusinesses and cooperatives. Agroclimatica specialises in generating risk scores using multidimensional data (e.g., climate, soil, crop) to inform decision-making by financial institutions such as credit providers and insurers.

8 ISF Advisors, Agricultural "Platforms" in a Digital Era: Defining the Landscape (2021).
9 Open Data Charter, "Key data categories for agriculture, datasets and data standards."

MOBILE PHONES ARE DEMOCRATISING DIGITAL AGRICULTURE

Mobile phones—and increasingly, smartphones—are perhaps the most impactful tool when it comes to making digital and data-driven agriculture accessible even to smallholder farmers in developing countries. Mobile phone and mobile internet penetration has grown rapidly over the last decade. More than seven out of ten households in the world have access to a mobile phone.[10] Almost 28 percent of rural households in LMICs had access to the internet by 2019, with mobile phones accounting for over 87 percent of all broadband connections.[11]

This has fostered a vast universe of mobile phone-enabled solutions across all stages of agri-food value chains. Cultiv@te Finalist Farmz2U, for example, leverages a mobile phone app as the primary gateway for farmers to access its digital platform, providing a variety of services—from farm advisories to access to inputs, markets, and credit. Even when mobile phone apps are not vital for the core agritech service being offered, several solutions still leverage them to provide easier access to users. 18 out of the 31 Cultiv@te Finalists, for instance, had either a supporting mobile phone app or used capabilities of mobile phones as part of their solutions.

Beyond custom apps, agritech solutions can leverage existing apps and capabilities of smartphones (e.g., inbuilt camera, GPS sensor, accelerometer, CPU). Pastoral, for instance, relies on a chatbot based on Telegram (the popular messaging app) as an interface for livestock farmers to access its digital platform. Using apps and tools that farmers and other users are already familiar with can greatly reduce the friction in accessing and adopting new agritech solutions.

10 World Bank Group, *World Development Report 2016: Digital Dividends* (Washington, DC: World Bank, 2016).
11 ITU, Measuring digital development: Facts and figures 2021 (Geneva: 2021); GSMA, *The State of Mobile Internet Connectivity Report 2021* (2021).

Image: Wazkkii/Adobe Stock

SATELLITES ARE ENABLING THE DEVELOPMENT OF HIGHLY SCALABLE SOLUTIONS

Satellite technology has evolved steadily and substantially over the decades. Satellite imaging resolution (spatial, temporal, and spectral) has increased sufficiently (particularly with commercial satellites) to support applications at the farm-level. Even the open and freely available satellite data from public programmes such as European Space Agency's (ESA) Sentinel and National Aeronautics and Space Administration's (NASA) Landsat programmes is of sufficiently high resolution to support the development of a variety of applications with potential to benefit millions of farmers globally.

High-resolution satellite imagery enables precision farming—a data-driven farm management approach that takes into account the needs of individual farms. It provides farmers with information about intra- and inter-farm variability regarding aspects such as soil moisture and nutrient levels, enabling them to take necessary action. It also enables applications such as yield estimation. On a meso-level, satellite imagery can help in the early detection of climate threats such as droughts and floods as well as crop disease outbreaks.

All of this is facilitated by advances in data computation and management through technologies such as cloud computing, artificial intelligence, and machine learning. These allow the processing of vast amounts of high-resolution geospatial data, combining them with other datasets such as weather and climate, infrastructure, and markets, thereby enabling the detection of patterns and generation of insights to support decision and policymaking in agriculture.

Image: Victor/Adobe Stock

SENSORS AND INTERNET OF THINGS (IOT)

In-field sensors make data available to farmers in real-time to help inform their decisions. These data can be related to various soil conditions (e.g., pH, moisture, temperature) or weather (e.g., temperature, humidity, wind speed). Data from in-field sensors are localised and often more accurate than remote sensing data. The falling costs of various sensors along with advances in networking technologies (e.g., IoT) are making them accessible for even smallholder farmers.

UjuziKilimo, for instance, has developed a low-cost handheld sensor named 'Soil Pal' to measure the pH levels, macro nutrients (NPK), electrical conductivity, and organic content of farm soil quickly and easily. Upon uploading the measurements to the cloud, the solution also provides tailored recommendations to farmers based on the crop they wish to grow.

Beyond data collection, sensors can also aid automation in farms, helping improving productivity and reduce the consumption of resources such as water and energy. BIOPS Agrotekno, an Indonesia-based agritech hardware startup, has developed 'ENCOMOTION', an IoT-enabled device which can be attached to existing farm irrigation infrastructure such as sprinklers and drip systems to control irrigation based on water needs of crops. These needs are inferred from local environmental conditions which are monitored real-time by the device itself also acting as a weather station.

IoT can help increase productivity and yields in urban farms as well. The Wely Device, created by Canada-based Phytochem Consulting, is an IoT device that regularly records and reports the temperature and weight of a tray of seedlings—two important data points for monitoring their health—enabling various applications such as precision irrigation, greenhouse control performance, and pest control strategies.

Sensors find several uses in the livestock industry as well, where they can be used to monitor relevant parameters related to animals such as their location, activity, and weight. Digitanimal, a Spain-based startup, has developed IoT-enabled collars and ear tags to track and monitor cattle. Data collected through the collars is processed using AI algorithms to provide insights to livestock for optimising livestock productivity.

NOVEL-FARMING SYSTEMS

While urban farming is not a new concept, the use of modern techniques and technologies is enabling manifold increases in yields and productivity compared with traditional open-field farming. For instance, soilless growing techniques such as hydroponics[12] offer precise control over water and nutrient application and elimination of soil-borne diseases. Similarly, growing plants indoors—replacing sunlight with artificial lighting—allows greater control over growing conditions, allowing increased yields, all-year growing, and better protection against inclement weather and diseases.

Various hydroponic farming systems have been developed around the world to meet local needs. The African Grower, for example, is a robust vertical hydroponic system developed for the African context that enables growing of fresh vegetables in a limited space, without the use of electricity, and using up to 90 percent less water than traditional methods.

Novel farming systems could also involve growing crops in unconventional spaces such as warehouses, rooftops, or even shipping containers. Citiponics is operating multiple urban farms in Singapore that produces a variety of leafy green vegetables on carpark rooftops. Using a proprietary vertical farming technology to keep every drop of water used in a closed loop, Citiponics can limit water consumption to 1/100 of that in traditional farming.

Use of technology also enables yield improvements in conventional farming models such as greenhouses. LLEAF, for example, is an Australian agritech company that has developed luminescent dyes to absorb portions of the solar spectrum that are less active in supporting plant growth, while emitting significant amounts of supplementary luminescent light at wavelengths that are more directly supportive for plant growth. A typical installation of the technology comprises thin, polymer films that are retrofitted to an existing greenhouse or integrated into the roofing panels of a new greenhouse during their manufacturing.

Finally, novel farming systems could extend beyond urban areas. For instance, Seawater Solutions, a U.K.-based agri-environmental startup turns degraded and salinized land into healthy saltmarsh ecosystems, where high-value "superfood" vegetables can be grown with seawater. Their Integrated Seawater Farming Systems (ISFS) use solar and wind-powered irrigation systems to deliver seawater into coastal farmland. These are redeveloped to optimise water flows, mimicking the natural tidal saltmarsh ecosystems to which these species are native.

12 Hydroponics is a production method where the plants are grown in a nutrient solution rather than in soil.

CONTROLLED ENVIRONMENT AGRICULTURE (CEA) IS THE NEXT FRONTIER IN AGRITECH INNOVATION

Controlled environment agriculture (CEA) is arguably the most technologically advanced form of farming currently. Depending on the crops to be grown and the availability of resources, it involves a combination of multiple techniques and technologies. These could include indoor growing, environmental control, soilless growing, vertically stacked production layers to maximise space-efficiency, and the use of sensors and AI for optimising production environment.

Currently, a wide variety of horticultural crops can be grown indoors. The most common ones include leaf lettuce, tomatoes, peppers, cucumbers, strawberries, watercress, celery, and herbs.[13] CEA allows yield improvements of several times compared to traditional open-field farming. For leafy greens, this could be 10-100 times—using the same amount of land and with water savings of up to 99 percent with recycling and recirculation.[14]

However, there are still several limitations with regards to the feasibility of scaling up CEA. Staple crops such as rice, wheat, and corn still cannot be reliably grown indoors. Additionally, while saving space and water compared to traditional farming, CEA requires high amounts of energy for artificial lighting, environment control, and for running electronic equipment.

However, this is an active area of research. Technological breakthroughs in various domains such as plant genetics and efficient lighting systems promise to enhance the viability of CEA, helping transform current agricultural production systems. Future developments in CEA will have important ramifications on sustainable development globally, including on the livelihoods of traditional farmers, land use, circular economy, and biodiversity.

13 University of Massachusetts Amherst, "Hydroponic Systems."
14 S. H. van Delden et al., "Current status and future challenges in implementing and upscaling vertical farming systems," *Nature Food* 2, 944–956 (2021).

An indoor farm with artificial lighting.
Image: Petr Magera/Unsplash

ON-FARM EQUIPMENT

There is a wide spectrum of electro-mechanical solutions to support on-farm agricultural activities—from sowing to harvesting to post-harvest.

Mechanisation in agriculture can play a vital role in making post-harvest, processing, and marketing activities more efficient, effective, and environmentally friendly, thereby contributing to increased incomes for farmers. Moreover, it can help promote gender equality in agriculture by reducing drudgery in farm activities for women, who contribute up to 80 percent of farm labour in some countries. However, farm mechanisation is an aspect that has historically been neglected in the context of developing countries.[15]

High investment cost is one of the key barriers inhibiting wide-scale mechanisation in developing countries. As a result, a variety of affordable solutions, ranging from low-cost pumps, tillers, harvesters, and threshers are being developed around the world. For relatively expensive equipment such as tractors, use of equipment sharing platforms (e.g., Hello Tractor) can bring down the cost of application for individual farmers.

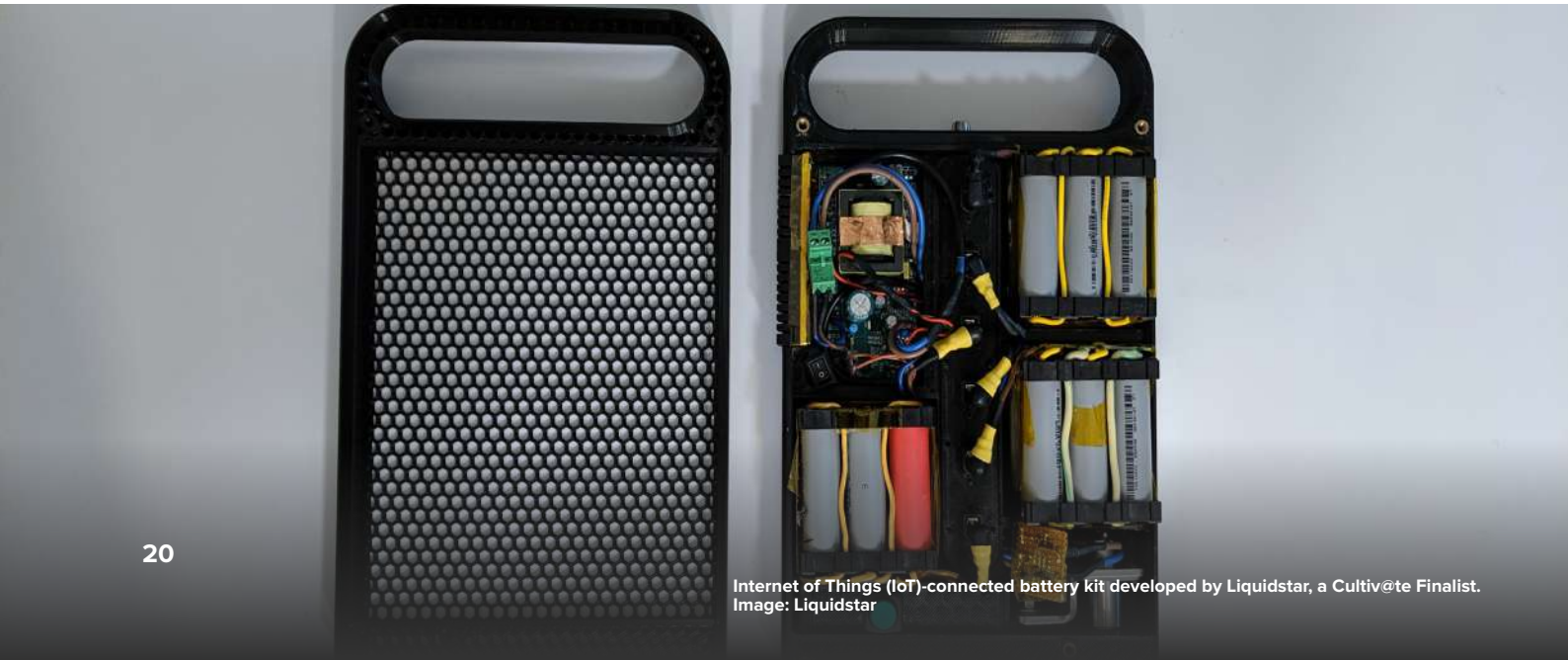
Another barrier to mechanisation is the lack of access to energy for powering electric equipment. Battery sharing platforms like Liquidstar can provide farmers access to portable energy sources at the farm-level. Renewable energy sources can also be leveraged where access to electrical grid is limited. For instance, Solaristique has developed a range of solar-powered farm equipment for off-grid applications including dryers, refrigerators, and pumps.

BLOCKCHAIN-POWERED TRACEABILITY SYSTEMS

Blockchain—the distributed ledger technology (DLT) at the heart of cryptocurrencies—has several applications for advancing sustainable development, including in the agri-food sector. The complex web of suppliers hides several sustainability issues such as deforestation, child labour, and inequitable compensation of farmers. The unique features of blockchain technology such as the immutability of data, its decentralised nature, and smart contracts enables innovative solutions to these complex issues.

Convergence.Tech is a technology and consulting company specialising in building blockchain-powered solutions to address complex issues relating to environmental and social sustainability. Convergence.Tech had previously worked with UNDP to pilot the use of blockchain for creating a market for sustainably sourced cashmere in Mongolia. Through Cultiv@te, the company created a roadmap for implementing a blockchain-powered end-to-end traceability platform for tracking and ensuring the environmental sustainability of livestock products originating in the Ecuadorean Amazon.

15 FAO, "Sustainable Agricultural Mechanization."



Internet of Things (IoT)-connected battery kit developed by Liquidstar, a Cultiv@te Finalist. Image: Liquidstar

AQUACULTURE

Aquaculture is the controlled cultivation of aquatic organisms such as fish, crustaceans, molluscs, algae, and aquatic plants. As of 2018, aquaculture provided nearly 52 percent of all seafood consumed globally.[16] With populations of wild fish and other aquatic animals declining globally, aquaculture provides a solution for meeting the growing demand for animal protein in diets.

Land-based aquaculture (e.g., fish tanks) is considered to be more sustainable and less environmentally harmful than conventional fishing and sea-based fish farming, owing to its smaller carbon footprint and potential proximity to markets.[17] However, land-based aquaculture too contributes to sustainability challenges such as pollution. Aquaculture can lead to the release of organic wastes into water bodies, causing harmful algal blooms.[18]

A range of technologies and innovations have emerged to tackle the problem of aquaculture-generated waste. For instance, the Institute on Membrane Technology (ITM), a research institute of the Italian National Research Council (CNR), has developed a system based on advanced membrane technology to filter out organic and suspended solids as well as dissolved ammonium compounds, phosphorus, and metal traces in wastewater from aquaculture plants. This can contribute to a high water-reuse rate (up to 95 percent) as well as increased fish yields resulting from better water quality.

MAquaponics, a Yerevan, Armenia-based company, has developed a process for remediating and converting solid and liquid waste from aquaculture plants into an organic liquid fertiliser that can be used to grow produce for human or animal consumption.

To decontaminate water bodies where wastewater from aquaculture plants is already being released, De Rebus Plantarum, a spin-off of the University of Padova, Italy, has developed a 'floating treatment wetland' technology named TECH-IA. It involves a floating platform made from a non-toxic material which supports plants, which cannot naturally float on water but whose roots can absorb toxic materials in the water, thus purifying it.

16 FAO, "The State of World Fisheries and Aquaculture 2020."
17 Esan Swan, "In photos: Land-based aquaculture promises more sustainable seafood," *Financial Times*, November 30, 2021.
18 The Ocean Foundation, "Sustainable Aquaculture."

An aquaculture pond.
Image: iGrow

An Internet of Things (IoT)-connected weather station developed by Agrosmart, a Cultiv@te Finalist.
Image: Agrosmart

Spotlight on Thought Leadership

Cultiv@te has shone a spotlight on the complex sustainability challenges surrounding agri-food systems, as well as on the potential of technology-enabled (and particularly 'digital') solutions in addressing them. Recognising the knowledge gap among development practitioners in the application of such solutions, the UNDP Global Centre Singapore has developed two knowledge products to guide the exploration of, experimentation with, and scaling of digital agricultural solutions.

Advances in digital technologies like mobile phones, remote sensing using satellites, uncrewed aerial vehicles (UAVs), Internet of Things (IoT), artificial intelligence (AI), and cloud computing, as well as their growing affordability are making precision agriculture applications accessible for smallholder farmers in developing countries.

Precision Agriculture for Smallholder Farmers is meant as a guide for project managers exploring the use technology and innovation in agricultural initiatives. It provides an overview of the above technologies and the precision agriculture applications they enable, through real-world examples and use cases. It also highlights technical and operational considerations such as the technological feasibility of solutions, suitable business models for scaling up adoption, and potential barriers.

Agri-food supply chains are complex and involve a large number of actors—from small-scale farmers, primary processors, and traders to product manufacturers, distributors, retailers, and consumers. This complexity limits farm-to-table traceability, which is key to identify sustainability-related issues in agri-food systems including extreme inequality and poverty, human rights violations, and environmental degradation.

Blockchain for Agri-Food Traceability explores the technology's potential in advancing the SDGs related to the agri-food sector, leveraging its unique features like its decentralised nature, data immutability, and smart contracts. The report also highlights key considerations for implementing an end-to-end traceability system that is scalable, sustainable, and inclusive, ensuring that the most disadvantaged stakeholders—the small-scale producers—are not left behind.

A greenhouse using LLEAF's polymer film that aims to optimise sunlight for growing plants. LLEAF is a Cultiv@te Finalist.
Image: LLEAF

SPOTLIGHT ON INNOVATION

THE CULTIV@TE GLOBAL CALL FOR APPLICATIONS ATTRACTED SUBMISSIONS FROM OVER 200 AGRITECH STARTUPS AND R&D TEAMS FROM AROUND THE WORLD.

Out of these, 31 of the most promising applications were selected as Finalists following evaluations by experts. Through 2020 and 2021, UNDP Global Centre, Singapore—in collaboration with UNDP Country Offices—supported a select number of Cultiv@te Finalists pilot their solutions in countries across Asia, Africa, and Latin America.

These ranged from agri-biotechnological solutions to improve yields and pest resilience, and urban farming kits, to digital platforms to raise farming productivity, and Internet of Things (IoT)-powered devices for monitoring plants.

This section showcases some of these innovations in the context of the development challenges they seek to address.

AFRICAN GROWER

ROBUST FARMING KITS TO ENHANCE FOOD SECURITY AMONG URBAN COMMUNITIES

Context

Nearly 80 percent of food produced is consumed in urban areas, although most of it is produced in rural areas.[19] By 2050, the share of urban population in the total world population is projected to increase to 68 percent, from 55 percent currently.[20] Changing diet patterns and food demands of a growing urban population will put increasing pressures on the already strained traditional food production systems.

While not a new concept, urban farming is a growing trend around the world. Compared to traditional 'rural' farming, urban farming views traditional agriculture from a different lens, leveraging technology to effectively grow food in the urban environment using fewer resources. Exploiting urban infrastructure as 'arable land' to grow food closer to consumption can improve urban food security. It can reduce food miles, thereby reducing the environmental footprint of long supply chains.

Urban agriculture is not a common practice or a source of livelihood in Uruguay. To date, only a few small-scale initiatives led by individuals, neighbourhood associations, or schools exist. On the other hand, there is significant agricultural activity in Uruguay's peri-urban areas, where food is grown to supply to urban residents, who constitute 95.4 percent of the country's total population.

In recent years, however, new initiative conducive to urban farming have emerged, indicating a growing interest in this area among public authorities and the civil society. For example, in 2018, the Uruguayan parliament approved a law declaring its interest in promoting agro-ecological production, distribution, and consumption, which includes urban and peri-urban agriculture. Similarly, the National Adaptation Plan for Cities and Infrastructure (NAP Cities), currently under elaboration, has identified the integration of urban agriculture solutions into social housing programmes as one of the measures to build urban resilience and adapt to climate change.

Innovation

The African Grower is a robust vertical hydroponic system that allows growing of fresh and nutritious vegetables at home. Developed by South Africa-based startup Fresh Life Produce, it consists of stackable growing 'pods' made from recycled plastic. The structure can be suspended above ground, increasing its pest resilience. The modularity and small footprint of the African Grower makes it versatile in configuration and easily deployable in urban environments. It is space-saving (up to 100 plants/m^2), water-saving (90 percent reduction in usage) and requires no energy to operate. The African Grower was developed to address the challenges with several of the existing hydroponics systems available in South Africa, which were often too technical, high in capital costs, time intensive, and bulky.

Impact

Having borne promising results in South Africa and multiple other African countries, UNDP is testing the system in Montevideo, Uruguay. In collaboration with Municipality B of Montevideo, 40 African Growers are being piloted in schools, public institutions, and community gardens in the Uruguayan capital. The pilot will help Fresh Life Produce understand the short-term user needs and help lay the groundwork for systematic transformation of the local community through decentralised urban food production systems.

This approach is aimed towards turning traditional food 'consumers' to 'producers', empowering them to meet their own nutritional needs while also providing an income opportunity. The African Grower—the technology—is the first of a three-stage process conceptualised by Fresh Life Produce for achieving this. The second stage involves establishing central 'food hubs' for motivating and connecting home growers using digital tools and data, while the third final stage involves building agro-processing capacity of these food hubs, enabling them to source, process, and market the surplus produce of home growers.

> *A product in my eyes is never finished. We always need to adjust and seek feedback to make necessary changes to the solution.*
>
> **— Louis-Gillis Janse van Rensburg, Founder and CEO, Fresh life Produce**

19 FAO, "Tackling food insecurity at the urban level - turning global commitments into local realities," *FAO*, February 19, 2019.
20 United Nations, "2018 Revision of World Urbanization Prospects," *United Nations*, May 16, 2018.

The African Grower is a robust hydroponic vertical farming system developed for the African context.
Image: Fresh Life Produce

FARMZ2U

USING DATA TO ENABLE THE NEXT GENERATION OF FARMERS FARM BETTER

Context

Small farms—measuring less than 2 ha—constitute about 84 percent of all farms in the world and produce nearly 35 percent of the world's food.[21] The figure is much higher in developing countries. Farming is often the primary source of livelihood for smallholder households, who face several challenges to increasing yields and farm incomes. These include lack of access to quality inputs, credit, insurance, markets, as well as access to relevant information to enable them to farm better.

There is another challenge grappling agriculture globally: the falling proportion of youth engaged in the sector. Youth across the world are moving away from traditional agriculture to other more lucrative livelihood opportunities in cities. The average age of farmers has been rising globally. Older farmers are unlikely to adopt new and better farming practices and embrace the advantages offered by digital technologies.[22]

In Kenya, population has boomed over the past 25 years and has resulted in youth making up over 78 percent of the total population. This has fuelled massive rural-urban migration. The average age of Kenyan farmers has been rising too. It currently stands at an estimated 61, against an expected life expectancy of 65.[23] The Kenyan government faces huge challenges in attracting youth to agriculture, threatening the country's food security.

> *"Our target farmer is aged 18 to 30. It is the [age range] we have in mind when developing a solution that is digitally savvy and can provide job opportunities for young people in agriculture, and we seek to achieve this provision through our mission to boost data-centric products that increase productivity.*
>
> **— Aisha Raheem, Co-founder and CEO, Farmz2U[24]**

Innovation

Farmz2U is a social enterprise from Nigeria whose core offering is a software-as-a-service (SaaS) digital platform for providing various extension services to farmers. These include tailored agricultural expertise and enabling market access using data. For its tailored advisory, Farmz2U leverages free and open as well as proprietary information sources to advise farmers on 'what', 'where' and 'how' to grow based on their location, soil type, as well as market demand. Farmz2U also ensures that the farmers adopt best practices such as proper spacing between crops and increasing the use of organic matter as an alternative to chemical fertilisers.

The solution also features a digital wallet to provide farmers access to affordable loans from banks and microfinance institutions, with Farmz2U acting as a guarantor. Through the platform, farmers can also connect with input suppliers and buyers of agricultural produce. In Nigeria, Farmz2U's solution has demonstrated, on average, increase in yields by 20 percent, waste reduction by 38 percent, and increase in farming income by $500.[25]

Impact

UNDP has supported Farmz2U in introducing their solution to young farmers in Kenya. Through Cultiv@te, the solution has attracted more than 1,000 users in the country, which the company hopes to make its hub for expansion into East Africa.

By creatively framing technology-enabled agricultural employment and entrepreneurship opportunities, digital tools like Farmz2U's offer a solution to attract Kenyan youth to the declining agricultural sector. With the right training and mentoring, youth are likely to be attracted to take up employment on a technology-enabled farm or to become an entrepreneur that offers them a decent livelihood. Kenyan youth are primed to leverage the opportunities brought on digital agriculture solutions as the country is already a regional leader in terms of broadband connectivity, general ICT infrastructure, value added services, mobile money, and mobile banking services.

21 Sarah K. Lowder, Marco V..Sánchez, and Raffaele Bertini. "Which farms feed the world and has farmland become more concentrated?" *World Development* 142 (June 2021): 105455.
22 Rob Vos, "Is global food security jeopardised by an old age timebomb?" *The Guardian*, February 4, 2014.
23 Alliance for a Green Revolution in Africa (AGRA), "Over 40 above average," *AGRA*, October 23, 2019.
24/25 Ventures Africa, "How Aisha Raheem's Startup, Farmz2U, is Empowering the Next Generation of Sub-Saharan African Farmers with Data," *Ventures Africa*, August 25, 2021.

Aisha Raheem, Co-founder and CEO of Farmz2U, speaking with Kavita, a farm manager in Kenya's Machakos County. The Farmz2U team conducted an extensive study with potential users of their platform to identify key pain points and customise their solution for the Kenyan market.
Image: Farmz2U

THE TOOTHPICK PROJECT

A BIOLOGICAL SOLUTION TO A BIOLOGICAL THREAT AFFECTING FOOD SECURITY IN AFRICA

Context

Agriculture is Ethiopia's largest economic sector, contributing nearly 37 percent to its GDP. It employs about 78 percent of Ethiopia's working population and generates about 90 percent of its export earnings. However, agriculture in Ethiopia—like in several other least developed countries (LDCs)—is threatened by the increasingly severe impacts of climate change, degradation of soils and other natural resources, and low productivity due to lack of access to technology.

One of the greatest threats to crop production in Ethiopia (and Sub-Saharan Africa, broadly) is *Striga hermonthica*, commonly known as witchweed. It is a parasitic weed that attacks the roots of cereal crops like corn, sorghum, millet, cowpea, and upland rice, and reduces crop yields by 20-80 percent.[26] Currently, about 20 percent of Ethiopia's sorghum production is lost due to *Striga*. Up to 50 million hectares of African croplands show *Striga* infestation, causing $9 billion in annual crop loss. *Striga* is hearty and thrives in poor soil and drought—persisting as climate changes. It is considered Africa's worst pest threat to food security.

Innovation

Biocontrol has gained considerable attention in recent years as a promising nature-based supplement to other agricultural pest control methods. Instead of chemicals, it involves using living organisms such as insects or fungi, or natural substances to prevent or reduce damage caused by harmful organisms.

The Toothpick Project is an initiative spearheaded by Dr David Sands of Montana State University, who has devised a cost-effective biocontrol solution named FoxyT14 to fight *Striga*. It involves using a highly virulent fungal pathogen *Fusarium oxysporum f. sp. strigae* (FOXY) which is originally isolated from *Striga* itself. The name of the project comes from the use of toothpicks on which the primary inoculum of FOXY is grown. Field trials of the solution in Kenya have demonstrated an increase in corn yields of 42-56 percent.[27]

Scaling biocontrol techniques, however, could be a long and complicated journey involving field trials and securing a number of country-specific regulatory approvals. FoxyT14 has secured the necessary regulatory approvals in Kenya, where it is currently being marketed as 'Kichawi Kill'.

Impact

Over the years, several *Striga* control measures such as hand weeding, crop rotation, trap crops and catch crops, intercropping, fertilisers, and herbicides have been proposed, but with limited success and adoption by farmers.[28] Particularly, mechanical (e.g., hand weeding) and chemical (e.g., herbicides, fertilisers) control options have been ineffective because they affect *Striga* after it has already attached to and damaged the host. There is thus a pressing need for effective *Striga* control techniques that could potentially be widely adopted in context of the unique needs and challenges in Sub-Saharan African countries.

A biocontrol solution like FoxyT14 could help transform *Striga* control and management in Ethiopia and Sub-Saharan Africa, broadly, helping overcome the challenges with existing measures. Through Cultiv@te, UNDP is helping introduce the solution to Ethiopia with the aim of achieving at least 20 percent increase in yields of cereal crops, and consequently, improved food security and livelihoods for Ethiopian smallholder farmers.

For this, UNDP has facilitated a research collaboration between The Toothpick Project and the Ethiopian Biotechnology Institute (EBTi), the country's nodal agency for biotechnology research and development. The collaboration is aimed at identifying local Ethiopian FOXY strains, conducting field trials on different crops, evaluating the efficacy of locally identified strains by comparing with commercially available ones, and preparing the groundwork for potential commercialisation of the solution.

> *"The beauty of this project lies in the low-tech delivery of high-tech agricultural research. With a toothpick and cooked rice, we can provide farmers the ability to make their own fresh on-farm inoculum.*
>
> **— Dr David Sands, Lead Scientist, The Toothpick Project**

26 A.Oswaldab and J. K. Ransomc, "Striga control and improved farm productivity using crop rotation," *Crop Protection* 20, no. 2 (March 2001): 113–120; B. Badu-Apraku and R. O. Akinwale, "Cultivar evaluation and trait analysis of tropical early maturing maize under Striga-infested and Striga-free environments," *Field Crops Research* 121, no. 1 (February 2011): 186–194.
27 Henry S. Nzioki et al., "Striga Biocontrol on a Toothpick: A Readily Deployable and Inexpensive Method for Smallholder Farmers," *Frontiers in Plant Science* 7 (August 2016): 1121.
28 Tadesse Yohannes et al., "Genotypic Variation for Low Striga Germination Stimulation in Sorghum 'Sorghum bicolor (L.) Moench' Landraces from Eritrea," *American Journal of Plant Sciences* 7, no. 17 (December 2016).

A Kenyan farmer showing two corns; the smaller one grew on a *Striga*-infested field.
Image: The Toothpick Project

PASTORAL

A DIGITAL LAND MANAGEMENT PLATFORM TO IMPROVE LIVESTOCK YIELDS AND PRESERVE PASTURES

Context

Like its neighbouring countries in Central Asia, pastures dominate the landscape of Uzbekistan, the most populous country in the region. About 75 percent of Uzbekistan's landmass consists of dryland pastures. The livestock sector, which depends on pastures, accounts for 46 percent of Uzbekistan's agricultural output.[29] More than 90 percent of the country's livestock, and consequently, most of the meat and dairy supply, are produced by smallholder (known as *dekhan*) farmers.[30]

However, the absence of effective pasture management systems and prevalence of unsustainable practices such as overgrazing and lack of rotations have led to degradation of pastures over the decades. Most smallholder farmers lack the resources and know-how to practice sustainable pasture management.[31] Moreover, with a growing population, there is constant demand pressure to raise more livestock on scarcer and increasingly unproductive pastures.[32]

Pasture degradation threatens the livelihoods of smallholder farmers, sustainability of the livestock sector, as well as endangers biodiversity. Between 1970 to 2017, average agricultural yield in pastures has reduced from 3.3 to 2.6 metric tons per hectare whereas plant diversity has reduced from 103 to 79 species. 20-30 percent of Uzbekistan's pastures have already degraded while approximately an additional 1.5 percent are degraded annually.

In May 2019, the Government of Uzbekistan signed a new landmark law "On Pastures" which categorised pastures as national wealth and to be protected by the state.[33] The law defines the types of pastures found in the country and lays out the roles and responsibilities of different stakeholders for pasture management.

Innovation

Pastoral is a precision livestock farming platform developed by Karakoram, a U.K.-based innovation consultancy company. The solution combines a low-cost 2G-based location sensor and open-source remote sensing data to provide farmers with relevant information to improve livestock productivity. This includes indicating areas where the animals would be the least destructive to the environment and climate. Pastoral is robust and designed to function even in low-connectivity environments. Instead of a mobile phone app, the information is delivered to the farmers through a Telegram chatbot-based interface, requiring much lesser amount of internet data. The project was initiated by Karakoram specifically to address the Cultiv@te challenge for Uzbekistan.

Impact

Digital land and livestock management platforms such as Pastoral can aid government authorities in the sustainable management of pastures, while also helping raise farmers' incomes. Combined with remote sensing technologies, digital land management platforms can assist in monitoring pasturelands and enforcing closure of certain areas for grazing.[34] Such platforms can also offer pasture users, including smallholder farmers, actionable intelligence such as grazing sequence, necessary subdivisions, and optimal grazing time to help maximise livestock productivity. [35]

UNDP helped Karakoram introduce and test the solution in Uzbekistan through 'design sprint'[36]—a five-day process that involves engaging with key stakeholders, rapid prototyping of solutions, and testing them with end-users. Future iterations of the platform will involve adding more sensors for measuring animal weight and water and feed intake. The solution and will undergo an extensive pilot in the country as a steppingstone to improve biodiversity in pastures, restore ecosystem health, and improve livelihoods of rural communities and farmers.

29 Agorize, "Innovation for Sustainable Agriculture," 2021.
30 IFAD, "Investing in rural people in Uzbekistan," October 2018.
31 Yuliy Yusupov, "The Agricultural Sector of Uzbekistan: Features, Key Problems, the Need for Reforms," *Central Asian Bureau for Analytical Reporting (CABAR)*, March 25, 2019.
32 World Bank, "Population growth (annual %) – Uzbekistan."
33 CIS Legislation, "Law of the Republic of Uzbekistan 'About Pastures'," May 20, 2019.
34 Subash Dahal, "Sustainability in Pasture-based Livestock Production System: A Review," January 2017.
35 FONTAGRO, "Innovation for pasture management."
36 The Design Sprint is a five-day process developed at GV (formerly Google Ventures) for answering critical business questions through design, prototyping, and testing ideas with customers.

UNDP and Karakoram team demonstrating the Pastoral prototype to Abduvali, a livestock farm manager in Uzbekistan. UNDP supported the Karakoram team in conducting a five-day Design Sprint in the country, aimed at engaging with key stakeholders, rapid prototyping of solutions, and testing them with end-users.
Image: Karakoram

THE SUSTAINABLE NITROGEN FOUNDATION

AN ALTERNATIVE TO ENVIRONMENT-HARMING SYNTHETIC NITROGEN FERTILISERS

Context

Synthetic nitrogen fertilisers, along with high-yielding crop varieties, irrigation, and mechanisation, were a key pillar of the Green Revolution, which greatly improved agricultural yields in the Global South and enhanced food security for a rapidly growing world population in the mid-20th Century. Today, synthetic nitrogen fertilisers are used extensively across the world to boost crop yields.

However, when the nitrogen released by the fertilisers is not fully utilised by the growing plants, it can be lost from the fields and negatively impact air and downstream water quality. Synthetic nitrogen fertilisers are also a major source of N_2O—a potent greenhouse gas 300 times more powerful than carbon dioxide.[37] Moreover, the Haber-Bosch process used to make synthetic nitrogen fertilisers is extremely energy-intensive and accounts for about 1-2 percent of total global energy consumption.[38]

Organic fertilisers such as manure, compost, and peat are seen as alternatives to synthetic nitrogen fertilisers. But these are often more expensive, limited to moist and warmer soils, and are considerably slower in releasing nutrients.[39] Organic fertilisers are thus not a satisfactory alternative to synthetic fertilisers, especially in the context of meeting the food needs of a growing world population. To effectively tackle the growing climate crisis and environmental degradation globally, there is an urgent need to find sustainable alternatives to synthetic nitrogen fertilisers.

> *"The key to rolling out these new technologies is having the enthusiasm and energy to make something happen. What was so great about talking to our colleagues in Gabon is that [the energy and enthusiasm] were clearly there.*
>
> **— Dr David Dent, Founder Trustee, The Sustainable Nitrogen Foundation**

Innovation

The Sustainable Nitrogen Foundation (TSNF) undertakes and supports scientific research associated with biological nitrogen fixation and its use in agriculture to reduce reliance on synthetic fertilisers. Plant biological nitrogen fixation is the process by which naturally occurring bacteria take nitrogen from the air and convert it into a form that can be used both by the bacterium and its host plant, in exchange for a safe place to inhabit and to avail nutrients such as sugars.

TSNF has extensive experience working with *Gluconacetobacter diazotrophicus* (*Gd*), a naturally occurring nitrogen-fixing bacterium found in sugarcane that fixes up to 80 percent of plants' nitrogen requirements. Unlike other nitrogen fixing bacteria that inhabit the soil or only the roots, *Gd* has the rare ability to colonise any crop plant's cells intracellularly, fixing nitrogen throughout the plant. The *Gd* technology developed by TSNF has demonstrated yield benefits ranging from an average of 6-17 percent, with 25-85 percent reduction in artificial nitrogen fertiliser usage.

Impact

Biological nitrogen fixation technologies like *Gd* could offer a credible alternative to synthetic nitrogen fertilisers, enabling their gradual replacement and helping alleviate their harmful environmental impact. However, to scale up their adoption, there is a need for further research and experimentation, particularly in developing countries.

Through a Cultiv@te-supported visit to Gabon, UNDP has helped TSNF introduce the solution to the country and is facilitating a potential collaboration with Gabon's Ministry of Agriculture in piloting the use of *Gd* technology as a climate-smart solution to increase crop yields without using synthetic nitrogen fertilisers. The technology will be trialled on priority crops like cassava, banana, and tomato in Gabon. The pilot will evaluate the efficacy of local strains of *Gd* and quantify yield benefits of nitrogen fixation in priority crops, potentially leading to further product development and commercialisation of an easy-to-use crop input.

37 Facundo Calvo, "Tackling Hunger and Global Food Insecurity: Why we must leave nitrogen fertilizers behind," *International Institute for Sustainable Development (IISD)*, March 24, 2022.
38 Aaron von Frank, "5 Facts You Should Know About Synthetic Nitrogen Fertilizer," *GrowJourney*, August 10, 2016.
39 Calvo, "Tackling Hunger and Global Food Insecurity: Why we must leave nitrogen fertilizers behind."

Synthetic nitrogen fertilisers are a potent source of greenhouse gases. Their production is also extremely energy intensive, accounting for about 1-2 percent of total global energy consumption.
Image: Encierro/Adobe Stock

WELY DEVICE

LEVERAGING THE INTERNET OF THINGS (IOT) TO IMPROVE PRODUCTIVITY IN URBAN FARMS

Context

Internet of Things (IoT) in the context of agriculture refers to the interconnected ecosystem of data collection hardware, the cloud network infrastructure that it exists in, and the data management and analyses using the information obtained.[40] Improvements in hardware technologies—particularly those resulting in size reduction and reduced power consumption—have increased the on-field efficacy of these devices.[41]

In urban farms, crop health data and monitoring are particularly important due to the unique growing conditions of the urban built environment. Simulating the optimal growing environment of crops requires some level of human intervention. However, labour costs often comprise the largest share of operational expenditure in urban farming. Using IoT, various urban farming activities such as irrigation, nutrient application, temperature control, and light exposure can be carried out autonomously, reducing the need for human intervention and saving labour costs.

Innovation

The 'Wely Device' is an Internet of Things (IoT) device designed by Phytochem Consulting, a Vancouver, Canada-based startup. It is a wireless device that regularly collects and reports the temperature and weight of a tray of seedlings—two important data points for monitoring their health. This allows diverse applications such as precision irrigation, greenhouse control, and various pest control strategies. The information on seedlings health can be accessed remotely through a smartphone with an internet connection.

Impact

IoT-enabled devices such as Wely Device can help automate various activities in urban farms, reducing the amount of human intervention. This can reduce labour costs—which usually represents the largest share of operational expenses in urban farms—thereby helping improve overall profitability.

UNDP collaborated with the Singapore Food Agency (SFA) to pilot the Wely Device with urban farmers in Singapore. This pilot was part of the Government of Singapore's '30 by 30' agenda to leverage technology and innovation for improving productivity and yields, thereby boosting domestic food production. Testing of the devices in commercial vegetable farms generated valuable user feedback which will help Phytochem Consulting improve upon the product design to meet local needs.

Following the Wely Device's selection as Cultiv@te Finalist solution, Phytochem Consulting also won a matching grant from Metro Vancouver to run a short programme for high school students, in collaboration with non-profit Open Science Network. It is aimed at introducing students to the concept of 'digital agriculture' through hands-on trainings on IoT design and development and data analysis.

40 Emerson Navarro, Nuno Costa, and António Pereira, "A Systematic Review of IoT Solutions for Smart Farming," *Sensors* 20, no. 15 (August 2020): 4231.
41 Ji-chun Zhao et al., "The study and application of the IOT technology in agriculture,"*2010 3rd International Conference on Computer Science and Information Technology* (July 2010): 462–465.

A Wely Device being tested at Singapore's National Centre for Food Sciences.
Image: Singapore Food Agency

Image: Only_kim/Adobe Stock

GUIDANCE ON RUNNING INNOVATION CHALLENGES

INNOVATION CHALLENGES LIKE CULTIV@TE CAN HELP INTRODUCE NEW IDEAS, TECHNOLOGIES, AND SOLUTIONS TO HELP ADDRESS COMPLEX DEVELOPMENT CHALLENGES.

The agri-food-tech landscape has evolved greatly over the last decade. Digitalisation is impacting all stages of agri-food value chains—from the use of mobile phones by various actors to supply chain-level solutions involving emerging technologies like blockchain.

However, while digital technologies hold great potential as enablers for transforming agri-food systems, there is much scope for improvement in understanding their true potential among all stakeholders. This is particularly true in the context of developing countries, which are at the forefront of tackling complex developmental challenges, but lack the resources to invest in scientific and technological research and depend on developed countries for knowledge and technology transfer.

Innovation challenges have emerged as a popular mechanism among development organisations in soliciting innovative solutions which cannot be achieved through traditional processes. These include requests for proposals and quotations through which the way a given objective can be accomplished is well-known, and an effective approach to solve a problem is also known, so that the only remaining concern is to identify who will accomplish them.

Based on Cultiv@te's two-year journey which involved collaborating with diverse stakeholders, managing divergent interests, navigating through COVID-19-induced uncertainties and changes in local contexts and national priorities, we have captured insights which could guide development practitioners in planning and implementing future innovation initiatives.

1. GET INITIAL BUY-IN FROM KEY STAKEHOLDERS

Agri-food systems involve diverse stakeholders. These include value chain actors (e.g., producers, cooperatives, manufacturers) as well as external entities (e.g., certifiers, policymakers, NGOs). While it is nearly impossible to generate commitment from and align interests of *all* stakeholders when beginning to tackle a particular development problem, it is crucial to identify and get buy-in from the *key* ones.

These are the entities who have the most at stake from successfully addressing a given problem and possess the necessary resources and convening power to bring together other relevant stakeholders. For example, thse could include relevant government agencies with the mandate and ownership of certain agri-food issues or multinational corporations (MNCs) with the financial resources and commercial interests in solving sector-wide problems.

By acting as an anchor for particular development problems and by *owning* the solutions developed, key stakeholders act as champions of an innovation initiative and could contribute greatly to ensuring its sustainability. In addition to the above resources, they can also offer additional support such as knowledge and industry insights, access to networks, and resilience against political, social, and economic shocks.

2. DEFINE PROBLEMS CLEARLY

Agri-food systems face a wide variety of complex developmental problems. Encompassing the entire spectrum of SDGs, these range from poverty, hunger and nutrition, gender inequality, climate change, and biodiversity loss. While these issues are interconnected, tackling them requires targeted interventions and collaborations.

It could be tempting for programme designers to attempt to address several issues through a single innovation initiative. This ambition is understandable given the scale of issues plaguing the sector. But with limited resources and attention, such an approach may likely result in fragmented and unfocused efforts.

It is thus advisable to identify—in alignment with the priorities of the key stakeholders—a small number of problems and clearly define them in terms of the objectives to be achieved through the innovation initiative. Try to pin down the ***why, what, where, who***, and if possible, ***how*** in the problem statements in clear words. For instance:

> In context of the alarming rate of tropical forest loss due to illegal mining in India **[the *why* and *where*]**, how can we leverage satellite data **[the *how*]** to empower forest officers **[the *who*]** to tackle deforestation **[the *what*]**.

Such clarity in purpose would enable programme managers to perform a thorough landscape review of existing technologies, innovations, and solutions before publicising a call for submissions. It would also make evaluation of the received submissions easier and allow the problem to drive the solution, instead of the other way round. As the famous quote goes: "A problem well stated is half solved."

For Cultiv@te, the UNDP Global Centre Singapore partnered with Agorize, a software-as-a-service (SaaS) platform for organising and managing innovation challenges and hackathons. Johannes Jaeger of Agorize, whose company has helped over 2,000 organisations worldwide in various industries in running innovation initiatives, shared some useful tips:

> *Write problem statements without industry jargon to widen the pool of potential startups/scaleups that could see themselves providing a solution.*
>
> **— Johannes Jaeger, Vice President of Enterprise (Global), Agorize**

3. SEEK SOLUTIONS AT ROUGHLY THE SAME LEVEL OF MATURITY

The maturity of proposed solutions could range from mere ideas, published research findings, and proof of concept (PoC), to a minimum viable product (MVP) and a fully functioning solution. These require varying levels of support for testing and scaling. Considering resource constraints and available expertise, carefully assess the nature of support your organisation or the key stakeholders could provide to developing and/or scaling the proposed solutions. For instance, if offering financial assistance, consider how it could be spent (e.g., research, prototyping, piloting) to add the most value to the solution's development and potential success.

Based on this reflection, it is advisable to seek solutions at roughly the same level of maturity, which would make it easier to compare and evaluate them. It could also enable your organisation to make the best use of available resources as they could be shared among all participants of the innovation challenge. For example, if technical assistance in a particular domain (e.g., mentoring on go-to-market strategy) is what your organisation could offer through the innovation challenge, the same set of experts could be engaged to support all the candidates.

Image: Agroclimatica

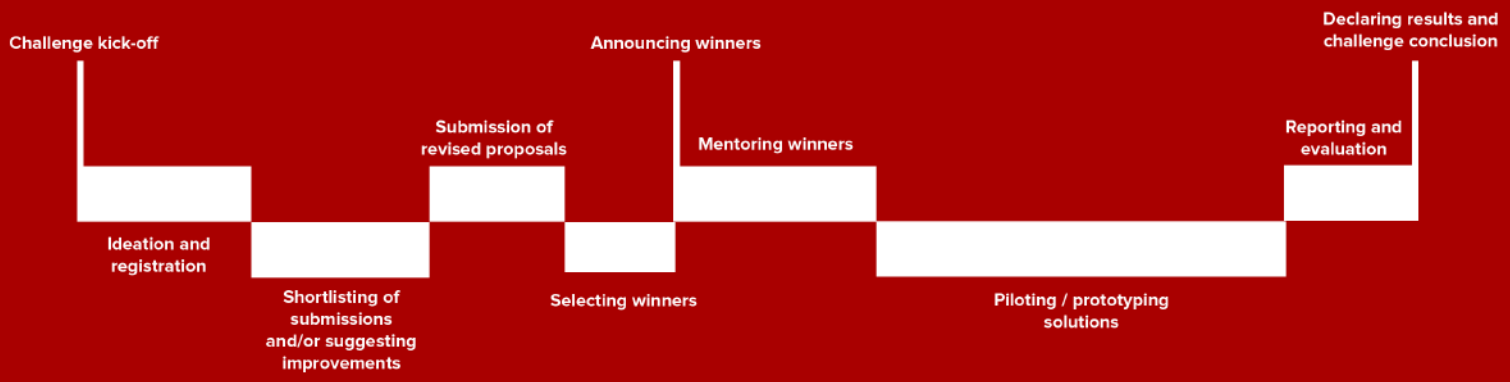
4. PLAN THE JOURNEY

Innovation is almost never a linear and predictable process. For innovation to succeed and scale requires time and cooperation from several actors—and several innovations fail without these. Yet a single entity/ organisation implementing an innovation challenge would certainly be constrained in both time and resources.

A well thought out journey can help minimise the effect of various uncertainties in the process. It would involve identifying the key assumptions and variables, the roles of key stakeholders at different stages, and any likely forks in the path.

Establishing a clear timeline keeps the challenge moving forward at the right pace—with or without success. This naturally highlights the need to define 'success' from the outset. For each problem statement, start by envisaging the big picture—the expected impact—and down to specific outcomes. Key result areas (KRA) for each may be defined using the SMART principle (specific, measurable, achievable, relevant, and time-bound).

A sample innovation challenge timeline and an overview of the key steps is given below.



Challenge kick-off: The challenge is announced. Leverage your network and social media to widely publicise the event and create a buzz.

Ideation and registration: Potential applicants ideate about their solutions and submit their applications. Make the process as simple as possible for potential applicants. Ensure that the problem statements, eligibility criteria, process of selecting winners, and the benefits/prizes offered through the innovation challenge are clearly articulated and communicated.

Shortlisting of submissions: Panel of evaluators/ jury members conduct a preliminary assessment of submissions, shortlist the most promising ones aligning with the problem statements, and seek clarifications or suggest areas for improvement in the submission.

Submission of revised proposals: Shortlisted applicants incorporate received feedback and submit revised applications.

Selection of winners: Panel of evaluators/jury members evaluate final submissions and select challenge winners in accordance with the predetermined criteria. Ensure that the panel members have the required expertise—contextual, technical, and business-related—to conduct fair and thorough evaluations of the submissions. Also ensure gender diversity within the panel.

Announcement of winners: Winning applications are announced and publicised. Ensuring good visibility for the winning solutions could help attract potential partners to support their implementation.

Mentorship support for winners: You may choose to provide needed technical assistance and mentorship to winners—via in-house experts or external collaborators—for fine-tuning their proposed solutions. Make sure that the support is relevant and uniquely addresses their pain points.

Piloting/prototyping: This is the most variable and dynamic stage of the challenge. Its nature would depend on the problem statements being addressed, the winning solutions, and a variety of contextual factors including available support from partners and key stakeholders.

Reporting and evaluation: Results and learnings from the piloting/prototyping stage are compiled and analysed. These could include the number of beneficiaries/users, scope for improvement in the solution design, business plans for scaling, and fundraising opportunities.

Declaring results: Outcomes of the innovation challenge, noteworthy examples of success and failures, and key learnings are synthesised and communicated to relevant stakeholders and partners. This report is an example output of this stage.

5. CREATE A LEARNING AND KNOWLEDGE SHARING COMMUNITY

The innovation challenge itself is only one part of the innovation journey. The true value of such initiatives also lies in the community of peers and experts it helps create. Ensuring active engagement with the community—both during and after the initiative—can bring many benefits to participants including learning from peer experience, troubleshooting problems, and exposure to additional opportunities.

Make use of digital tools like chat/messaging apps, social media groups, and productivity enhancing software to create and engage with digital communities of innovators, mentors, partners, and key stakeholders. Regular engagement during the innovation challenge keeps the participants interested and the momentum going. Digital communities created during the challenge could be transformed into communities of practice focusing on particular areas of interest such as sharing of funding opportunities, industry updates, and as channels for re-engagement for future initiatives.

> *Don't lose momentum at the end of the programme. Define the post-challenge steps pre-launch—from securing budgets for piloting solutions, to identifying key stakeholders, and establishing processes to onboarding selected solution providers.*
>
> **— Johannes Jaeger, Vice President of Enterprise (Global), Agorize**

6. PROMOTE HUMAN-CENTRED DESIGN

The agri-food-tech sector has experienced rapid growth in recent years. While the trend is encouraging, several technology-led solutions have failed to scale up, especially in low- and middle-income countries and among smallholder farmers. A key reason is that solution designers fail to identify and address the 'real' needs of their intended users.

Human-centred design is an iterative design process that puts the end user at the centre of the process. It is becoming a popular approach for designing solutions to address various developmental challenges. 'Designing *with* the user, instead of *for* them' is the philosophy which is embodied in this approach. For instance, instead of building a solution around the assumption that farmers "should" have access to cheaper loans, a good place to start could be identifying a specific pain point that a farmer might be willing to pay to get resolved.[42]

A good example of user-centred design from Cultiv@te is the evolution of Pastoral—the precision livestock management platform that was prototyped and tested through a Design Sprint in Uzbekistan. During their interactions with livestock farmers, the Pastoral team realised that given the lack of internet connectivity in rural areas, smartphone apps—which are data-heavy—might not be the ideal way to deliver information and advisory to farmers. Instead, existing tools that farmers are familiar with, and which could work even in low-connectivity settings (e.g., the Telegram messaging app), would be ideal for delivering these services. Such an insight, gained from a deep understanding of the ground realities of and feedback from users, was instrumental in the team's decision to pivot from a dedicated app to a Telegram chatbot-based user interface.

Moreover, it is important to realise that technology, while having transformative potential, is not a panacea. Farmers and other marginalised agri-food actors face multiple challenges that cannot necessarily be solved using technology and require community- or policy-level interventions. Adopting human-centred design can help solution designers identify these non-technological barriers and seek support from relevant stakeholders (e.g., government agencies) to help address them.

42 Paul Voutier, "Human-Centered Design Immersion Training," *GrowAsia*, April 22, 2019.

7. PROMOTE DIGITAL PRINCIPLES AND BEST PRACTICE

The public and private sectors have invested in several digital agriculture solutions in recent years. However, siloed efforts have prevented the development of standards for the industry, particularly relating to the management of agricultural data. Proprietary hardware and software solutions make interoperability between different systems a hurdle, affecting the scalability of digital agriculture initiatives.

The *Principles for Digital Development*, endorsed by UNDP and multiple other international development and humanitarian organisations, are a set of "nine guidelines to integrate best practices into technology-enabled programs".[43] These include designing *with* users; understanding the existing ecosystem; designing solutions to be scalable; being data-driven; and adopting an 'open' approach to software development.

The latter includes taking an 'open' approach to designing digital interventions, such as the use of open-source software, open data, and developing and adopting open standards. With an open approach, programme managers can increase collaboration among diverse stakeholders and avoid the duplication of efforts. This could include exploring any existing open-source solutions which might have been successfully deployed elsewhere, or openly sharing project data (ensuring that it won't infringe on privacy.)

If supporting the creation of new digital solutions through the innovation challenge, programme managers can promote the mainstreaming of these principles during the design, development, and deployment stages.

43 Principles for Digital Development, "About".

Looking Forward

The relevance and importance of technology and innovation in agriculture is growing. Digital technologies particularly are enabling a systemic transformation of agriculture globally—the greatest one since the Green Revolution of the mid-Twentieth Century. The digitalisation of agri-food systems has important consequences sustainable development—from the socio-economic inclusion of some of the most marginalised groups such as smallholder farmers and producers, to improving the complex relationship between agriculture and the environment.

Cultiv@te has perhaps been the first truly global innovation challenge for sustainable agriculture, spanning 11 countries across three continents, and identifying a wide variety of technology-enabled solutions. It has generated important learnings for fostering grassroots innovation and experimenting with and scaling solutions—both within and beyond UNDP. Future innovation initiatives in agriculture could draw insights from Cultiv@te, particularly on problem statement definition, roadmapping, and ensuring the sustainability of interventions.

But these need not necessarily be global. Cultiv@te has adequately highlighted the context-specificity of agricultural interventions; the local nuances in agri-food systems in different countries cannot be ignored. While there is a need to scale proven solutions beyond national and international boundaries, innovation usually takes shape at the grassroots. There is a clear need for supporting innovation ecosystems in developing countries. Future innovation initiatives for sustainable agriculture could focus on strengthening the interlinkages between the diverse stakeholders involved.

Image: Scharfsinn86/Adobe Stock

Annex: Cultiv@te Finalists

Phytochem Consulting (Wely Device)
Canada
https://www.phytochemconsulting.ca/

Moringa What
India
https://www.moringawhat.com/

LLEAF
Australia
https://www.lleafgrow.com/

Hello Tractor
Nigeria/Kenya
https://hellotractor.com/

Citiponics
Singapore
https://www.citiponics.com/

Agrosmart
Brazil
https://agrosmart.com.br/

Fresh Life Produce
South Africa
https://freshlifeproduce.co.za/

Agritask
Brazil
https://start.agritask.com/

Farmz2U
Nigeria/Kenya
https://www.farmz2u.com/

CropIn
India
http://www.cropin.com/

Liquidstar
Hong Kong
https://www.liquidstar.io/

Digi Agri
India/UAE
http://digi-agri.com/

BIOPS Agrotekno
Indonesia
https://www.biopsagrotekno.co.id/

The Toothpick Project
United States of America
https://www.toothpickproject.org/

CROWDE
Indonesia
https://crowde.co/

UjuziKilimo
Kenya
https://www.ujuzikilimo.com/

Agroclimatica
Denmark/Nicaragua
https://www.agroclimatica.com/en

Boreal Lights
Germany
https://www.winture.de/

iGrow
Indonesia
https://igrow.asia/

Solaristique Nigeria
Nigeria
http://www.solaristique.com.ng/

The Sustainable Nitrogen Foundation
United Kingdom
https://www.tsnf.org.uk/

Convergence.Tech
Canada
https://www.convergence.tech/

FarmCorps
Nigeria
https://farmcorps.net/

OneSoil
Belarus
https://onesoil.ai/en/

Digitanimal
Spain
https://digitanimal.com/

MAquaponics
Armenia
https://www.facebook.com/CleanFoodArmenia/

Karakoram
United Kingdom
https://karakoram.co/our-projects/pastoral

Institute on Membrane Technology
Armenia
https://www.cnr.it/en/institute/097/institute-on-membrane-technology-itm

Agromart
Uzbekistan
https://agromart.uz/en/

Seawater Solutions
United Kingdom
https://seawatersolutions.org/

De Rebus Plantarum
Italy
https://drp.bio/en/

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