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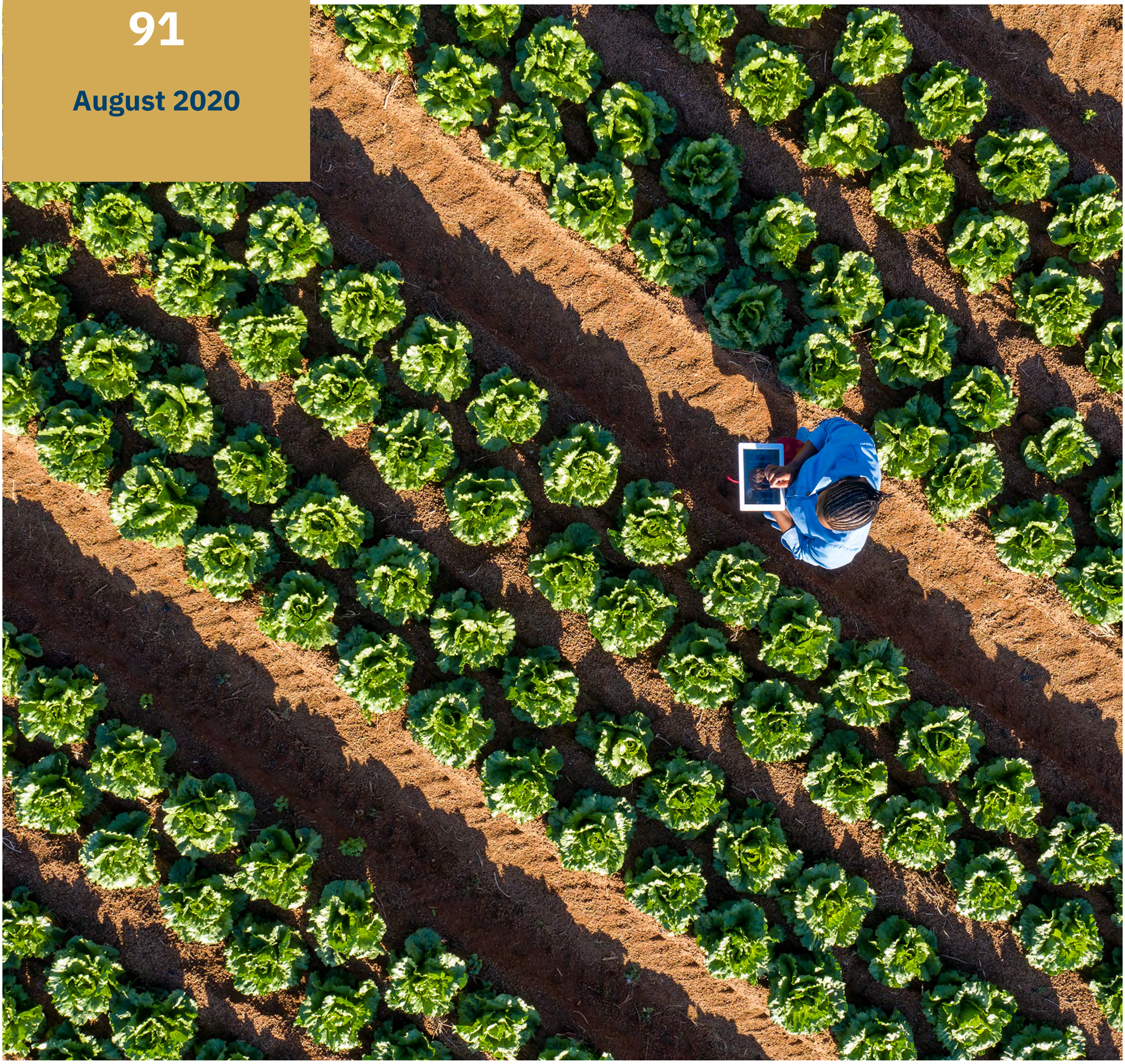

4IR and Water-smart Agriculture in Southern Africa: A Watch List of Key Technological Advances

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African perspectives
Global insights

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Executive summary

This paper considers the relevance of the recent wave of technological advances – so-called Fourth Industrial Revolution technologies – for the agricultural sector in drought-prone countries of Southern Africa. The resulting 'watch list' of technologies covers three broad categories. First, in the biotechnology and genomics space, traditional selective breeding and transgenic modification (also known as GM) have recently been joined by gene-editing technologies like CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), which bring with it the promise of faster and cheaper development of drought-resistant cultivars and breeds. Second, sensors and the use of artificial intelligence have led to significant advances in precision agriculture – in essence expanding the smart cities movement to farms too. Better data and risk models also allow for the development of new agricultural insurance products, including for small-scale farmers. Third, controlled environment agriculture (including indoor farming and hydroponics) offer an opportunity to break free from the seasonal and climatic limitations that bind traditional farming. To date, however, this type of farming is only possible for certain niche crops. It also brings with it new challenges, including relating to energy efficiency. In conclusion, the paper argues that policymakers and farmers in the region should consider technology as a key tool in their climate adaptation toolbox.

Introduction

There has been a lot of hype recently around the Fourth Industrial Revolution (4IR). The term was popularised by the World Economic Forum and refers to the current wave of disruptive technologies, characterised by a blurring of the lines between the physical, biological and digital spheres.[1] 4IR technologies include advanced data analytics and artificial intelligence (AI), the Internet of Things (IoT), cloud computing, robotics, autonomous robots and vehicles, additive manufacturing and 3D printing, cyber-physical systems, genome editing, blockchain technologies, and virtual, augmented and mixed reality.

This paper considers this wave of technological advances and their relevance for the agricultural sector in drought-prone countries of Southern Africa. In other words, are 4IR technologies of any use to a small-scale farmer in Malawi whose crop failed due to drought? The relevance of this question is underscored as Southern Africa emerges from two severe dry spells. Moreover, climate projections tell us that warmer, drier weather should not be considered a rare exception but is instead a 'new normal' for the region.

1 Klaus Schwab, 'The Fourth Industrial Revolution: What it is and how to respond,' *World Economic Forum*, January 14,2016, https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.

The paper makes use of horizon scanning[2] – a foresight tool aimed at identifying emerging developments that could impact the way the future unfolds. It deals with the 'not (quite) yet'. Rather than looking back at what we know from the past (like a literature review would), horizon scanning looks forward to the future and to the side or periphery. It asks: 'What early signs of change - what weak signals or seeds of the future - that are visible today, could become more prominent over time?' Innovation often comes from the edge, ie, from an adjacent field or outside of a core domain. This approach has implications for methodology. Firstly, grey literature (eg, blogs, social media conversations) is considered valid, as it is there that one will find weak signals. Second, it is also acceptable, and in fact desirable, to consult different fields and to consider alternative or even controversial views.

For this technology-focused study, scanning of patent- and innovation/start-up databases[3] was supplemented with a review of peer-reviewed journal articles and grey literature. The result is a preliminary watch list of potentially disruptive technological developments. This non-exhaustive list can serve as a starting point for dialogue with stakeholders – both agricultural (including farmers) and technological stakeholders.

Agriculture in Southern Africa

Southern Africa is cereal and livestock country. Maize is the staple food across most of the region, followed by cassava, wheat and rice. The region also produces sorghum and millet, beans and pulses, ground and tree nuts, and fruit and vegetables. Cash crops include tobacco, sugar, cotton, seed oils, tea, coffee, deciduous fruits, citrus, and grapes (both table and wine grapes).[4] Livestock production in the region is diverse, with populations at around 64 million cattle, 39 million sheep, 38 million goats, 7 million pigs, 1 million horses and 380 million poultry (including some ostrich).[5] Cattle is produced for meat and milk, and also holds cultural significance. Marine fishing is found along the coast, and wildlife ranching inland in countries like Botswana, Namibia and South Africa.[6]

This summary, however, hides key differences across the region, related to climate and crops produced as well as the type of farming practiced and its role in society and the economy.

In terms of climatic zones, the region ranges from desert (in Namibia, Botswana and parts of South Africa), through savannah to tropical (in the Democratic Republic of Congo, Madagascar, Seychelles and Mauritius) and subtropical, with areas of Mediterranean

2 For more about the method, see Kerstin Kuhls, 'Horizon Scanning in Foresight - Why Horizon Scanning is only part of the game,' *Futures & Foresight Science 2*, no 1 (2019): 1-21.

3 See: World Intellectual Property Organization (WIPO), WIPO IP Portal: Patentscope, https://patentscope.wipo.int; Briter Bridges, Briter Intelligence. https://www.briterintelligence.com/.

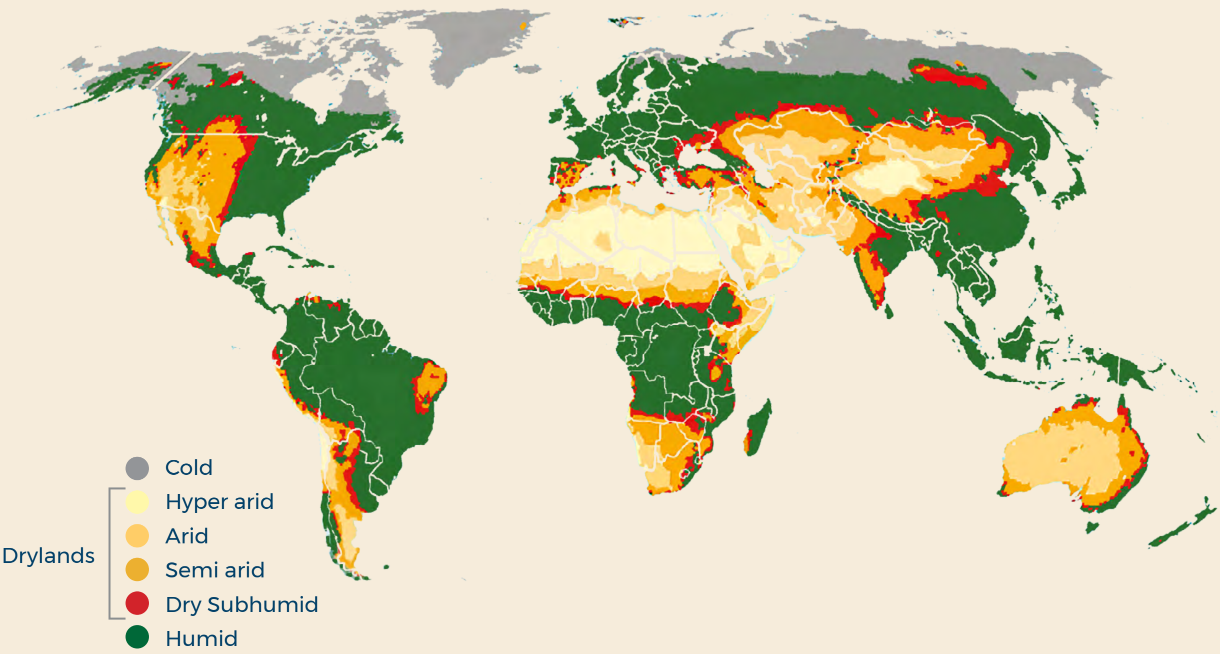
4 For more details, see SADC, *Regional Agricultural Policy (RAP): Country Summary Agricultural Policy Review Reports* (Gaborone: SADC Directorate of Food, Agriculture and Natural Resources, 2011).

5 'Livestock Production,' SADC, https://www.sadc.int/themes/agriculture-food-security/livestock-production/.

6 SADC, *Regional Agricultural Policy*.

climate along South Africa's south coast. Crops vary accordingly. It is interesting to note, however, that the region's main agricultural products are not particularly well-suited to its climate. Professor Guy Midgley notes, for example, that maize is sensitive to drought and extreme temperatures, making it ill-suited for the areas in Africa where it is grown.[7] In terms of livestock, bovine meat has a far higher water footprint than other livestock, requiring on average 15 415 litres per kilogram produced, compared to 4 325 litres for chicken, and 8 763 litres for sheep or goat meat. This compares even more starkly with crops: the average water footprint per calorie for beef is twenty times larger than that for cereals and starchy roots.[8]

Figure 1 Global distribution of dryland subtypes



Source: Robert McSweeney, 'Explainer: 'Desertification' and the role of climate change', *CarbonBrief* (August 6, 2019), https://www.carbonbrief.org/explainer-desertification-and-the-role-of-climate-change

The types of farming practiced in the region are just as diverse, ranging from large-scale commercial farming to medium- and small-scale farming, all the way to subsistence farming. So too, the importance of agriculture to the economy and livelihoods differ. Overall, more than 70% of the rural population in Southern Africa depends on agriculture for their livelihoods.[9] In a country like Malawi, for instance, agriculture contributes 90% of

7 Sarah Wild, 'Factsheet: Why Africa is vulnerable to climate change,' *Africa Check*, December 8, 2015, https://africacheck.org/factsheets/factsheet-why-africa-is-vulnerable-to-climate-change/.

8 Mesfin Mergia Mekonnen and Arjen Hoekstra, *The Green, Blue and Grey Water Footprint of Farm Animals and Animal Products*, Value of Water Research Report Series No. 48 (Delft: UNESCO-IHE, 2010).

9 USAID, *Agriculture and Food Security*, https://www.usaid.gov/southern-africa-regional/agriculture-and-food-security.

export earnings and supports 85% of the rural population. Around 1.2 million hectares (ha) of land is used to produce cash crops like tobacco, tea and sugarcane on large-scale estate farms, while smallholder farming supports over 3 million families on 6.5 million ha of land. In countries like Lesotho and Mozambique rain-fed, subsistence agriculture dominates. While South Africa is self-sufficient in most crops and is a net food-exporter, other countries in the region (eg, Botswana) rely on food imports for a large part of its food supply.[10]

Water stress and adaptation tech

Southern Africa suffered two recent El Niño-induced droughts, in 2015/16 and 2018/19. The 2015/16 drought was highlighted as the worst in 35 years.[11] In 2018/19, grain production was down 30% across the region (53% in Zimbabwe) and livestock farmers suffered losses due to stock starvation and culling forced by water and feed shortages.[12] By early 2019, over 10.5 million people found themselves severely food insecure (Integrated Food Security Phase Classification (IPC) Phase 3 and 4, Crisis and Emergency levels).[13]

Though the recent droughts have been particularly severe, dry spells are unfortunately not rare anomalies.[14] In fact, droughts in the region are projected to become more frequent.

That said, droughts are not new. Over time, many technologies and adaptation methods have developed and advances are continuing. Farmers have found ways to manage scarce water resources, through water storage and capture (eg, dams, storage tanks), water reuse and recycling (eg, wastewater treatment, desalination), drip irrigation, and water retention technologies (eg, mulching, water retaining films). They have found ways to improve soil health and increase soil organic matter, including through crop diversity, planting nitrogen-fixing plants (eg, beans and pulses) and the use of fertilizer and biochar. In large parts of Southern Africa, they have to deal with acidic soils vulnerable to aluminium toxicity and low nutrient reserves. Farmers have practiced drought-smart cultivation methods for water and soil health including intercropping, agroforestry, conservation agriculture and precision agriculture. They have relied on weather forecasting for planning. Farmers, scientists and seed companies have also focused on cultivar development, producing drought-resistant seeds through selective breeding, biotechnology and, for the last 25 years or so, genetic modification.

10 SADC, "Regional Agricultural Policy".

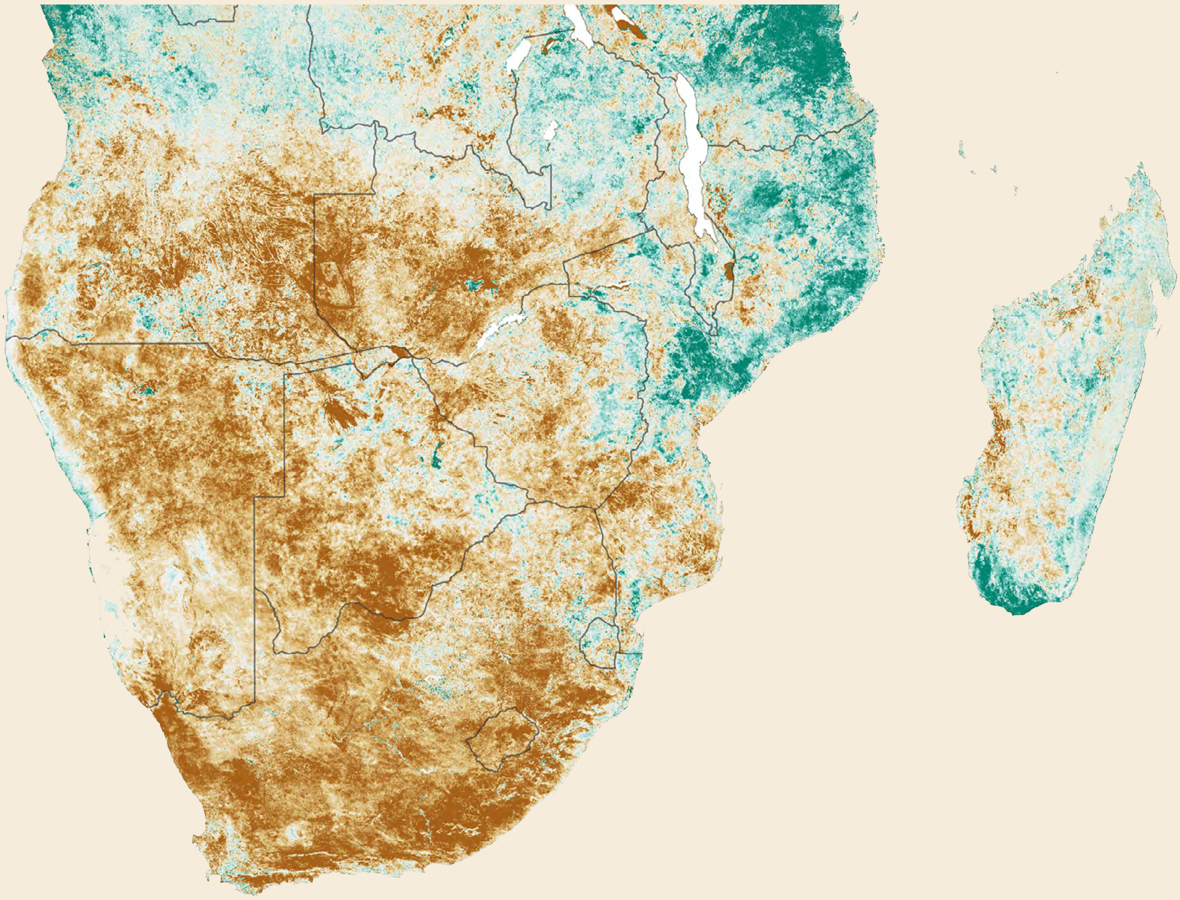
11 Lewis Hove and Cuthbert Kambanje, 'Lessons from the El Nino-induced 2015/16 drought in the Southern Africa region,' in *Current Directions in Water Scarcity Research, Volume 2*, (Amsterdam: Elsevier, 2019): 33-54.

12 Michael Carlowicz, 'Drought threatens millions in Southern Africa,' *NASA Earth Observatory*, 2019, https://earthobservatory.nasa.gov/images/146015/drought-threatens-millions-in-southern-africa.

13 Lewis Hove and Dominique Burgeon, '2018/19 El Niño Response Plan for Southern Africa,' *FAO*, February, 2019, http://www.fao.org/emergencies/resources/documents/resources-detail/en/c/1180165/.

14 Lewis Hove and Cuthbert Kambanje, 'Lessons from the El Nino-induced 2015/16 drought', 33-54.

Figure 2 NDVI anomaly map for Southern Africa



Note: The map compares the health of vegetation in southern Africa from the dry season in 2019 to the same period from 2000-2010. Brown areas show where plant health or 'greenness' was below normal. Greens indicate vegetation that is more widespread and abundant than normal.

Source: 'Drought Threatens Millions in Southern Africa,' *NASA Earth Observatory*, https://earthobservatory.nasa.gov/images/146015/drought-threatens-millions-in-southern-africa

Sometimes climate- or weather-related factors force farmers to change the crops they grow or the animals they rear. For example, sorghum is more drought-resistant than maize and ostriches are better-adapted to dryland areas than water-intensive cattle. Insect protein is even more water-smart, using only half the water of poultry farming.[15] Here the region is ahead of the curve, with examples like mopane worms considered a delicacy in Zimbabwe and South Africa, and edible stink bugs in South Africa, Malawi and Zimbabwe. Companies like AgriProtein and The Insect Experience are leveraging the insect-protein trend, while

15 Kristian Sjøgren, 'How much more environmentally-friendly is it to eat insects?' *ScienceNordic*, May 17, 2017, https://sciencenordic.com/agriculture--fisheries-climate-climate-solutions/how-much-more-environmentally-friendly-is-it-to-eat-insects/1445691.

both researchers and innovators are looking at ways to make insects more palatable to consumers.[16] And we may soon be able to order lab-grown meat in a restaurant[17], thanks to advances in cellular and acellular technologies[18] promoted through companies like Future Meat (though broad consumer acceptance may be some way off as yet).

In this paper, the focus is on advances related to technologies of the 4IR. These frontier technologies build on the ones above and also on the digital and information and communications technologies of the Third Industrial Revolution, also termed the 'Information Age'.

Watch list of 4IR technologies for water-smart agriculture

Biotechnology and genomics for new cultivars

Humans have practiced cultivar development for thousands of years, first through selective breeding and, in the last 25 years, through genetic engineering. For example, maize was domesticated from native American teosinte thousands of years ago. It was exported from the Americas to the rest of the world at the end of the 15th century. Over time, farmers and scientists selectively bred in certain traits. When genetic engineering emerged, it too was applied to maize.[19] In 2013, the first transgenic or genetically modified (GM) drought tolerance trait in a line of maize hybrids called DroughtGard® was launched by Monsanto.[20] There have been a number of advances since[21], including by African researchers.[22] The introduction of genetically engineered maize has, however, not been without controversy.[23] Concerns are both environmental and business model-related. On the environmental side, they relate to an increased use of pesticides, the loss of biodiversity (including insects) and local crop varietals, as well as the introduction of engineered genes into wild populations. On the business model side, GM seeds are tightly controlled and even trademarked by a

16 Guiomar Melgar-Lalanne, Alan-Javier Hernández-Álvarez and Alejandro Salinas-Castro, 'Edible insects processing: Traditional and innovative technologies,' *Comprehensive Reviews in Food Science and Food Safety 18*, no 4 (2019): 1166-1191.

17 Jonathan Shieber, 'Lab-grown meat could be on store shelves by 2022, thanks to Future Meat Technologies,' *TechCrunch*, October 10, 2019, https://techcrunch.com/2019/10/10/lab-grown-meat-could-be-on-store-shelves-by-2022-thanks-to-future-meat-technologies/.

18 Luke MacQueen, et al., 'Muscle tissue engineering in fibrous gelatin: Implications for meat analogs,' Nature Partner Journals *Science of Food* 3, 20 (2019): 1-12, https://www.nature.com/articles/s41538-019-0054-8.

19 Ania Wieczorek and Mark Wright, 'History of Agricultural Biotechnology: How Crop Development has Evolved,' *Nature Education Knowledge 3*, no. 9 (2012): 9, https://www.nature.com/scitable/knowledge/library/history-of-agricultural-biotechnology-how-crop-development-25885295/.

20 OECD, 'BioTrack Database,' MON87460, https://biotrackproductdatabase.oecd.org/Product.aspx?id=MON-8746%C3%98-4.

21 Joshua Muli, et al., 'Genetic improvement of African maize towards drought tolerance: A review,' *Advances in Life Science and Technology*, 48, (2016): 1-9.

22 See for example: Leta Bedada, et al., 'Drought tolerant tropical maize (Zea mays L.) developed through genetic transformation with isopentenyltranferase gene,' *African Journal of Biotechnology 15*, no. 43 (2016): 2447-2464.

23 See for example: Sheree Bega, 'Monsanto maize seed a 'Trojan horse,' *IOL*, March 18, 2017, https://www.iol.co.za/business-report/economy/monsanto-maize-seed-a-trojan-horse-8241924.

few big biotech companies, leading to concerns of these companies 'colonising' local food systems.[24]

The latest excitement in the field of biotechnology is around CRISPR. CRISPR is a gene-editing technique – based on a natural process – that allows researchers to cut out bits of DNA in order to control traits. It is applied to selective breeding, and an alternative to transgenic engineering.[25] CRISPR, and methodologies like it, differ from transgenic engineering in a number of ways: it doesn't introduce foreign genes (at least not yet[26]), plants created with this technique are practically indistinguishable from traditional selective breeds, it is simpler, faster and cheaper to do, and it is not as tightly controlled by a few companies.[27] This makes it more accessible. Regulators are divided on how to approach gene-editing: while Europe's courts regulate gene-edited plants as GMOs (genetically modified organisms), the US currently does not regulate techniques that mimic natural processes. No African country has yet passed unique regulation for gene-edited crops, though transgenic GMOs are strictly regulated and it is expected that gene-editing will fall under the same regulation, at least initially.[28]

A number of studies are specifically looking at gene-editing for drought tolerance. For example, a gene has been identified in a native variety of maize that produces more grain in dry conditions, while a variety of rice has been developed that produces 25 to 30% more grain without compromising tolerance to tough climatic conditions.[29] Companies and researchers are jumping on-board. For example, DuPont is collaborating with Caribou Biosciences to grow corn and wheat strains edited for drought resistance.[30] Another US company, Acceligen, is collaborating with the University of Edinburgh and research institutes in Ethiopia, Kenya, Nigeria and Tanzania to produce African cattle that can better tolerate heat.[31]

Sensors and Artificial Intelligence (AI) for smart farms

Farming techniques have adapted to climate- and weather-related factors for millennia. More recently, precision agriculture has made this more of an exact science. It started with

24 Bega, "Monsanto maize".

25 Eric Niiler, 'Why gene editing is the next food revolution,' *National Geographic*, August 10, 2018, https://www.nationalgeographic.com/environment/future-of-food/food-technology-gene-editing/.

26 Megan Molteni, 'Crispr can help solve our looming food crisis - Here's how,' *Wired*, August 8, 2019, https://www.wired.com/story/gene-editing-food-climate-change/.

27 Niiler, "Why gene editing".

28 Genetic Literacy Project, 'Global Gene Editing Regulation Tracker – Africa crops,' https://crispr-gene-editing-regs-tracker.geneticliteracyproject.org/africa-crops-food/.

29 Niiler, "Why gene editing".

30 Maywa Montenegro, 'Opinion: Crispr is coming to agriculture – with big implications for food, farmers, consumers and nature,' *Ensia*, January 28, 2016, https://ensia.com/voices/crispr-is-coming-to-agriculture-with-big-implications-for-food-farmers-consumers-and-nature/.

31 Genetic Literacy Project, 'Global Gene Editing Regulation Tracker – Africa animals', https://crispr-gene-editing-regs-tracker.geneticliteracyproject.org/africa-animals.

drip irrigation, invented by an Israeli father and son team in 1959.[32] Drip irrigation has since spread widely, and has been adapted for different environments. For instance, in Senegal, the Tipa (or 'drop') irrigation system uses gravity when there is no water pressure. It has allowed farming families in dryland areas to reap multiple crops a year and experiment with higher-value crops.[33] Israel remains a world leader in precision agriculture and dryland farming.

Today, data- and sensor-technologies allow precision farming to be more advanced than ever.

Geospatial technologies like GPS (global positioning systems), GIS (geographic information systems) and remote sensing provide new ways to produce and use maps to manage communities, industries and farms. Remote sensing with satellites, unmanned aerial vehicles (UAVs or drones) or land vehicles can use optical sensors to measure soil properties, including organic matter and moisture content. One of the most widely used optical sensor measures is the Normalized Difference Vegetation Index (NDVI), a measure of how plants absorb visible light and reflect infrared light – the technology used in NASA's image in Figure 1. So too, drone-mounted low-cost sensors in the infrared spectrum can detect crop stress about two weeks before the human eye can see it.[34]

Remote sensing is increasingly used in agriculture. South African FruitLook, for instance, uses satellite technology to provide weekly, semi-real time information on crop growth, crop nitrogen and evapotranspiration deficits to grape and deciduous fruit farmers in the Western Cape, allowing them to save on inputs like water, fertilizer and electricity. Aerobotics uses drone technology to detect crop health. ThirdEye uses flying sensors to support small-scale farmers in Mozambique and Kenya in decision-making around the application of inputs, including water. And the Technical Centre for Agricultural and Rural Cooperation (based in Wageningen in the Netherlands, a world leader in agricultural innovation) provided support to 30 youth-led enterprises focused on drone technology through a project titled 'Transforming Africa's Agriculture: Eyes in the sky, smart techs on the ground'.[35]

As ThirdEye shows, remote sensing data is not only for large-scale commercial farmers. Increasingly, this type of data is also harnessed for small-scale farmers and combined with extension services. Though some satellite data is available for free, not all small-scale farmers have access to the requisite devices, connectivity or skills to make use of it. It is, however, possible to communicate advanced monitoring information to farmers using

32 Abigail Klein Leichman, '5 Israeli precision-ag technologies making farms smarter,' *Israel21c*, July 13, 2017, https://www.israel21c.org/5-israeli-precision-ag-technologies-making-farms-smarter/.

33 Karin Kloosterman, 'Modern 'rain dance' for Senegal,' *Israel21c*, September 11, 2011, https://www.israel21c.org/modern-rain-dance-for-senegal/.

34 ThirdEye Water, 'ThirdEye Flying Sensors,' http://www.thirdeyewater.com/.

35 CTA, 'Transforming Africa's agriculture: Eyes in the sky, smart tech on the ground,' https://www.cta.int/en/projects/eyes-in-the-sky.

a basic tech interface (eg. via SMS, USSD[36], interactive voice response or SMS chatbot). StepAbove is working with the University of Johannesburg to support smart decision-making for small-scale farmers through drone- and sensor technology coupled with a data-sharing platform, based on a freemium[37], knowledge-based business model.

Remote sensing data can be combined with ground sensors and other data. Ground sensors for water-smart agriculture include electromechanical sensors that measure soil properties and nutrients, mechanical sensors and tensiometers that measure the force used by roots in water absorption, dielectric sensors that assess moisture by measuring an electric property in soil and airflow sensors that measure soil permeability.[38]

IoT or sensor networks have often been prohibitive to rural, small-scale farmers, whether due to cost, energy requirements or connectivity challenges.[39] Advances on this front include LPWAN (low-power wide-area network) – a radio technology for long-range wireless data communication that connects low-bandwidth, low-power battery-operated devices at low cost. Alternatives to LPWAN are technologies that piggyback off cellular networks like LTE-M, which uses existing phone masts and that can work with 2G, 3G or 4G, or narrow-band IoT (NB-IoT) that operates existing LTE and GSM infrastructure.[40] There are also plans afoot to connect the world's four billion unconnected[41] – many of whom reside in rural areas – through satellite broadband[42]. Some argue that satellite 5G[43] technology will eventually replace LPWAN for rural IoT applications. On the other end of the spectrum, one can consider hand-held sensors or built-in mobile phone sensors (possibly unconnected to IoT networks).

Many smart agriculture models combine different data types, including remote-sensing and meteorological data, sensor data and farm-level data. For example, NADiRA – an EU-funded project aimed at developing agriculture in Africa through digital solutions – combines earth observation data, ground sensor data and data collected through on-the-ground agents on digital platform agCelerant. Similarly, the Gates-funded STARS project supports agriculture in sub-Saharan Africa and South Asia by adapting advances in remote sensing technologies for use in these contexts. The project combines satellite and drone

36 Unstructured Supplementary Service Data – a protocol used by GSM cell phones to communicate with the service provider's computers via text messages.

37 'Freemium' describes a business model between 'free' and 'premium'. A freemium model allows users to utilise basic features of a software package or service for free, then charges for upgrades to the basic package.

38 Steven Schriber, 'Smart agriculture sensors: Helping small farmers and positively impacting global issues, too,' *Mouser Electronics*, https://www.mouser.co.za/applications/smart-agriculture-sensors/.

39 For considerations of IoT use in rural Africa, see: Congduc Pham, Abdur Rahim and Philippe Cousin, 'Low-cost, long-range open IoT for smarter rural African villages,' *WAZUIP Project*, http://cpham.perso.univ-pau.fr/Paper/ISC2-16.pdf.

40 Margaret Rouse, 'Definition: LPWAN (low-power wide area network),' *TechTarget IoT Agenda*, September 2017, https://internetofthingsagenda.techtarget.com/definition/LPWAN-low-power-wide-area-network.

41 Kalvin Bahia and Stefano Suardi, 'The State of Mobile Internet Connectivity Report 2019,' GSMA, July 2019, https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2019/07/GSMA-State-of-Mobile-Internet-Connectivity-Report-2019.pdf.

42 Aaron Pressman, 'Why Facebook, SpaceX and dozens of others are battling over internet access from space,' *Fortune*, January 25, 2019, https://fortune.com/2019/01/25/facebook-spacex-internet-access-space/.

43 Sastri Kota and Giovanni Giambene, "Satellite 5G: IoT use case for rural areas application", The Eleventh International Conference on Advances in Satellite and Space Communications, Valencia, 2019).

data with field-level data collected by technicians to provide targeted advice for smallholder farmers groups, agribusiness and public agencies.

Apart from supporting farmers' decisions, this data can also be used in advanced data science or AI models for weather index insurance (see, for instance, Pula or ACRE Africa) or agricultural credit provision (see, for instance, Apollo Agriculture). On the insurance side too there is room for innovative business models. For instance, the Africa Risk Capacity (ARC) – a specialised agency of the AU – aims to transfer the burden of climate risk away from governments by using finance mechanisms such as risk pooling and risk transfer to create pan-African climate response systems for natural disasters. ARC uses Africa RiskView[44], an advanced satellite weather surveillance and software developed by the UN World Food Programme to estimate and trigger funds to African countries hit by severe weather events.

Controlled-environment agriculture does more with less

Finally, if the environment is inhospitable to crops, it is possible to change the environment or control it. This is something that humans have been doing for hundreds if not thousands of years. The first ever greenhouse built for food production (in around 30 AD) is attributed to the Romans who created a structure for growing plants during cold weather with a translucent roof to allow sunlight in while keeping heat from escaping. The first 'modern' greenhouses emerged during the Renaissance and were used as indoor botanic gardens for exotic crop species brought home by explorers.[45] Today, greenhouses and tunnels are used widely in agriculture.

More recent advances in controlled-environment agriculture relate to indoor or vertical farming and hydroponics (though some claim that hydroponics can be traced as far back as the Hanging Gardens of Babylon[46]). Co-founder and Chief Science Officer of Plenty – the Jeff Bezos-backed vertical farming start-up that raised $200 million in Series B funding in 2017[47] – notes that 'we're now at a point where the tech matches the need; technology has caught up with the vision'[48]. With their blue and pink LED lights providing artificial photosynthesis and sensors and data-driven methods promising the most advanced form of precision agriculture (by providing the exact water and nutrients needed in climate-controlled environments), indoor farms hold the promise of breaking free from the seasonal and climatic limitations that constrain traditional farming. These farms are often found in urban environments, where they could help to localise food production. The demand for indoor farming is projected to be high in deserts and drought-stricken regions, including the Middle East and parts of Africa, in small and urbanised countries like Israel, Japan and

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44 For more about Africa RiskView, see: https://www.africanriskcapacity.org/2016/10/31/africa-riskview-introduction/.

45 Agritecture, 'Growing more with less: The past, present and future of greenhouses' https://www.agritecture.com/blog/2019/5/7/growing-more-with-less-the-past-present-and-future-of-greenhouses.

46 Evan Folds, 'The history of hydroponics,' *Medium*, March 10, 2018, https://medium.com/@evanfolds/the-history-of-hydroponics-99eb6628d205.

47 Agritecture, "Growing more".

48 Jan Jacobs Mekes, 'The road ahead for vertical farming,' *Hortidaily*, June 4, 2020, https://www.hortidaily.com/article/9222334/the-road-ahead-for-vertical-farming/.

the Netherlands and in countries that suffer from heavy pollution and soil depletion (eg, parts of China).[49]

Limitations of vertical farming include the limited range of crops suitable for this business model (initially crops like vegetables, leafy greens, tomatoes and berries rather than staples like maize or wheat), and while indoor farms use much less water, they are quite energy-intensive. That said, recent advances in technology have made these systems more energy-efficient and/or integrated renewable energy sources like solar panels and wind turbines (which are becoming more efficient themselves), making it possible to run these farms off-grid. Further advances in storage battery technologies[50] and semiconductors[51] will serve to further decrease the cost of inputs. Despite all these advances, vertical farming remains a challenging business model, with many vertical farms still struggling to achieve profitability.[52] Nevertheless, trends point towards a substantial growth in these types of farming models in the next 10-15 years.

Examples of indoor, vertical and hydroponic farms and related tech start-ups in Africa include Kenya-based Ukulima Tech, Tanzanian AgriTechs and South African MCX Tech (a provider of hardware and software for controlled environment systems).

Conclusion

Horizon scanning is well-suited to the study of frontier technologies and innovation. In the case of Southern Africa, it is important to consider not only what is scientifically or technically possible, but also how it can be adapted to the specific regional context. For example, technologies cannot be used in the same way for large-scale commercial farmers and small-scale or subsistence farmers. The region also faces specific challenges, including unequal access to energy and connectivity.

Gene editing technology is cheaper and easier than transgenic engineering, and it is also not as tightly controlled by a few companies. It may therefore develop in a more democratic way. In fact, there are already many African researchers conducting research on gene editing for drought resistant crops and breeds. Countries are also considering how to regulate these new technologies. Southern Africa will have to decide whether to follow existing models (eg, the US or EU one), or chart their own way.

When it comes to precision agriculture, it is possible to develop solutions that use advanced technologies in the back-end with a basic user interface in the front-end. For example, freely available satellite data can be analysed centrally and communicated in a targeted

49 Kurt Benke and Bruce Tomkins, 'Future food-production systems: Vertical farming and controlled-environment agriculture,' *Sustainability: Science Practice and Policy* 1, no. 1 (2017): 13-26.

50 Benke and Tomkins (2017).

51 Mekes, "The road ahead".

52 Mekes, "The road ahead".

way to small-scale farmers using an SMS/USSD interface. This allows more targeted and efficient extension services.

Companies can equally develop low-cost or innovative business models for this data. Drone operators are also looking at business model innovations to make their services and data available to small-scale farmers. Universities and development partners are well-placed to help develop these models – often in partnership with companies – by shouldering some of the risk inherent in developing new technologies.

New data sources and risk models also enable new insurance models, including for previously unserved clients (eg, weather index insurance for small-scale farmers or insurance bundled with seed purchases). The ARC provides an example of how risk pooling allows the transfer of climate risk away from individual governments to pan-African climate response systems for natural disasters.

Sensor and IoT networks have yielded advances in connectivity like LPWAN that prioritise energy efficiency over speed or bandwidth (as these technologies often do not need to operate real-time or carry huge amounts of data). This may well have application beyond IoT. Broadband via 5G satellite is another example of frontier technology originally aimed at connecting rural or remote areas to the internet, but that may well spread more broadly.

Innovators are also considering what sensor technologies can be built into a mobile phone – a technology that is fast spreading across the world. In fact, many advances in mobile technologies emerge from the developing world (for example mobile money).

Controlled environment agriculture is projected to increase in the next 10–15 years and Southern Africa is well-placed to benefit from this growth, and even contribute to it. Researchers and businesses should consider how to make these farms energy-efficient, through the use of off-grid renewables such as solar technologies. There is also space for innovation around business models for indoor/vertical farming and hydroponics.

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SAIIA is an independent, non-government think tank whose key strategic objectives are to make effective input into public policy, and to encourage wider and more informed debate on international affairs, with particular emphasis on African issues and concerns.

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Cover image

Modern farmers are using digital technology to collect data and monitor crops (Martin Harvey/Getty Images)

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