Agriculture in Africa: the emerging role of artificial intelligence.

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2023

Chapter 14

Agriculture in Africa: The emerging role of artificial intelligence

14.1 Introduction

This chapter critically considers the application of artificial intelligence (AI) to agriculture in Africa. It contends that, while African countries can utilise AI to address agricultural challenges, realising the full potential of AI in agriculture requires the judicious adaptation of pervasive AI technologies to serve African interests. Africa's young, vibrant population along with the movement of people, goods and services around the continent, promoted under the African Union's (AU) Agenda 2063 provide a fecund platform for AI-driven agricultural transformation. This is pivotal because of the multilayered agricultural paradoxes on the continent. For instance, Africa is endowed with an abundance of uncultivated arable land and diverse agro-ecological zones, from rain-forest vegetation to dry and arid vegetation, which engender the growth of wide-ranging food and cash crops, yet it suffers an alarming increase in food insecurity.[1] An AU, United Nations (UN) Economic Commission for Africa (UNECA) and Food and Agriculture Organisation of the UN (FAO) Report on Food Security and Nutrition in Africa confirmed that 281.6 million people on the continent, comprising one-fifth of the population, faced hunger in 2020;[2] 346.4 million Africans suffered from severe food insecurity while 452 million suffered from moderate food insecurity in the same year.[3]

The food insecurity crisis in Africa is triggered by a plethora of factors, including conflicts, climate change, crop diseases, soil degradation, population growth, and economic volatility.[4] In addition, the coronavirus disease (Covid-19 pandemic) along with national measures undertaken to tackle it, precipitated economic downturns and disrupted activities in African agricultural sectors.[5] These multifaceted factors, exacerbated by inequalities, inadequate agricultural financing, inadequate research and development (and inadequate application of research and development), poverty, poor infrastructure and inappropriate laws and policies, compound the food insecurity crisis in Africa. Despite the AU and African Development Finance Institutions' agricultural initiatives, Africa is not

1 GNAFC and FSIN: '2022 Global Report on Food Crises: Joint Analysis for Better Decisions' at 20–25.

2 FAO, UNECA and AUC: 'Africa – Regional Overview of Food Security and Nutrition: Statistics and Trends' at 2.

3 Ibid.

4 Gebre GG and Rahut DB 'Prevalence of Household Food Insecurity in East Africa: Linking Food Access with Climate Vulnerability' at 1–15; GNAFC and FSIN: '2022 Global Report on Food Crises' at 25; Awange J *Food Insecurity and Hydroclimate in Greater Horn of Africa: Potential for Agriculture Amidst Extremes*.

5 Ezirigwe J et al. 'COVID-19/Food Insecurity Syndemic: Navigating the Realities of Food Security Imperatives of Sustainable Development Goals in Africa' at 129–162.

poised to meet the Sustainable Development Goal (SDG) 2 along with its targets to end hunger, ensure access by all people to safe, nutritious and sufficient food all year round, and end all forms of malnutrition by 2030.[6]

Agriculture provides not only food but also a vital source of livelihood for the majority of female and male small-scale farmers in rural parts of Africa. In addition, it provides the raw materials required to produce primary products, ranging from biofuels, and clothing to pharmaceuticals. Presented in six parts, this chapter analyses Africa's agricultural landscape alongside nascent AI developments. Following the introduction in the first part, the second part examines some of the crucial threats to agricultural production in Africa. The third part unpacks the role of AI in tackling threats to agricultural production in Africa. The fourth and fifth parts map the AU's agriculture and AI-related laws and policies respectively. In discussing the future of agriculture in Africa, the sixth part concludes with a succinct synthesis of the core analysis along with pertinent calls to action.

14.2 Threats to agricultural production in Africa

Before the advent of European maritime traders and the colonisation of Africa, African countries had sophisticated, sustainable and resilient agricultural systems that safeguarded food sovereignty and food security.[7] European imperialism radically disrupted Africa's traditional agricultural trajectory.[8] External disruptions during colonisation introduced industrial agriculture that focused on a few export crops from the early nineteenth century, such as cocoa, coffee, cotton and palm oil, which displaced staple crops adapted to local socio-ecological landscapes and limited agrarian livelihoods.[9] In particular, industrial agriculture triggered multiplex detrimental environmental problems, including increased soil degradation, release of greenhouse gases (GHGs), deforestation, decline in agricultural biodiversity, emergence of novel plant pests/diseases and reliance on chemical inputs.[10]

Post-colonial Africa has not recovered from these external disruptions, although they now materialise differently. Contemporary avenues of external disruptions include international, regional, or bilateral treaty obligations, sovereign debt conditionalities, foreign investment terms, economic partnership agreement provisions along with western-styled agricultural capacity building, technology/green revolutions and training. These external disruptions promote western-style agriculture that engender the gradual loss of African

6 FAO, IFAD, UNICEF, WFP and WHO: 'The State of Food Security and Nutrition in the World 2022: Repurposing Food and Agricultural Policies to make Healthy Diets more Affordable'; Fonjong LN and Gyapong AY 'Plantations, Women and Food Security in Africa: Interrogating the Investment Pathway towards Zero Hunger in Cameroon and Ghana' at 138; AfDB: 'Feed Africa: A Strategy for Agricultural Transformation in Africa 2016–2025'; AU: 'Linking Agenda 2063 and the SDGs'.

7 Thorton J 'Precolonial African Industry and the Atlantic Trade, 1500–1800' at 1–19, Inikori J 'The Development of Commercial Agriculture in Pre-Colonial West Africa'.

8 See generally Arewa OB *Disrupting Africa: Technology, Law, and Development.*

9 Bjornlund V, Bjornlund H and Van Rooyen AF 'Why Agricultural Production in Sub-Saharan Africa Remains Low Compared to the Rest of the World: A Historical Perspective' at S20–S53.

10 Tongwane MP and Moeletsi ME 'A Review of Greenhouse Gas Emissions from the Agriculture Sector in Africa' (2018) at 124–134, Graham S, Ihli H J and Gassner A 'Agroforestry, Indigenous Tree Cover and Biodiversity Conservation: A Case Study of Mount Elgon in Uganda' at 1893–1911; Ntiamoah EB et al. 'Estimating and Mitigating Greenhouse Gas Emissions from Agriculture in West Africa: Does Threshold Matter?' at 1–29.

traditional agricultural knowledge and limit African farmers' ability to employ traditional tools, technologies and practices that can tackle threats to their agricultural production. This part discusses three interrelated threats to agricultural production in post-colonial Africa: climate change, crop diseases and pests, and soil degradation as exemplars of threats that can be tackled with AI as covered in the third part.

14.2.1 *Climate change*

Climate change threatens everyday lives in different sectors across Africa, including agriculture.[11] The Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report asserts that human activities have warmed the climate at unprecedented rates.[12] According to the IPCC, atmospheric carbon dioxide (CO_2) concentrations were higher in 2019 than anytime in at least 2 million years.[13] The concentration of methane (CH_4) and nitrous oxide (N_2O) were also higher in 2019 than at any time in at least 800,000 years.[14] Special Reports in the Sixth IPCC Assessment Cycle estimate that agriculture, forestry and other land use (AFOLU) activities accounted for about 13% of CO_2, 44% of CH_4, and 82% of N_2O from human activities between 2016 and 2019, which represented 23% of the total net anthropogenic emissions of GHGs.[15] Despite climate mitigation measures, global temperatures are predicted to rise by at least 1.5°C to 2°C above pre-industrial levels in the 21st century.[16]

Human agriculture-related activities that contribute to climate change include deforestation and livestock breeding for food consumption.[17] Deforestation resulting from the process of clearing land for agricultural purposes contributes to global methane production leading to the loss of abilities of forests and trees to store carbon. When forests are completely cleared or degraded by fire, the stored carbon has the potential to be released back into the atmosphere as carbon dioxide. Furthermore, methane is produced by livestock during digestion due to enteric fermentation and it is released through belches.[18] For instance, a cow belches about 220 pounds of methane every year. Methane is also released from stored manure and organic waste in landfills, which contribute to global warming.[19]

Real-world effects of climate change such as intensified and frequent heavy precipitation and associated flooding alongside droughts have unfolded around Africa as predicted in the aforementioned IPCC Report.[20] For example, in January 2022, Tropical Storm Ana resulted in the damage to agricultural lands and loss of crops in Madagascar, Malawi, Mozambique, Zambia and Zimbabwe; the storm circulated through heavy rains and

11 Lyam PT et al. 'Genetic Diversity and Distribution of Senegalia senegal (L.) Britton under Climate Change Scenarios in West Africa' at 1–20; Ampaire et al. 'Gender in Climate Change, Agriculture, and Natural Resource Policies: Insights from East Africa' at 43–60; Alemaw BF and Matondo JI 'Overview of Climate Variability and Change in Africa: Perspectives and Experiences' at 3–8.

12 IPCC: 'Climate Change 2021: The Physical Science Basis'.

13 Ibid.

14 Ibid.

15 Ibid.

16 Ibid.

17 Epule TE et al. 'A New Index on Agricultural Land Greenhouse Gas Emissions in Africa' at 598–613.

18 Iyiola-Tunji AO et al. 'Dual Pathway Model of Responses Between Climate Change and Livestock Production' at 523–533.

19 Ibid.

20 IPCC: 'Climate Change 2021: The Physical Science Basis'.

floods.[21] Similarly, in March 2019, Tropical Cyclone Idai that ravaged Southern African countries, including Madagascar, Malawi, Mozambique, and Zimbabwe, wiped out agricultural lands and halted food production; it circulated through strong winds, heavy rains and severe floods.[22] Meanwhile, countries in the Horn of Africa, including Ethiopia, Kenya and Somalia suffered severe droughts in 2021; failed rainy seasons and shortages of water caused loss of crops and livestock.[23] These vicissitudes in weather conditions resulting in interruptions to agricultural production and low agricultural yields remain core future threats to agricultural production in many countries across Africa.

14.2.2 *Crop diseases and pests*

The FAO estimates that about 40% of worldwide crops are lost to diseases and pests.[24] Crop diseases and pests can spread through environmental forces (such as weather and wind), insects (or other vectors), trade and human migration/movements.[25] Some of the common plant pests and diseases in Africa include cassava mosaic disease or brown streak, desert locust and wheat rusts. Cassava (*Manihot esculenta*) is mostly produced by small-scale farmers in the humid and semi-humid tropics.[26] Africa accounts for more than 50% of the global cassava production and about 70 million Africans depend on cassava as their primary source of food. Cassava is popular across Africa because of its resilient and versatile characteristics. For instance, it can grow successfully in wide-ranging agro-ecological zones, it produces higher yields per unit of land (more than other crops such as maize, yams, wheat or rice), it is tolerant to drought, and it can produce yields even on depleted lands. In addition, it is vegetatively propagated (farmers can replant their cuttings), and it does not require the extensive use of chemical inputs (such as fertilisers). Cassava can be eaten fresh and in various processed forms (such as cassava flour and *garri* which are popular in Nigeria). In parts of Africa, especially East Africa, cassava leaves are consumed as green vegetables. The cassava mosaic disease produces foliar symptoms including mosaic patterns, mottling, twisted leaflets, and a reduction in the size of leaves and plants.[27]

Desert locusts (*Schistocerca gregaria*) destroy agricultural production and engender food loss across Africa.[28] Desert locusts are the most destructive migratory pest in the world. A locust can devour about 2 grams of plants every day, which is equal to its own weight. As desert locusts migrate in swarms, one million desert locusts can devour about

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21 Mushtaq F et al. *A Rapid Geospatial Analysis of the Impact of Tropical Storm Ana in Madagascar, Malawi, Mozambique, Zambia and Zimbabwe* at 5–7.

22 Tevera D et al. 'Assessment of Cyclone Idia Floods on Local Food Systems and Disaster Management Responses in Mozambique and Zimbabwe' at 59–68; Mutasa C 'Revisiting the Impacts of Tropical Cyclone Idai in Southern Africa' at 175–189.

23 Seife TK 'The Impact of Climate Change on Agriculture and Food Security in the Greater Horn of Africa' at 98–114; Wassie SB, Mengistu DA and Birlie AB 'Agricultural Drought Assessment and Monitoring using MODIS-based Multiple Indices: The Case of North Wollo, Ethiopia' at 787–812.

24 IPPC Secretariat: 'Scientific Review of the Impact of Climate Change on Plant Pests: A Global Challenge to Prevent and Mitigate Plant-Pest Risks in Agriculture, Forestry and Ecosystems'.

25 Oerke EC 'Crop Losses to Pests' at 31–43; Sharma S, Kooner R and Arora R 'Insect Pests and Crop Losses' at 45–66.

26 Ceballos H et al. 'Cassava' at 53–96.

27 FAO: 'Cassava Diseases in Africa: A Major Threat to Food Security'; CaCESA: Strategic Programme Framework 2010–2015; Alabi OJ, Kumar PL and Naidu RA 'Cassava Mosaic Disease: A Curse to Food Security in Sub-Saharan Africa'.

28 Cressman K 'Desert Locust' at 87–105.

one tonne of food every day; large swarms devour even more. A single swarm can have 80 million desert locusts, travel up to 90 miles a day and eat the same amount of food per day as 35,000 people. Indeed, the desert locust is one of the most dangerous locust pests because of the ability of its swarms to fly across great distances. Desert locusts consume almost all crop and non-crop plants including barley, cotton, maize, millet, pasture grasses, rice, sorghum, sugarcane, and vegetables. During plagues, desert-locust invasions destroy and limit agricultural harvests that would have been produced to feed humans. Driven by anthropogenic climate change and increased climate variability, there was a desert-locust upsurge between 2019 and 2021 in parts of the Horn of Africa.[29] In particular, in December 2020, there were huge desert-locust swarms around Kenya, coming up to 60 kilometres wide in certain instances, with the potential to eat million tonnes of cereals meant for human consumption.[30]

Wheat rusts (leaf or brown rust of wheat) caused by *Puccinia triticina* (Pt) is widely circulated across Africa and other wheat producing regions.[31] Wheat (*Triticum aestivum* L.) and wheat products are increasing significantly in Africa as they comprise part of the staple foods in many countries around the region. While African countries such as Ethiopia, Kenya, Nigeria, South Africa, Sudan, Zambia and Zimbabwe produce wheat, Africa is also a major importer of wheat.[32] Diseases are major contributors to low wheat yields. In particular, wheat rusts spread rapidly and reduce the yield and quality of the wheat. Factors that contribute to wheat-rust infections include the climate (such as drought, precipitation, wind, temperature, carbon dioxide, nitrous oxide, methane and other greenhouse gases), race of the pathogen, susceptibility of the wheat cultivar to diseases and timing of the infection.[33] The consequential damage to the wheat depends on the level of plant development at the time of the infection and the gravity of the disease.

14.2.3 *Soil degradation*

Soils are invaluable natural resources and living ecosystems that are the foundations of agricultural production.[34] Healthy soils comprise a good mixture of soil structure, organic-matter content, chemistry, biology and water permeation, which are fundamental to the growth of nutritious plants.[35] Healthy soils are also rich in biological diversity that help to fight against diseases and pests. Notably, soils play a crucial role in mitigating climate change as they provide the second largest carbon sink (first is the ocean), which regulate atmospheric carbon dioxide and greenhouse gas effects. Soil degradation can both be natural, and human made.[36] Soil degradation occurs when the quality of soil diminishes, through the loss of certain biological, chemical, or physical qualities, resulting in its

29 Salih AAM et al. 'Climate Change and the Locust Outbreak in East Africa'.
30 UN: 'East African Countries Better Prepared, but Desert Locust Threat "'Not Over"'.
31 Singh RP, Huerta-Espino J and Roelfs AP *The Wheat Rusts* at 35; Bhardwaj SC et al. 'Wheat Rush Research: Then and Now' at 1231–1244.
32 Tadesse W, Bishaw Z and Assefa S 'Wheat Production and Breeding in Sub-Saharan Africa: Challenges and Opportunities in the face of Climate Change'.
33 Mylonas I et al. 'Better Farming Practices to Combat Climate Change' at 10. Race in Plant Pathology refers to a pathogen's ability to cause disease on its host. See Anderson JP et al. 'Plants versus Pathogens: An Evolutionary Arms Race' at 499–512.
34 Wild A *Soils and the Environment*.
35 See Summer ME *Handbook of Soil Science*.
36 Mganga KZ 'Agricultural Land Degradation in Kenya' at 273–300.

inability to support plants and animals. Soil degradation, which make agricultural lands less fertile, remain a prevalent threat to agricultural production in Africa.[37]

The primary causes of human-made soil degradation in Africa include deforestation, excessive grazing, excessive use of agrochemicals and unstainable intensive farming practices.[38] For instance, unstainable intensive farming can contribute to the erosion of the top layer of soils, which are typically rich in organic matter and essential nutrients.[39] Over time, the erosion leads to the depletion of fertile agricultural land, reducing its yield and sometimes even rendering it barren. Consequently, farmers usually resort to applying more agrochemical inputs, resulting in environmental problems like acidification, nutrient imbalances, and eutrophication in water bodies. Similarly, intensive farming activities such as the use of heavy machinery and ploughing can compact the soil, reducing its porosity and ability to absorb water. As compacted soils are less aerated, they restrict root growth, which leads to reduced crop yields and increased vulnerability to drought. The runoff from compacted soils can also contribute to erosion and water pollution.

The three interrelated threats examined in this part are non-exhaustive as there are innumerable threats to agricultural production in Africa. However, a recurrent theme across the three threats covered is the role of human activities and climate change. The third part analyses how AI can tackle these threats to agricultural production in Africa.

14.3 The role of artificial intelligence in tackling threats to agricultural production

AI has the potential to tackle threats to agriculture and improve productivity and efficiency at all stages of agricultural value chains.[40] AI can be employed to tackle the threats to agricultural production examined in the preceding part. On factors relating to climate change: AI can be employed to forecast floods and droughts. It can target water and input use to limit waste and environmental pollution. In addition, AI can be utilised for harvesting, thereby limiting agricultural loss and waste. On factors relating to pests and diseases: AI can detect and treat pests and diseases with precision. On soil degradation: AI can monitor soil conditions. Before unpacking the contemporary role of AI in tackling threats to agricultural production, a brief historical trajectory of AI is elucidated next.

14.3.1 *The historical development of artificial intelligence*

The history of AI can be traced back to the 1950s and to an epochal conference organised by John McCarthy entitled ‘Dartmouth Summer Research Project on Artificial Intelligence’, which was held at Dartmouth College in Hanover, New Hampshire in 1956.[41] During the conference, the proof of concept for AI, called *Logic Theorist* was initialised by Allen

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37 Lal R and Stewart BA (eds) *Soil Degradation and Restoration in Africa*.

38 Ibid.

39 See generally FAO and ITPS: ‘Status of the World’s Soil Resources: Main Report’.

40 Young S ‘The Future of Farming: Artificial Intelligence and Agriculture’ at 45–47; Shaikh TA, Rasool T and Lone FR ‘Towards Leveraging the Role of Machine Learning and Artificial Intelligence in Precision Agriculture and Smart Farming’ at 1–29, Nguyen C et al. ‘Early Detection of Wheat Yellow Rust Disease and Its Impact on Terminal Yield with Multi-Spectral UAV-Imagery’ at 1–28.

41 Copeland J *Artificial Intelligence: A Philosophical Introduction*.

Newell, Cliff Shaw, and Herbert Simon.[42] The Logic Theorist was programmed to mimic human ability to solve mathematical problems and proved to be more efficient than human mathematicians after beating two renowned mathematicians: Alfred North Whitehead and Bertrand Russell. The Logic Theorist significantly contributed to birth the field of AI. The term 'AI' was coined at the conference and this period was termed 'the birth of Artificial Intelligence'.[43]

Over the years, AI has undergone tremendous growth and development.[44] The years between 1956 and 1974 was known as 'the golden years – Early enthusiasm'.[45] Within this period, the first chatbot was created. Following 'the first AI winter' a period between 1974 and 1980 where interest in AI decreased, 'the boom of AI' (1980–1987) saw the development of expert systems. The 'second AI winter' came between 1987 and 1993. This was then followed by 'the emergence of intelligent agents' (1993–2011), a period where IBM Deep Blue, an AI system, beat a world chess champion.[46] This period also saw the development of an AI vacuum cleaner and the rise of AI-powered businesses such as Facebook, Twitter, and Netflix.[47] From 2011 to the present, the era of 'deep learning, big data and artificial general intelligence', has seen the application of AI in various aspects of our lives, such as augmenting workforce, better language modelling, cybersecurity, autonomous vehicles and, more recently, metaverse (a unified persistent digital environment).[48]

In the past six decades, there has been a massive shift in technological and engineering developments towards AI. Over these decades, AI started living up to its design as a technology that leverages on Big Data to deliver real value. However, the meaning of AI remains unclear.[49] Most people refer to AI as a machine that mimics human intelligence or a machine that thinks and acts like humans. Although this may appear to be correct, there is no generally accepted definition of AI.[50] At the same time, there are several misconceptions and anecdotes about AI. AI has been described as a methodology that works like the human brain, as a technology that describes how the human brain works, and as machines that learn by themselves. Emmert-Streib, Yli-Harja and Dehmer suggest that the preferable approach to understanding AI is to recognise that AI deals with an artificial form of intelligence.[51]

Since the definition of AI is still evolving and contentious, it is important to establish its goals. Winston and Brown note that the primary goal of AI is to make machines smarter,

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42 Newell A and Simon H 'The Logic Theory Machine – A Complex Information Processing System' at 61–76; Gugerty L 'Newell and Simon's Logic Theorist: Historical Background and Impact on Cognitive Modelling'.

43 Ibid.

44 Mc Corduck P and Cfe C *Machines Who Think: A Personal Inquiry into the History and Prospects of Artificial Intelligence*; Buchanan BG 'A (Very) Brief History of Artificial Intelligence' at 53–60; Haenlein M and Kaplan A 'A Brief History of Artificial Intelligence: On the Past, Present, and Future of Artificial Intelligence' at 5–14, Ekmekci PE and Arda B *Artificial Intelligence and Bioethics* at 1–15, O'Regan G *A Brief History of Computing* at 249–273; Kampakis S *Predicting the Unknown: The History and Future of Data Science and Artificial Intelligence*.

45 Taulli T *Artificial Intelligence Basics: A Non-Technical Introduction* at 1–17.

46 Ibid.

47 Ibid.

48 Ibid.

49 Nilsson NJ *The Quest for Artificial Intelligence: A History of Ideas and Achievements*.

50 Ibid.

51 Emmert-Streib F, Yli-Harja O, Dehmer M 'Artificial Intelligence: A Clarification of Misconceptions, Myths and Desired Status' at 91.

while its secondary goal is to make machines more useful.[52] Drawing from these goals, AI can be defined as the development of machines or algorithms that reason, learn, percept, and solve problems. AI enjoys a synergistic relationship with Big Data.[53] To be sure, AI and Big Data are closely associated. AI models train on Big Data; without AI, the insights hidden in Big Data would remain uncovered. Furthermore, AI consists of several sub-fields. One of the major sub-fields of AI is machine learning (ML) which is often misunderstood as AI rather than an application or subset of AI.[54] ML is the study of computer algorithms with the ability to learn and improve their experiences by using the data –with little or no human intervention.[55] Other sub-fields of AI include natural language processing, neural networks and computer vision. Natural language processing covers how machines analyse and process large amounts of natural language data. Neural networks are algorithms designed to recognise patterns in data. Computer vision comprise algorithms trained to replicate the system of human vision and can recognise objects and understand images.

Although AI is not infallible, it presents pioneering opportunities. For instance, AI machines or algorithms can operate effectively around the clock without breaks or interruptions. As such, they can be deployed to carry out tasks that are repetitive and time-consuming. AI facilitates simplified, speedy and smarter decision-making processes. Furthermore, AI is adaptable, which means that it can be deployed across industries including the automobile, education and finance industries through self-driving cars, robotics, voice assistants, personalised learning, automated financial assistance and fraud preventions/detection.

14.3.2 *How is artificial intelligence applied in the agricultural industry?*

AI plays a pivotal role in agriculture.[56] It offers technological advances that aim to proffer innovative solutions to tackle threats and challenges to agricultural production while improving agricultural activities. To be specific, AI in agriculture can cover the application of technologies to (i) monitor and address climate change impacts; (ii) monitor and control diseases and pests; and (iii) monitor and improve soil conditions, with the overarching tripartite objectives to produce healthier crops, improve yields and enhance agricultural-related tasks.

(a) Applying artificial intelligence through precision agriculture

One of the key avenues through which AI is applied in agriculture is precision agriculture. Precision agriculture is a strategy that combines a set of technologies such as information systems and management, remote sensor networks, survey drones, satellite position data and enhanced machineries to optimise agricultural production.[57] Put differently, precision agriculture produces effective and operational results that enhance the quantity and

52 Winston PH and Brown RH (eds) *Artificial intelligence, An MIT perspective*.
53 Duan Y, Edwards JS and Dwivedi YK 'Artificial Intelligence for Decision Making in the Era of Big Data-Evolution, Challenges and Research Agenda' at 63–71.
54 De Saint Laurent C 'In Defence of Machine Learning: Debunking the Myths of Artificial Intelligence' at 734.
55 Palanivinayagam A et al. 'An Optimized Machine Learning and Big Data Approach to Crime Detection'.
56 Liu SY 'Artificial intelligence (AI) in agriculture' at 14–15; Jha K et al. 'A Comprehensive Review on Automation in Agriculture using Artificial Intelligence' at 1–12.
57 Zhang N, Wang M and Wang N 'Precision Agriculture: A Worldwide Overview' at 113–132; Gebbers R and Adamchuk V 'Precision Agriculture and Food Security' at 828–831.

quality of agricultural produce with less input. For instance, precision agriculture can monitor crop temperature, crop moisture and soil composition. It can also determine the quantity of seeds, water, fertiliser and other inputs to apply in farming to maximise yield and minimise waste – including greenhouse gas emissions from agrochemicals. The precision agriculture process starts with data collection and analysis that leads to informed and strategic decision-making. An example of this process is the use of ML algorithms to predict the suitability of crops based on soil type.[58]

As agricultural ecosystems are rapidly expanding, entrepreneurs and businesses are increasingly interested in investing in agriculture. However, most of these new players lack traditional agricultural knowledge.[59] Traditional knowledge includes the historical and intergenerational transfer of knowledge, resources, beliefs, and practices.[60] Traditional farming knowledge has evolved over centuries and has been shaped through experiments, crisis, and mistakes.[61] Traditional agricultural knowledge is often site-specific. This means that the traditional agricultural knowledge is primarily developed, conserved and applicable to crops in a specific environment. Nevertheless, traditional knowledge can also be fluid and dynamic as it encompasses lessons that can be adapted and transplanted.[62]

With limited traditional knowledge, contemporary farmers struggle to determine how to grow crops efficiently and effectively. For example, considering the nuances in soil types even within the same geographical state, farmers lacking the relevant traditional knowledge to determine suitable soil types for crop growth, can utilise precision agriculture to make informed decisions. Scientists and researchers have developed predictive analytics models that are trained on diverse soil classes and compositions to match and predict the best types of crops to grow on different soil types.[63] Accordingly, with precision agriculture, farmers with limited traditional knowledge can apply predictive analytics models to enhance their farming activities. However, not all farmers (especially small-scale farmers) can afford to adopt precision agriculture technologies due to the cost constraints.

(b) Applying artificial intelligence to diagnose crop diseases

Early, accurate diagnosis and monitoring of crop diseases offers the opportunity for prompt and targeted interventions. ML, image processing, big data and cloud computing have facilitated the development of AI driven interventions and solutions. By utilising datasets such as drones, images and satellites, AI engenders automated, accurate and rapid diagnosis and monitoring of crop diseases, which advance agriculture efficiencies. Crop disease management is crucial for ensuring food security, as diseases have adverse impacts on yields and agricultural harvests. Still, crop disease management is challenging, as

58 Chen Q et al. 'AI-Enhanced Soil Management and Smart Farming' (2022) 38 *Soil Use and Management* at 7–13.

59 Flora IP 'On Kereksuk Rice Farm, Resolute 4.0 and Agriculture in Nigeria: An Interview with Rotimi Williams (Part 1)'.

60 Okediji R 'Traditional Knowledge and the Public Domain' at 1–16; Oguamanam C 'Wandering Footlose: Traditional Knowledge and the "Public Domain" Revisited' at 306–325; Okediji R 'A Tiered Approach to Rights in Traditional Knowledge' at 271–321.

61 Berkes F and Turner NJ 'Knowledge, Learning and the Evolution of Conservation Practice for Social-Ecological System Resilience' at 479–494.

62 Kloppenburg J 'Social Theory and the De/Reconstruction of Agricultural Science: Local Knowledge for an Alternative Agriculture' at 519–548.

63 Rahman SAZ, Mitra KC and Islam SMM 'Soil Classification Using Machine Learning Methods and Crop Suggestion Based on Soil Series' at 1–4.

the ability of farmers to detect ailing plants and initiate recovery processes require significant expertise.

AI technologies have been adopted across the globe to diagnose and treat crop diseases.[64] For example, at the early stages of the adoption of computer-aided systems in agriculture, models were developed to forecast diseases on plant leaves, based on the wetness duration of the leaves.[65] The percentage of infection in leaves were detected by a hybrid system comprising fuzzy logic and image processing. Similarly, Cameroonian based company, Agrix Tech, developed an application that enables farmers to diagnose diseases and receive suggestions on suitable treatments after 10 seconds of uploading the pictures of ailing fruits.[66] Farmers in Kenya extensively use drones to identify pests and diseases. According to Bancy Mati, Director, Water, Research and Resource Centre (Warrec) at Jomo Kenyatta University of Agriculture and Technology, 'the use of flying sensors has enabled small and medium sized farmers to identify diseases early. The system is able to identify diseases at least ten times earlier than the naked human eye. It serves as an early detection system.'[67]

In addition, a multidisciplinary team including researchers from the Pennsylvania State University, FAO, International Institute of Tropical Agriculture (IITA) and International Maize and Wheat Improvement Centre (CIMMYT) among others developed an AI diagnostic tool, named Nuru, to diagnose crop diseases such as the cassava mosaic disease in Africa highlighted above.[68] Nuru is a deep learning object detection model that provides an inexpensive, simple but robust platform to undertake on-field diagnosis without access to the internet. An investigation conducted in East Africa to evaluate the effectiveness of Nuru as a diagnostic tool found that it could diagnose the symptoms of cassava diseases at a higher accuracy than agricultural extension agents and farmers. Nuru's diagnosis was 65% accurate in 2020, while agricultural extension agent's and farmers diagnostic accuracy were 40% to 58% and 18% to 31% respectively. Nuru's diagnostic accuracy was further developed (culminating in 74% to 88%) by increasing the number of leaves assessed to six leaves per plant.

(c) Applying artificial intelligence to soil (and crop) management

Soil quality assesses soil conditions and its capacity to sustain plant and animal production within an ecosystem boundary. Solid knowledge of various soil types and conditions would enhance crop production. However, not all farmers possess this knowledge. Indeed, it will be near impossible for some contemporary farmers to have comprehensive

64 Qin F et al. 'Identification of Alfafa Leaf Diseases Using Image Recognition Technology' at 1–26; Zamani AS et al. 'Performance of Machine Learning and Image Processing in Plant Leaf Disease Detection' at 1–7; Jeong S, Jeong S and Bong J 'Detection of Tomato Leaf Miner Using Deep Neural Network' at 1–11; Patil RR et al. 'An Artificial Intelligence Based Novel Rice Grade Model for Severity Estimation of Rice Diseases' at 1–19; Hamna W et al. 'A Mobile-Based System for Detecting Ginger Leaf Disorders Using Deep Learning' at 1–13, Al-Gaashani MSAM et al. 'Using a Resnet 50 with Kernel Attention Mechanism for Rice Disease Diagnosis' at 1277; Bouguettaya A et al. 'A Survey on Deep Learning-Based Identification of Plant and Crop Diseases from UAV-Based Aerial Images' at 1297–1317.

65 Sannakki S et al. 'Leaf Disease Grading by Machine Vision and Fuzzy Logic' at 1709–1716; Tilva V, Patel J and Bhatt C 'Weather Based Plant Diseases Forecasting Using Fuzzy Logic' at 1–5.

66 Agrix Tech: https://www.agrixtech.com/#home.

67 Mutembei P 'Farmers Turn to Drone to Fight Crop Diseases'.

68 Mrisho LM et al. 'Accuracy of a Smartphone-Based Object Detection Model, PlantVillage Nuru, in Identifying the Flora Symptoms of Viral Diseases of Cassava – CMD and CBSD'.

knowledge of soil types and conditions. AI, therefore, provides options to facilitate sustainable soil management. For instance, Zhao et al. developed an artificial neural network model that predicts soil textures based on certain soil attributes.[69] As a result of AI developments, automated systems have been incorporated in sensors to monitor and detect soil temperature, moisture, nitrogen status and to predict crop yields.[70] In 2021, an AI-driven platform, Crop Nutrition Laboratory Services Ltd (Cropnuts) launched an AI-based soil testing and digital crop advisory service for use around Africa, known as AgViza. Cropnuts spent five years in development and capturing thousands of calibrations of soil samples. AgViza measures soil fertility properties and delivers prime soil health management and fertiliser advice to farmers. The technology reduces the cost of soil testing by over 75%. This makes it affordable to farmers, especially small-scale farmers in the rural areas.

Building on soil management, crop management incorporates the holistic management of crops, including pre-sowing, the sowing process, growth monitoring, harvesting, crop storage and distribution. Like soils, a sound understanding of crop properties will not only increase crop yields but protect the environment. Crop-management systems have been developed to predict the suitability of crops to various soil parameters. These parameters include PH, soil type, temperature, humidity, rain, nitrogen, sulphur, phosphate, manganese, copper, calcium, iron, potassium, and depth. Dai, Huo and Wang propose a model that enables crops to respond to soil moisture and salinity.[71] Furthermore, Song and He recommend the implementation of models that detect crops nutrition disorder and predict crop yield.[72]

While the examples above show how AI technologies have been innovatively applied in agriculture, the adoption of AI can exacerbate challenges and disruptions to Africa's agricultural ecosystems. For instance, the adoption of AI technologies can disrupt small-scale farmers and farm workers activities, and lead to loss of jobs. Second, it can result in the influx of businesses that undertake large-scale industrial agriculture and focus on maximising profits to the detriment of farmers' livelihoods and environmental sustainability. Third, the cost of access to (and maintenance of) the AI technologies could exacerbate of the digital divide through the exclusion of some small-scale farmers from its benefits. Fourth, the adoption of AI could result in the capturing, storage and unauthorised use of Africa's robust agriculture data, opening up data privacy/data security concerns. This is especially concerning because AI developments are driven primarily by the private-sector actors who are predominantly interested in profit maximisation. Fifth, the wide-spread reliance on AI technologies could contribute to the decline and extinction of traditional agricultural knowledge in Africa.

However, the laws and policies introduced in Africa can address some of these challenges and shape the agriculture and AI trajectories in the region. With Africa's increasing push towards regional integration through the African Continental Free Trade Area (AfCFTA), AU instruments and initiatives will play a crucial role in setting the standards for national governments around Africa. For instance, year 2022 was earmarked 'The Year

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69 Zhao Z et al. 'Predict Soil Texture Distributions Using an Artificial Neural Network Model' at 36–48.

70 Chen et al. at 7–13.

71 Dai X, Huo Z and Wang H 'Simulation for Response of Crop Yield to Soil Moisture and Salinity with Artificial Neural Network' at 441–449.

72 Song H and He Y 'Crop Nutrition Diagnosis Expert System Based on Artificial Neural Networks' at 357–362; Ji B et al. 'Artificial Neural Networks for Rice Yield Prediction in Mountainous Regions' at 249–261.

of Nutrition: Strengthening Resilience in Nutrition and Food Security on the African Continent'.[73] The AU's current law and policy architecture for agriculture and AI is investigated next.

14.4 The African Union's laws and policies on agriculture

Under the AU's Pan-African Agenda 2063, which sets out its collective vision for an integrated, prosperous and peaceful Africa, driven by its own citizens and representing a dynamic force in the international arena, the AU seeks to consolidate the modernisation of African agriculture and agro-businesses, through scaled up value addition and productivity.[74] It sets out the following five pertinent action goals, which span across imports, trade, technology, finance, land, inputs and gender, to achieve its objectives. The goals are (i) to completely eliminate hunger and food insecurity; (ii) to reduce the imports of food and raise intra-African trade in agriculture and food to 50% of total formal food and agricultural trade; (iii) to expand the introduction of modern agricultural systems, technology, practices and training, including the banishment of hand-hoe; (iv) to develop and implement affirmative policies and advocacy to ensure women's increased access to land and inputs and ensure that at least 30% of agricultural financing are accessed by women; and (v) to economically empower women and youth by enhancing access to financial resources for investment.[75]

The AU's Department of Agriculture, Rural Development, Blue Economy and Sustainable Environment (ARBE) is responsible for realising the agricultural aspirations of Agenda 2063 and promoting agricultural development and agricultural transformation in Africa.[76] Its central mandates include promoting agricultural and rural development, promoting policies and formulating strategies to enhance food security and nutrition, conducting research on climate change and supporting the harmonisation of policies and strategies among regional economic communities (RECs).[77] To deliver its vision on agriculture, the AU has adopted several initiatives to promote agricultural transformation in Africa, including: The New Partnership for Africa's Development (NEPAD), Comprehensive Africa Agriculture Development Programme (CAADP), Africa Seed and Biotechnology Programme (ASBP), Ecological Organic Agriculture Initiative (EOAI) and Partnership for Aflatoxin Control in Africa (PACA).

14.4.1 *Agricultural systems: Comprehensive Africa Agriculture Development Programme*

CAADP aims to help African countries eliminate hunger and reduce poverty by raising economic growth through agriculture-led development.[78] Under CAADP, African governments agreed to allocate at least 10% of national budgets to agriculture and rural development, and to achieve agricultural growth rates of at least 6% per annum. Underlying these investment commitments are targets to reduce poverty and malnutrition, increase productivity and farm incomes, and improve the sustainability of agricultural

73 AU: 'The Year of Nutrition'.
74 AU Agenda 2063: 'The Africa We Want'. See also Fagbayibo B 'Nkrumahism, Agenda 2063, and the Role of Intergovernmental Institutions in Fast-Tracking Continental Unity' at 629–642.
75 Ibid.
76 AU: 'Agriculture, Rural Development, Blue Economy, and Sustainable Environment (ARBE)'.
77 Ibid.
78 AU: 'The Comprehensive African Agricultural Development Programme'.

production and use of natural resources.[79] CAADP also supports countries to enhance resilience to climate variability through the development of disaster preparedness policies and strategies, early warning response systems and social safety nets. In 2014, AU heads of states and governments reaffirmed their commitment to CAADP through the adoption of the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods.[80]

Under the Malabo Declaration, the heads of states and governments made seven specific interconnected commitments germane to agriculture. The commitments are (i) to recommit to the CAADP process; (ii) to enhance investment finance in agriculture; (iii) to achieve zero hunger and end hunger by 2025; (iv) to halve poverty by 2025 through inclusive agricultural growth and transformation; (v) to boost intra-African agricultural trade in agricultural commodities and services; (vi) to enhance resilience of livelihoods and production systems to climate variability and other shocks; and (vii) to conduct a biennial review of progress made in achieving these commitments. Similarly, in the AU's Third Biennial Review Report on CAADP, African countries renewed their commitment to enhance the implementation of CAADP commitments and priorities.[81] The Report revealed that Rwanda, Tanzania and Zimbabwe have demonstrated recommitment to the principles and values of the CAADP process. Egypt, Eswatini, Seychelles and Zambia are on course to achieve the commitment to enhance investment finance in agriculture while Kenya is on course to achieve the commitment to end hunger by 2025.

Although agriculture remains the mainstay of many African economies, the sector is vulnerable to volatility. National agriculture plans that commit to investment in sustainable agriculture, including by AI in agriculture, will help boost agricultural production. The synoptic overview of CAADP above reveals its multidimensional aims and commitments, which, if appropriately implemented, can help to reconstruct the complex social, economic, environmental and technological contexts required for agricultural development in Africa. This contextual and holistic approach is imperative because sustainable agricultural development in Africa cannot occur without addressing the continent's unique predicaments.

14.4.2 *Seed systems: Africa Seed and Biotechnology Programme*

The ASBP offers a strategic approach to the comprehensive development of seed and biotechnology sectors in Africa, considering the diverse needs of individual countries.[82] Endorsed by the AU Assembly in 2007, the ASBP is the outcome of AU discussions on the importance of improved seeds for increasing agricultural productivity in Africa.[83] It

79 Bruntrup M 'The Comprehensive Africa Agriculture Development Programme (CAADP) – An Assessment of a Pan-African Attempt to Revitalise Agriculture' at 79–106; Poulton C et al. 'The Comprehensive Africa Agriculture Development Programme (CAADP): Political Incetives, Value Added and Ways Forward'; Benin S 'Impacts of CAADP on Africa's Agricultural-Led Development' at 1–56; Makombe T, Tefera W and Ulimwengu JM 'Tracking Key CAADP Indicators and Implementation Processes' at 196–212.

80 AU Heads of States and Governments adopted the Malabo Declaration at the African Union Summit in Malabo, Equatorial Guinea in June 2014.

81 AU: 'African Union Launches the 3rd Biennial Review Report as AU Member States Renew their Commitment to Accelerate the Implementation of the CAADP for a Resilient African Food System'.

82 AU: 'African Seed and Biotechnology Programme'.

83 Ibid.

contributes to realising the aims and commitments under the CAADP as discussed above as well as realising SDGs 1, 2, 12 and 13.

The overall goal of the ASBP is to promote food security, nutrition and poverty alleviation in Africa, through the establishment of effective and efficient seed systems and enhanced application of biotechnologies within the seed sector.[84] As indispensable agricultural inputs, seeds developed in both the informal and formal sectors can contribute to increased agricultural productivity, food sovereignty and food security in Africa.[85] However, limitations of Africa's seed systems include prioritisation of the formal seed sector (over the informal seed sector), minimal attention to building resilient and sustainable seed systems, deficient extension services as well as ineffective implementation of seed policies and international agreements.

To address some of these limitations, the ASBP aims to boost national capacity for improved seed production, multiplication and distribution. It also strives to improve seed quality assurance procedures to ensure consistent production of high-quality seed for farmers. Simultaneously, it seeks (i) to strengthen linkages between the formal and informal seed sectors to meet farmers' needs; (ii) to promote effective seed policies and regulations that boost seed trade among African nations; (iii) to enhance capacity for conserving and sustainably using plant genetic resources for food and agriculture; (iv) to increase capacity to use biotechnology to enhance plant breeding and high-quality seed production; (v) to increase capacity to implement biosafety measures; and (vi) to establish model codes of conduct for seed use in emergency situations. However, civil society organisations (CSO) such as the African Centre for Biosafety, Eastern and Southern Africa Farmers Forum, and Network of Farmers and Agricultural Producers Organisations of West Africa have questioned the safety and efficacy of introducing biotechnological products such as genetically modified (GM) crops in Africa.[86]

Rigorous multidisciplinary scientific research and evaluations must be undertaken to ascertain safety and benefits of biotechnological products, to respond to the CSO concerns and to fully benefit from the promises of the ASBP. If well implemented, the ASBP can contribute to addressing the food insecurity challenges confronted in Africa from the perspective of the seed sector. Similarly, if well developed, Africa's vibrant informal seed systems have the potential to enhance food security. Nonetheless, there is a cessation between the AU positions and national realities as Africa's seed systems are increasingly flooded with seeds and chemicals by foreign multinational agrichemical companies, despite the ASBP and EOAI discussed below.

14.4.3 *Agroecological (agricultural and seed) systems: Ecological Organic Agriculture Initiative*

The EOAI was introduced in 2012 in response to the increased use of agricultural inputs, especially inorganic fertilisers, pesticides and irrigation systems, which have negative impacts on soils and biological diversity.[87] The use of these agricultural inputs adversely affects crop genetic diversity, human nutrition and exacerbate climate change. As discussed

84 Ibid. at 9.

85 Louwaars NP, De Pef WS and Edeme J 'Integrated Seed Sector Development in Africa: A Basis for Seed Policy and Law' at 186–214.

86 Singh JA and Daar AS 'The 20-Year African Biotech Plan' at 272–274; Mabaya E et al. 'Factors Influencing Adoption of Genetically Modified Crops in Africa' at 577–591.

87 Biovision Africa Trust: 'Ecological Organic Agriculture Initiative'.

during the Addis Ababa Declaration on Agroecology, Ecological Organic Agriculture and Food Sovereignty Conference that was held in November 2016, degraded soils that lack essential nutrients limit current and future agricultural production in Africa.[88] Nevertheless, driven by private national and multinational agribusinesses, large-scale intensive agriculture, which contribute to soil degradation continue proliferating because of preferential state support. Conversely, sustainable and resilient small-scale agriculture, which adopt agroecological practices that enrich soil qualities and nutritional values of food, are marginalised. The investment and intellectual property regimes around Africa often promote large-scale systems and side-line small-scale farmers' practices. Yet, small-scale farmers can sustainably increase agricultural production using agroecological practices.[89]

Drawing from the preceding context and in reaction to the AU Council's Decision on Organic Farming passed during the Eighteenth Ordinary Session held between 24 and 28 January 2011, African governments called for initiatives to help move the continent towards sustainable and resilient agricultural production systems. These efforts culminated in the adoption of the EOAI.[90] The EOAI's vision is to achieve resilient and vibrant ecological organic agricultural systems for enhanced food and nutrition security and sustainable development in Africa. Similarly, its mission is to scale ecologically and organically sound strategies and practices through institutional capacity development, scientific innovations, market participation, public policies/programs, outreach, communication, coordination, networking and partnerships in Africa. The EOAI has four core interconnected values: to respect nature and sustainable development; to promote family farming cultures, indigenous knowledge, cultural practices and wisdom; to embrace fairness and justice to the ecosystems; and to promote safe, nutritious and healthy food.

The EOAI's vision, mission and core values embody its laudable ethos to champion the extensive adoption and maintenance of ecological organic agricultural systems in Africa, driven by small-scale farmers. A question that emerges from the EOAI provisions is: How do countries ascertain appropriate implementation mechanisms at national levels? This is pertinent because the emerging agricultural trend around Africa, as driven by external donors, or 'philanthrocapitalists', is a shift towards chemical heavy input applications with minimal recognition and reward for agroecological techniques and traditional knowledge.[91]

14.4.4 *Crop-disease control: Partnership for Aflatoxin Control in Africa*

The PACA aims to support agricultural development by protecting crops, livestock, and consumer health through catalysing, coordinating, and promoting effective aflatoxin control along agricultural value chains in Africa.[92] Aflatoxin is a toxic and carcinogenic group

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88 Changing Food Systems in Africa: Agroecology and Food Sovereignty and their Role in Nutrition and Health 2016 Conference Declaration 'Addis Ababa Declaration on Agroecology, Ecological Organic Agriculture and Food Sovereignty: The Way Forward for Nutrition and Health in Africa'.

89 Mousseau F 'The Untold Success Story of Agroecology in Africa' at 341–345; Pereira L, Wynberg R and Reis Y 'Agroecology: The Future of Sustainable Farming?' at 4–17; Nyantakyi-Frimpong H et al. 'Agroecology and Healthy Food Systems in Semi-Humid Tropical Africa: Participatory Research with Vulnerable Farming Households in Malawi' at 42–49.

90 AU: 'Why Ecological Organic Agriculture'.

91 Schurman R 'Micro (soft) Managing a "Green Revolution" for Africa: The New Donor Culture and International Agricultural Development' at 180–192; Mushita A and Thompson C 'Farmers' Seed Systems in Southern Africa: Alternatives to Philanthrocapitalism' at 391–413.

92 PACA: 'About PACA?'

of fungal metabolites that contaminate food and agricultural products. Aflatoxin contaminates African staples such as cassava, maize, rice and groundnuts.[93] Launched by the African Union Commission (AUC) in 2012, the PACA Secretariat has a ten-year strategy to improve the efficiency of governments to tackle the aflatoxin challenge in Africa. It seeks to work with governments and other stakeholders through three primary activities: Continental/inter-regional convening, mainstreaming and knowledge management.

On continental/inter-regional convening, the swecretariat is committed to supporting RECs to organise regional convenings that promote collaboration across countries, share new developments and best practices, and resolve specific challenges across regions. On mainstreaming, the secretariat is committed to supporting mainstreaming of aflatoxin in regional frameworks including CAADP as mentioned above, to ensure aflatoxin issues are integrated and addressed within these platforms and that there is consistency and congruency between frameworks and harmonisation across countries. The secretariat also seeks to serve as a hub to identify, document, and disseminate best practices and effective technologies; and serve as a technical knowledge hub for aflatoxin-related information. Ultimately, PACA's vision is to achieve an Africa that is free from the harmful effects of aflatoxins. As mentioned above, AI can contribute to early crop-disease detection and treatment. Rapid, low-cost aflatoxin detection using AI have already been developed and introduced around Africa.

While the four instruments set out laudable provisions, core challenges to realising their goals and objectives are poor coordination, and disparity between the AU provisions and agricultural policies and practices promoted at national levels, especially triggered by external funding.

14.5 The African Union's laws and policies on artificial intelligence

Africa has the potential to leverage the opportunities presented by AI to enhance efficiency in wide-ranging industries, including agriculture.[94] Despite the opportunities that AI offers, it has inherent drawbacks.[95] Thus, suitable laws and policies are required to regulate its development. The Digital Transformation Strategy for Africa 2020–2030 (DTSA) represents a positive stride in this direction. It builds on existing AU regional integration programmes under its Agenda 2063 including the AfCFTA, Single African Air Transport Market, Free Movement of Persons and Policy/Regulatory Initiative for Digital Africa.[96] The DSTA seeks to promote an integrated and inclusive digital society and economy in Africa that improves the quality of life of Africa's citizens, strengthens existing economic sectors, facilitates their diversification and development, and empowers Africans to be creators of innovative products and not solely consumers in the global economy. Its overarching objective is to harness digital technologies and innovation to reshape African societies and economies. It aims to advance Africa's integration, spur inclusive economic growth, stimulate job creation, and bridge the digital divide on the continent. Additionally, the DSTA promotes ownership of contemporary digital management tools, inclusive

93 Keller B et al. 'The Potential for Aflatoxin Predictive Risk Modelling in Sub-Saharan Africa: A Review' at 101–118.

94 Effoduh JO '7 Ways that African States are Legitimizing Artificial Intelligence'.

95 Gwagwa A et al. 'Artificial Intelligence (AI) Deployments in Africa: Benefits, Challenges and Policy Dimensions' at 1–28; Ade-Ibijola A and Okonkwo C 'Artificial Intelligence in Africa: Emerging Challenges' at 101–117.

96 AU: The Digital Transformation Strategy for Africa (2020–2030).

digital skills and human capacity to lead digital transformation in Africa through, among other things, coding, programming, block chain, ML, robotics and AI.

The DSTA is guided by pertinent principles that address some of the drawbacks of AI. For example, it provides that the strategy and digital transformation in Africa should be inclusive, homegrown, and safe. An inclusive digital transformation in Africa is affordable, accessible, and ubiquitous. A homegrown digital transformation is controlled and owned by African institutions and generates solutions that respond to African realities. With a safe digital transformation, stakeholders are fully informed about the benefits and drawbacks of the digital technologies. A safe digital transformation guarantees healthy disruptions to markets and businesses. The DSTA also delineates key recommendations and action plans to promote the construction of relevant policy and regulation, digital innovation, digital infrastructures, and digital skills in crucial sectors, including agriculture. On agriculture, the DSTA sets out three key policy recommendations and proposed actions, namely create conducive environments to foster the development of digital agriculture, provide farmers with reliable marketing information that helps them reach their markets more effectively at lower costs, and promote the deployment of digital solutions in agriculture.

In addition to the AU initiatives, there is a nascent growth of AI laws and strategies at national levels in Africa.[97] For example, Tunisia and Senegal have laws that regulate AI start-ups. Kenya and South Africa have laws that provide for the use of technology and personal data. Botswana, Egypt, Mauritius, Tunisia and Zambia have national AI Strategies. Similarly, Egypt, Kenya, Mauritius, Nigeria, South Africa, Tunisia and Uganda have national AI agencies, task forces and commissions. As African countries continue to evolve and diversify, it is increasingly evident that AI is becoming a key strategic priority for several of these countries.[98]

14.6 Conclusion: The future of agriculture in Africa: Cautiously promoting the radical potential of artificial intelligence

Post-colonial Africa is struggling to supply enough food to meet demands of its growing population. While sustainable agricultural production in Africa was disrupted during colonisation and is still in the process of recovery, neo-colonial attempts to recapture agriculture are on the rise. However, the AU's Pan-African inspired Agenda 2063 places African interests at the centre of future inclusive and sustainable development in the region. The AU has several overlapping agricultural laws and policies on wide-ranging issues from trade, biotechnology, agroecology to crop diseases. The AU also has a digital transformation strategy that covers a variety of industries, including agriculture.

While AI has the potential to radically transform Africa's agricultural productivity and promote social and economic development, these aspirations can only be achieved through the introduction of technologies and legal regimes that are tailored to African realities. To start with, the AU should adopt a joined-up approach that reconciles its different agricultural laws and policies. For example, drawing from the initiatives discussed, the AU should clarify how African countries can balance small-scale and large-scale agriculture as well as formal and informal seed systems, while avoiding adverse effects of intensive agriculture on soils and the environment, conserving traditional agricultural knowledge,

97 See Effoduh.

98 Ibid.

utilising agroecological technologies and controlling crop diseases. Once the AU has a firm view on how to design balanced agricultural systems, it can formulate a common position to guide African countries on the application of AI in agriculture.

The AI solutions must resolve the challenges that Africa confronts based on the AU's common position on agriculture. In other words, before introducing AI for agriculture in African countries, questions to ask could include: What are the agricultural challenges in the country? How can we design AI technologies that align with the AU's visions for agriculture and AI in response to the challenges? For example, the AI technologies should not exacerbate climate change or lead to the decline of agrobiodiversity. This way, the AI introduced will contribute to the realisation of the AU's long-term transformation agenda for Africa. Nonetheless, the adoption of AI in agriculture raises some further concerns, including lack of suitable and supportive infrastructures and knowledge gaps as well as concerns about quality data, data access, digital divide and intellectual property rights (IPRs).

14.6.1 *Lack of suitable and supportive infrastructures*

In Africa, the adoption and implementation of AI technologies is often undermined by a lack of basic digital infrastructures. Two of the most important infrastructures needed for AI adoption, are connectivity and energy.[99] As AI development progresses, interconnection needs to keep pace. Unfortunately, network connections in Africa are still epileptic; the broadband coverage in the continent is one of the lowest.[100] The drawback of this lack of connectivity is that African farmers are often unable to make direct connections to data sources and IT systems spread across public data repositories and clouds.

14.6.2 *Technical knowledge and skill gaps*

Another challenge of AI in Africa is limited technical knowledge.[101] This is a serious threat to technological growth in Africa because it prevents the continent from fully adopting and leveraging the maximum potential of AI's transformative technologies. African governments must invest in improving the quality of their educational systems. This could be by providing funding for the development of digital ecosystems, research, training and startups. Education is key to national development.[102] Investment in and promotion of education is important, particularly subjects in Science, Technology, Engineering and Mathematics (STEM) as well as other AI-related fields. To address this, some African governments collaborate with multinational corporations to deliver AI-related degrees. For example, Google and Facebook have collaborated to deliver postgraduate studies in ML at the African Institute of Mathematical Sciences (AIMS) in Rwanda. Similarly, Google established an AI lab in Ghana to support developers with tools to enhance research and deliver technological solutions to AI-related problems. Additional initiatives must be introduced to facilitate training and development for farmers because agricultural-based AI technologies in Africa will primarily be used by farmers. Accordingly, it is essential that these farmers are trained in the use of technology in general along with AI-based technologies.

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99 Ponnan S et al. 'An Artificial Intelligence-based Quorum System for the Improvement of the Lifespan of Sensor Networks' at 17373–17385.

100 Kiemde SMA and Kora AD 'The Challenges Facing the Development of AI in Africa' at 1–6.

101 CIPIT: 'The State of AI in Africa Report 2023' at 1–25.

102 Ugochukwu-Ibe IM and Ibeke E 'E-Learning and COVID-19. The Nigerian Experience: Challenges of Teaching Technical Courses in Tertiary Institutions'.

14.6.3 *Quality data, data access and digital divide concerns*

As earlier mentioned, AI and Big Data enjoy a synergistic relationship.[103] AI technologies deliver more efficient outcomes when granted broader access to extensive datasets. Despite the substantial daily generation of agricultural data, access to such data remains limited in Africa. Barriers to access include the lack of technologies to capture the data and limited infrastructure to store them. While the increase in the development of AI systems in Africa must be recognised, most of the systems are trained on data generated outside Africa, which could lead to biases. As AI depends on data to be trained, a central step towards the enhancement of AI technologies in Africa will be the expansion of its data ecosystem. Governments need to invest in infrastructures for accurate data collection, storage, and accessibility. They should also implement laws and policies that enable both private and public sectors to do the same. For example, governments can establish research institutions and provide funds for scientific research. This will widen the sources of quality data available to stakeholders.

Governments must also establish regulatory frameworks for data privacy and security via investment in cybersecurity. The regulatory framework must control the AI technologies to avoid the development of 'bad' AI systems. The Republic of Korea invests 5% of its GDP in emerging technologies; Africa can learn from this.[104] To control the biases, government policies must encourage 'made in Africa' AI solutions, that is to say AI systems developed in Africa, by Africans and for Africa as promoted under DTSA. In certain circumstances, stakeholders from Africa such as researchers and farmers are constrained from access to data generated from their countries due to contract rules. For example, while digital sequence information (DSI) of plants may be extracted from Africa, multinational corporations may have exclusive rights and monopolies over the information.[105] Multilateral debates on the protection of DSI are ongoing among contracting parties to the Convention on Biological Diversity (CBD), International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and the UN Convention on the Law of the Sea.[106]

14.6.4 *Intellectual property rights queries*

Many multinational agribusinesses incorporate AI in their operations and subsequently profit from the data generated.[107] For example, DuPont Pioneer's Field360 and WinField R7 programs identify hybrid-seed selection, provide crop-management prognoses and crop-progress predictions as foundations to recommend planting methods.[108] Pioneer's Field360 Select Software combines historical and contemporary field data with current agronomic and weather information to influence farmers' management decisions. Similarly, John Deere fixes sensors to its farming equipment, analyses the data collected from

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103 O'Leary DE 'Artificial Intelligence and Big Data' at 96–99; Obschonka M and Audretsch DB 'Artificial Intelligence and Big Data in Entrepreneurship: A New Era has Begun' at 529–539.

104 Kiemde and Kora at 1–6.

105 Adebola T and Manzella D 'Access and Benefit Sharing and Digital Sequence Information in Africa: A Critical Analysis of Contemporary Concerns in Regional Governance' at 154–174.

106 Ibid. See also Convention on Biological Diversity 'Digital Sequence Information on Genetic Resources'; International Treaty on Plant Genetic Resources for Food and Agriculture 'Submissions on Digital Sequence Information (DSI)'.

107 Cook P and O'Neill F 'Artificial Intelligence in Agribusiness is Growing in Emerging Markets' at 1–8.

108 DuPont Pioneer: 'Pioneer Field360 Tools App for Crop Management Decisions'.

them and sells suggestions to farmers.[109] IPRs and related ethical questions that arise from the above include: Who owns the data generated from farms? Who has control over the data? Who can commercialise the data? Should consent have been sought before data collection? Should compensation (monetary and non-monetary) be returned for the use of the data?

IPRs and access- and benefit-sharing laws were originally designed to protect human creativity and innovation.[110] However, the expansion of AI generated creativity and innovation raises questions about the applicability of IPRs.[111] One central question here is: Can existing IPR instruments cater to AI developed innovation and creativity? AI triggers conceptual questions about IPRs including its scope, subjects and standards. There are ongoing discussions about these intersectional AI and IPRs issues at international level. For example, the premier intellectual property organisation, the World Intellectual Property Organisation (WIPO), provides a multi-stakeholder forum to promote the understanding of the IPRs issues involved in AI.[112] WIPO also hosts conversation sessions on IP and AI that assembles its members and stakeholders to discuss the impact of AI on IP.[113] The robust proceedings and papers from the conversations on IP and AI are freely accessible from the WIPO website.[114] While awaiting legal and policy clarity, contractual agreements and judicial decisions at national levels could provide tentative directions.

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109 Mateescu A and Elish MC 'AI in Context: The Labour of Integrating New Technologies' at 25; Gervais D 'Is Intellectual Property Law Ready for Artificial Intelligence?' at 117–118.

110 Sherman B and Bentley L *The Making of Modern Intellectual Property Law: The British Experience 1760–1911*; Adebola T 'Intellectual Property Rights').

111 See Lee J-A, Hilty R and Liu K-C (eds) *Artificial Intelligence and Intellectual Property*.

112 World intellectual Property and Intellectual Property Policy: 'Artificial Intelligence and Intellectual Property Policy'.

113 WIPO: 'AI and IP Policy: The WIPO Conversation'.

114 Ibid.

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