THE FUTURE OF THE WESTERN CAPE AGRICULTURAL SECTOR IN THE CONTEXT OF THE 4TH INDUSTRIAL REVOLUTION

Annexure B: AgTech 26 technologies

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1. Precision/Smart farming

Definition and application in agriculture

In future smart farming robots perform autonomously and sensors allow them to evaluate a situation and to take decisions. The data from these sensors can be used to compile ever expanding datasets ("big data")[1]. Smart farming is also known as satellite agriculture, location-specific crop management or precision farming/agriculture. It is agriculture in which the crop, animals and soil receive the exact treatment that they need.

Other than in traditional agriculture, in smart farming the farmer looks at the need per plant or animal instead of per field or herd. Taking into account the specific conditions of the soil, hours of sunlight and climate will optimise the yield. Effective smart farming is therefore based on data analysis. Treating the crops and animals as accurately and effectively as possible requires i.e sensors and other data value addition to determine the variation in soil, crop and animal behaviour. GPS is used to reference the variability. Smart farming also requires decision support systems - decision rules and models that will translate the measured variability into action which – while taking into account the economy and the environment – is tailored accurately to soil, plant or animal. The smart use of these core elements (detection, decision rules, execution, evaluation) requires adapted technology, which is mostly dependent on other technologies[2].

Recent developments in smart farming include ever increasing data exchange between machines, management systems and service providers, development of injection systems, weed burners and specific implements for the crop rows. The greenhouse industry already uses robots, e.g. in the plant tissue culture, and GNSS (Global Navigation Satellite System), allowing positioning within a plot or crop with an accuracy of a few centimetres[2]. According to experts, the expansion of smart farming will result in increased production per crop, and more efficient production systems.

Although no concrete definition on the difference between precision farming and smart farming could be found, it is proposed to define it as follows: Precision Farming (essentially now an "archaic term") utilises Global Positioning Systems (GPS), Geographic Information Systems (GIS), Variable Rate Technology (VRT) and Remote Sensing (RS) technologies, where Smart Farming also incorporates the technologies such as Robotics, IoT, Big Data etc. that are relevant to drive farming systems in future. For instance the AgriHandbook review[3] focuses more on the technologies used in Precision Agriculture vs the wide array of technologies available in Smart Farming.

Current uses

Uses of technologies related to precision farming has been dealt with elsewhere and includes amongst others precision fertiliser application, planting, compaction reduction with smaller tractors (autonomous), precision spraying, precision irrigation, field monitoring, data management, precision weeding (i.e. flame throwers, steam, chemicals). It however also in the smart farming context has to include the addition of farming intelligence to data,

Synergistic technologies

- Robotics
- UAV
- AI and ML
- Climate/weather
- ICT, IT, Big Data

therefore incorporating elements of user input and calibration, but also potentially AI, Machine learning etc.

Future development

The future development of smart farming may be anchored largely in the last point made under current use, namely value addition to data, but also in the "opening up" of both hardware and software platforms so that cost can decrease and wide use can be accelerated. The open-source world of the 4th IR may therefore revolutionise farming through technologies that are opened to the market, and locally manufactured, which may be in stark contrast to what large agricultural companies want to achieve.

2. Sensor Technology

Definition and application in agriculture

A sensor is an electronic component, module, or subsystem with the purpose to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. A sensor is always used with other electronics, whether as simple as a light or as complex as a computer (Wikipedia).

The agricultural sector uses sensor technology mainly to collect data on soil, crops and animals through integration into all kinds of agricultural equipment and machines, aircraft and drones or even satellites1. Different sensors can provide farmers with real-time information on the environment, their crops and livestock, as well as other processes on the farm, enabling them to manage the farm more effectively. Sensor technology can be useful in planning, crop/livestock management as well as processing/harvest phases, but also has other uses such as in transport technology, farm security, product marketing/traceability etc. Sensors are however not only limited to soil, crops and animals, but can be seen integrated into the entire value chain in farming, supply chain or post-harvest systems – from acquiring weather data to product processing, and even up to the market or consumer in the case of possible future food tagging technology.

Current uses

Of particular relevance to agriculture are **environmental (climate), soil and water monitoring (terrestrial sensors) as well as remote sensing devices**. Automatic weather stations (AWS) are automated versions of traditional weather stations, either to save human labour or to enable measurements from remote areas[4]. Today weather and climate (long term) data is available to farmers from weather station networks through several online sources as well as smartphone applications.

In terms of **soil remote/proximal sensing**, spectral imaging may be useful, but the spectral response can be difficult to discern when tillage conditions differ, and crop residue are present. Several on-the-go sensors are however available to map soil organic matter, electrical conductivity, nitrate content and compaction levels[5]. Electromagnetic induction and resistivity devices, as well as gamma-radiometry have been in use in precision agriculture for several years, but the technology remains expensive to deploy by individual farmers[6].

Soil moisture and temperature sensors are extensively reviewed (Zazueta and Xin)[7] and others. A common issue with soil sensors is that in highly variable soil conditions, as experienced in the Western Cape, deployment of research grade sensors to monitor conditions accurately can be very costly. The deployment of wireless sensor networks at field scale, coupled with low-cost soil moisture sensors may change the landscape of agriculture irrigation management in the years to come. A further issue in farm management, is the (now enforced by law from February 2017) **measurement of water resources** on farms, where keeping accurate data records is a requirement. Sensors can aid in the measurement of levels of tanks and dams, as well as flow measurement in furrows, but accurate measurements in pipes and boreholes are also important. These applications are expected to become more and more important as the quality of surface and ground

Synergistic technologies

- Smart farming
- UAV's
- Robotics
- IoT
- IT
- Machine learning, Big Data
- Nanotechnology
- Smart water
- Transport technology

water resources are under severe pressure[8].

Positioning/localisation/tracking sensors - global positioning system (GPS) technology has been in use in precision agriculture for a long time, but autonomous navigation for i.e. tractors or accurate position for implements such as laser ploughs or precision planters require more accurate localisation. Satellite based augmentation systems (SBAS) use additional messages from satellite broadcasts to support signal augmentation (refer to main review for details). Extension of the SBAS service to the whole African continent would make it available around the world, which could result in significant social and economic benefits[9]. Recently the technology has been tested in South Africa, which successful improvement of tractor localisation in trials in Stellenbosch as well as in Heidelberg by the South African National Space Agency (SANSA)[10], but it is not clear if the technology will be made widely available.

Sensor fusion in applications such as the Robot Operating System (ROS) and several other open-source solutions makes it possible to enable auto-navigation in complex environments at relative low cost, which opens the door for both autonomous robots or implementation on tractors and other vehicles in i.e. orchards or vineyards[11]. The sensors for these applications are in mainstream use in Unmanned Aerial Vehicles (UAV's), leading to exponential development of these fused platforms and accelerated cost decrease of both sensors and software. For instance, the cost of inertial navigation systems (INS) has decreased significantly during recent years with the use of micro-electro-mechanical system (MEMS) technology in production of inertial measurement units (IMU's). These units however does not provide the accuracy and stability of their mechanical counterparts, limiting its potential applications. This is especially problematic if high-accuracy GPS is not available, or unreliable. Studies have been launched to improve altitude and heading reference system (AHRS) algorithms fusing IMU and magnetometer data[12]. These are good examples of how sensors on their own cannot achieve certain objectives – the power lies in fusion and processing of the data in order to reach certain objectives.

LIDAR technology now also plays a critical role in localisation, as it can scan the environment with high accuracy[13], and now at relatively low cost. It has developed from an aerial survey tool with which high resolution digital elevation models (DEM's) can be created, to a system that can be used to navigate cars (or agricultural vehicles, robots) in an urban/rural environment using a process named simultaneous localisation and mapping (SLAM)[14].

Imaging sensors, spectrometry – for more technical information refer to the accompanying text. Recent developments include advances in microwave and millimetre wave sensors - i.e. millimetre wave sensors that enable contact free measurements in the core of a food product. The specific interaction between these waves and water allows manufacturers to optimise drying and freezing processes in the food industry[1].

Radiometric sensors also enable lab-on-a-chip technology integrating laboratory functions for i.e. diagnosing sick animals, gas detection or food freshness status monitoring. Hyperspectral and thermal cameras can also be used to detect anomalies and analyse or visualise composition of products at different stages[15]. The conventional application of these imaging or scanning sensory types in remote sensing on different platforms, i.e. satellites, aeroplanes, UAV's, have evolved mostly due to the cost reduction with regards to higher resolution as well as other sensor properties. A more than thirty-year old issue in satellite remote sensing, namely image fusion from different sources and technologies (multi-sensory, multi-temporal, multi-resolution and multi-frequency) have now become very relevant also on other platforms i.e. the possible fusion between satellite, aerial (i.e. UAV) and terrestrial (i.e. robotic) image data.

Apart from the previously mentioned applications, another consideration is that **smartphones** already are integrated "solutions" based on an array of sensors, as a recent review also emphasised[16]. The possible applications of this widely available solution and its potential integration with other sensors must not be underestimated, in fact, many UAV systems today make use of smartphone or tablet operating systems for control and navigation purposes.

Some more applications of sensors in agriculture are dealt with in the main review, including localisation and tracking (i.e. the Farmtrack application) solutions rolled out on conventional or adapted farm equipment. The tracking applications of RFID technology [17] are also mentioned, used in animal tracking, fruit cold chain management, irrigation technologies to name but a few.

Future development

Sensors are crucial base elements that form and mould several further applications. Without sensors, weather stations, remote sensing on different platforms, robotics, IOT applications as well as further data applications i.e. smart farming and precision agriculture are virtually impossible. Future developments are mostly reviewed under the applications of sensors, but importantly sensors are bound to become smarter, smaller, cheaper and more integrated into the farming system.

3. UAV technology

Synergistic technologies
- Robotics
- Sensors
- IoT, AI
- Precision/smart farming
- Smart water

Definition and application in agriculture

Unmanned aerial vehicles (UAV's), sometimes-termed drones, are part of unmanned aerial systems (UAS) with the latter referring also to the ground control and communication units, launching systems, software, apart from only the aircraft[18]. A UAV is an aircraft without an on-board human pilot, controlled either autonomously or by remote control. However, all remote-control aircrafts are not drones/UAV's – and some writers define the former as a toy and the latter as a tool18. Further definitions and the SA context can be found in the accompanying literature review.

The use of UAV's in agriculture is as diverse as general monitoring flyovers or farm security, to assess vegetation health, track animals or even direct mechanisation such as sterile insect release or crop spraying.

Apart from allowing farmers to work more targeted (see Smart Farming), they can also be more efficient by using less chemical fertilisers or sprays, resulting in reduced input costs and better margins. Many large agribusiness firms have already linked themselves to UAV manufacturers through acquisitions or partnerships, and will promote business for those manufacturers. Drones have many advantages over piloted/satellite surveys, such as improved accuracy/resolution, frequency, and turnaround time. The latter is important as acute crop pressures differ at different stages in the growing season. The current trends in precision agriculture suggest that drones-as-a-service will be more prevalent[19], especially for smaller business units. Goldman Sachs estimate the global agricultural drone market to be worth $5.9 bn.

Current uses

Surveying, digital elevation map (DEM) creation for farm planning applications - Drones can be useful at the start of the crop cycle to produce 3D maps for early soil or terrain analysis, for planning of fields. After planting, drone-driven soil analysis can provide data for irrigation and nitrogen level management[20]. High resolution DEM's are very useful in farm planning, erosion monitoring, and further analysis in geographical information systems (GIS), which can be achieved with relatively inexpensive drones[21].

Remote sensing of soil, plants, animal behaviour - apart from the obvious cost and availability considerations setting it apart from conventional aerial surveys, drones also enable imaging below cloud cover as well as higher capturing resolution, at an "on-demand" frequency. Specifically, on large farms, crop monitoring poses significant challenges for the farmer. These challenges are exacerbated by increasingly unpredictable weather conditions, which drive risk and field maintenance costs. Previously, satellite imagery offered the most advanced form of monitoring, but with the drawbacks of advanced image ordering, limited turn-around (revisit) times, and low resolution.

Further, services were extremely costly and image quality were reduced on cloudy/foggy days. Today, time-series animations can show the precise development of a crop and reveal production inefficiencies, enabling better crop management20.

Irrigation - drones with hyperspectral, multispectral, or thermal sensors can identify which parts of a field are dry or need improvements. When the crop is growing, drones allow the calculation of vegetation indices, which describes the relative density and health of the crop, and show the heat signature, the amount of energy or heat the crop emits20.

Crop health assessment - apart from spotting bacterial or fungal infections, plant health can be assessed, which may also point to root problems or even virus infection. Speedy response can save an entire orchard, and precise detection can also lead to less chemical inputs if a farmer need to intervene. In the unfortunate case of crop failure or damage (also with incidence of hail or frost), another benefit is that the farmer can document losses more efficiently for insurance claims[20].

Livestock/wildlife management - apart from counting and monitoring of animals[22], UAV's can be extremely important measures in anti-poaching campaigns, especially where they can be equipped with night vision video cameras. In larger wildlife management areas, UAV's are also used with wireless sensor networks to monitor animal movement and behaviour[23]. Distant water points and livestock that require checking up on can be handled by sending a UAV (during the day or night) to check all is in order[24].

Mechanisation considerations - start-ups have created drone-planting systems that achieve an uptake rate of 75 percent and decrease planting costs by 85 percent. These systems shoot pods with seeds and plant nutrients into the soil, providing the plant all the nutrients necessary to sustain life[20]. Japanese farmers have been using Yamaha's R-50 and RMAX unmanned (petrol) helicopters to dust their crops since 1987, and some farming initiatives in the USA use UAV's for crop spraying, as they are often cheaper than a full-sized helicopter[26]. Distance-measuring equipment, ultrasonic echoing and lasers such as those used in the light-detection and ranging, or LiDAR, methods enables a drone to adjust altitude as the topography and geography vary, and thus avoid collisions. Consequently, drones can scan the ground and spray the correct amount of liquid, modulating distance from the ground and spraying in real time for even coverage. The result: increased efficiency with a reduction of in the amount of chemicals penetrating into groundwater. In fact, experts estimate that aerial spraying can be completed up to five times faster with drones than with traditional machinery[20]. Drones are being used to identify and precisely apply pesticide to crops which minimises the need for pesticides through early detection, as well as the absolute quantity needed due to the extreme accuracy of the drone sprayer. Agribotix, an agriculture data-analysis company in Boulder, Colorado, supplies drones and software that use near-infrared images to map patches of unhealthy vegetation in large fields.[25] UAV's are also becoming invaluable tools for farmers in other applications, such as monitoring livestock (along with for instance RFID sensors/collars), dam water levels[26] as well as in farm security, which is an extremely important and sensitive issue in South Africa[27].

Future development

Considerations in the not-too-distant future could include viability of large-scale spraying technologies, with soil scanning as well as yield detection using other sensing systems (i.e. low energy microwave or millimetre wave technology). Agri-tourism may also enter a revolution where the consumer can visit a farm where their food is produced through virtual reality. Perhaps the digital marking of crops or livestock could enable a consumer to trace a product right back to its origins.

Drones may also change the way weather sensors are operated if superlight drones can be made to stay in the atmosphere for long (even unlimited) times powered by fuel cells and solar energy. This may enable localised and real-time weather data on farm level.

4. Robotics

Definition and application in agriculture
Robotics is a technology dealing with the design, construction, and operation of robots in automation.[28] Broadly speaking, robots are machines that are designed to operate independently of human control. They can take in information about the environment around them, process this sensory information and respond accordingly without continued instruction from an operator. However, some robots are designed to operate under constant input from a controller (human or otherwise) e.g. remote-controlled vehicles.

Robotics is a field where multiple technologies and disciplines overlap, namely, machine learning artificial intelligence, computer science and electromechanical engineering. Robots are typically designed to perform tasks that humans cannot do, or cannot do as well as a machine could. This can range from tasks that require immense power combined with precision e.g. high-pressure water cutting, to very dangerous tasks, e.g. bomb detection and deactivation. Agricultural robotics is currently mostly limited to autonomous vehicles i.e. autonomous tractors or even specific implements.

Current uses
Industrial robotics, bionics and in general autonomous vehicles are examples of uses for robotics. In agriculture, robotics and autonomous vehicles have clear and important use cases. Many tasks such as planting, harvesting, sorting, and packing, lend themselves to automation as they are repetitive, pre-planned and require the operation of heavy, slow-moving machinery.[29] Fleets of robots can be used to perform tasks on a farm, centrally controlled by a farmer, instead of many individuals performing many tasks in isolation. This can greatly enhance efficiency. In Agriculture robots that need mobility can comprise of the autonomous vehicle (e.g. tractor) and the autonomous implement (e.g. crop sprayer).[30]

Due to significant overlap of the systems used in both the vehicle component and the implement component (e.g. GPS, computing units) there are redundant systems in current agricultural robots, many of which are largely conversions and modifications from Commercially-available equipment.[31] Specially designed and integrated agricultural robots can reduce the number of systems and components to create a simpler and more reliable machine, which will result in greater adoption. There are several existing applications of autonomous agricultural machines.[32] An example of this is the Agrobot, a robot which identifies ripe berries and harvests them automatically at high speeds without damaging the crop.[33]

Many of the tasks that agricultural robots perform are operations which were previously performed by human labourers. While this advent has both pros and cons, it seems inevitable that as artificial intelligence becomes more powerful, human involvement in tasks such as recognising ripe fruit or manually operating a machine will become less valuable. As costs of robotics fall, opportunities for farm labourers seem likely to decline in frequency. See UAV application for more info on another type of "airborne robot".

Synergistic technologies
- Big data
- Sensor technology
- Precision/smart farming
- IT and IoT
- UAV technology
- Machine learning/AI

In packing and sorting systems can achieve a high level of consistency per box of fruit i.e. the Greefa robotic sorting machine. Because more bins are packed, the human sorters displaced by the machine are now employed in packing, thus illustrating how robotics also have the potential to create opportunities for employment even whilst displacing current jobs.

Robotics is at the cutting edge of increasing food supply to a growing earth population, with increased yield and decreasing costs of farming happening all over. Robotic cow milking machines have improved yields from cows by 28% and have improved the health of the livestock as they are more comfortable.[34]

Future development

Automation is not a new concept, being around for decades, however it was held back due to the limitation of AI. With advances in machine learning and big data analytics, robots can learn from incredibly large samples of data. Robots seem likely to start to emulate human intelligence and usefulness more closely. More and more tasks previously reserved for the human operator who had to use discretion, will be performed by constantly working machines. The line between what humans can do well and what machines can do well is becoming increasingly blurry. More autonomous vehicles and implements may emerge, specifically those which require advanced detection and recognition capabilities such as identifying fungal infestations only visible in the electromagnetic spectrum or dehydrated crops.[35]

Robotics may present new opportunities for human employment by uncovering new opportunities for economic growth and improvement, but they are likely to have a devastating effect on employment for menial tasks in particular. Trying to prevent progress in robotics is futile. Governments and companies need to begin radically upskilling the workforce so that they are empowered to perform tasks outside the purview of robots.

Robotics makes less sense in countries where labour is cheap like South Africa, but this may change if labour policy and costs increase significantly. Positives such as 24-hour operation with no breaks make robotics very compelling and improve the ROI on the fairly expensive machinery. Farmers in South Africa will certainly look to adopt robotics in all facets of farming should the price reduce enough to warrant investment.

5. Transport technology

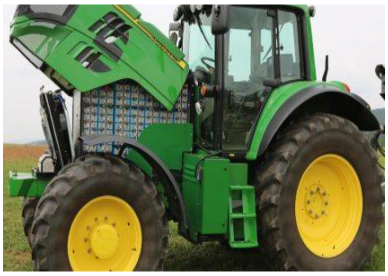
Synergistic technologies
- AI and ML
- IoT

Definition and application in agriculture
Transport technology is a generic term to describe the use of technology in improving transport. Transport includes moving goods or commuters by road, rail, air and water. Some of the key components of transportation addressed by technology include infrastructure (roads, rails), equipment and vehicles, people, supply and demand for cargo, and energy.

Current uses
General aspects of transport technology include transport aggregation, no transport (see vertical agriculture), self-driving cars and electric vehicles, of which the latter three mentioned have also transitioned into agriculture. Europe's CNH Industrial, known for its Case IH tractor brand, unveiled an autonomous concept tractor in Iowa at the Farm Progress Show, one of the world's largest farm shows. CNH's autonomous tractor could presumably work unmanned around the clock and uses GPS and sensor technology.[36] The grower could remotely monitor and control the machine using a device such as a tablet. By having numerous, smaller autonomous tractors, farmers could reduce soil compaction and reduce labour costs. These tractors are reducing in price as sensors reduce in price and will soon be economically viable in labour-scarce areas such as California.

In 2016, John Deere launched its prototype all-electric tractor, the SESAM. The SESAM has many positive qualities including: cheaper maintenance and fewer breakdowns due to far fewer moving parts, no energy loss during idling, and large amounts of torque from electric motors. Currently, one battery charge lasts for up to four operating hours in typical mixed-mode operations or for around 34 miles of road transport work. Charging time is about three hours. The battery is designed to last for 3100 charging cycles.[37]

Battery technology still needs to improve for effective usage of electric tractors. However, in an African context, on a continent that receives large amounts of sunlight, the usage of electric tractors will soon become cheaper than existing machines as the price and efficiency of batteries and solar panels improves.



John Deere Electric Tractor, source: johndeere.com

Future development
Apart for the hyperloop train, flying cars and magnetic levitation, cryptocarbon credits may be applicable to the agriculture value chain.

6. ICT/mobile tech, IT infrastructure, big/geodata

Definition and application in agriculture

Information and Communications Technology (ICT) refers to the connection of telecommunications (telephone lines and wireless signals), computers as well as software, middleware, storage, and audio-visual systems, which enable network users to access, store, transmit, and manipulate information. ICT infrastructure components include hardware, software, networking, wireless, computer systems, internet access, mailing systems, servers, videoconferencing equipment etc. along with the human capacity that manages and operates the ICT infrastructure. Thus, the scope of ICT is vast with myriad components involved in the capture, transmission, storage and analysis of information. This review will focus on ICT as it relates to big data and geo data specifically.

The potential of convergence in agricultural and rural development has yet to be fully assessed, but as the importance of being connected in order to create analysable data vital to the business-of-tomorrow increases, this potential will rapidly start to be realised. It is easy to see the benefits of convergence in the context of agriculture and big data, when we think of IoT sensors capturing images, sounds, locations, temperatures etc. digitalising those inputs and transmitting them using optical fibre, 3G networks, low range bluetooth, satellite etc.

Current uses

With regards to GeoData in Agriculture, the FAO commented that the embedding of ICTs in farm processes using sensors that can measure various elements of nature and human operations, are enabling more precise farm management. These processes are also linked through GPS and mobile GIS to cultivate, fertilize and spray pesticides and monitor harvests. Robotics and automation have reduced human labour in many tedious farm operations. Video cameras help monitor crops remotely. As the cost of sensors declines, networks of embedded sensors to continuously monitor irrigation, fertilizer and pesticide application, nutrient intake in livestock, environmental conditions such as air and water quality and pollution are being used in farming in developed countries. Coupled with maps of less than 0.25 m resolution, real time data input from sensor networks and the ability to process 'big data' that are generated by new ICT systems, farmers can improve the efficiency of all their operations significantly by reducing water, nutrient and energy wastage and improve the quality and safety of their produce.

Stating this they also emphasised that there's a need for these technologies to transition from large farms in developed countries to smallholder agriculture in developing countries. Luckily sensors are becoming cheaper, but also more versatile, multifunctional and robust and more easily networked. They mentioned that to bring this technology into smallholder agriculture, there would need to be significant aggregation and

Synergistic technologies

- Robotics
- Vertical farming
- Sensors

sharing of data and information. This becomes possible by using higher resolution 3D maps now available at the plot level.

The capture of big data is discussed in more detail in the IoT report and the analysis of that data in the AI and Machine Learning report.

From an ICT infrastructure perspective, many of the key data components required to perform meaningful big data analytics are small in size and can thus be transmitted via the existing 3G connectivity that covers the majority of South Africa. For example, temperature readings, soil readings, water readings etc. can be transmitted as very small character strings over the slowest of networks. Indeed, in developing countries (such as Bangladesh and remote areas in India) where smaller independent farmers experience very poor connectivity, the trend has been to transmit data using existing ICT infrastructure, rather than waiting for more powerful networks to solve the problem (for example the FAO's Avian Flu prevention system, where health workers submitted medical data from farms via sms. This resulted in an 87% reduction in Avian Flu outbreaks).[38]

Conversations on big data so often centre around networks and sensors, as these devices become more numerous. However, in agricultural areas where limited to no internet connectivity exist, the power of the crowd should not be discounted as a data source. A billion people worldwide sending information via text message is a powerful source of data. The key to building meaningful data sets will come from managing the transition from traditional circuit switching to packet switching through innovative hybrids of data capture and transmission.

Future development
Systems such as LPWA and its ideal features that favours agriculture applications are discussed in the reference review, along with the ubiquitous internet, which may change connectivity options especially for remote/rural farmers. It will also advance agriculture by enabling real time access to cloud computing, in particular image recognition and video analytics.

7. AI and Machine Learning

Synergistic technologies

- ICT, IT big data
- Robotics

Definition and application in agriculture

Artificial intelligence (AI) is a branch of computer science dealing with the simulation of intelligent behaviour in computers[39]. It is a term which describes a machine which exhibits human intelligence by performing acts such as language recognition, learning, reasoning, perception, planning and problem solving. AI is an area of study that has existed since the 1950s[40]. The field has enormous potential for change at almost every level of human activity. The types of AI are dealt with in the larger review. Machine vision is the technology which, in machines, automates the capture of images and the analysis thereof[41]. It can perform image analysis at high speed and in combination with other sensory information. Machines are also not bound by the visible spectrum of light and can utilise x-ray and other imaging technology. Natural language processing (NLP) is the processing of human language in various forms e.g. text or speech. One of the older and best-known examples of NLP is spam detection, which looks at the subject line and the text of an email and decides if it's junk. Current approaches to NLP are based on machine learning. NLP tasks include text translation, sentiment analysis and speech recognition[42].

Machine learning is a method of data analysis that automates analytical model building. Using algorithms that iteratively learn from data, machine learning allows computers to find hidden insights without being explicitly programmed where to look[43]. It is essentially a predictive computer program that becomes better over time as it learns from success and failure. It is an iterative process where a model is updated continuously. For example, voice recognition that improves as it is used, would be the result of AI having a larger sample of ways that certain instructions are given by the user, thus increasing the chances that it recognises the next one. The concept of machine learning has been around for some time, but advances in technology allow enormous quantities of data to be processed in less time. Machine learning automatically builds models. Imagine building your own model from a set of 10 million rows of data. This would take a lot of time and you would need to update your model each time the data changed. You may be able to do this twice week and at great opportunity cost of your time and resources. With machine learning, the model is continuously updated, and the data is analysed automatically. The result of this is high-value predictions that can guide better decisions and smart actions in real time without human intervention.[44] For different methods of Machine Learning refer to the main review.

Current uses

General uses of AI include customer service applications, education, law and medicine applications and manufacturing.

AI has many uses in smart and automated agriculture. A key area of its use is in the analysis of farm data. Data is collected through a system of sensors around the farm in an IoT network (refer). Sensors around the farm give real time updates to the AI system, which can be trained to send the correct response to that area. For instance, if the soil moisture sensors indicate that a certain field is dry, the AI system would be able to recognise this and irrigate that specific area until it is at the required moisture content. Furthermore, AI could be used to determine optimal soil conditions for crops based on access to soil science databases, yield data, and machine learning. Weather predictions (which are a product of AI themselves) are built into the AI system such that crops are irrigated only when rain is not expected. The AI could also offer farmers advice in terms of optimal planting or harvest times based on weather predictions and crop ripeness. AI can also assist in caring for livestock by analysing vitals of the animals and diagnosing any problems[45]. This can guide a farmer toward 'perfect' farming, and when used at scale would create huge efficiencies.

An actual example of a system that uses an AI to determine optimal growing conditions and actively monitor crops using machine vision is Huxely[46]. This system can even be combined with augmented reality (AR) to overlay farming information to the user of the AR device and offer recommended actions based on what the user is looking at. This tool could give farmers, particularly hydroponic farmers, a huge productivity boost, by effectively giving the farmer access to machine-learned farming expertise.
Within farm robotics, an AI system could coordinate many robots to work harmoniously so that the farm runs more efficiently and reacts to changes more quickly and effectively. This would reduce labour and costs associated with slow reaction to problems. In summary, AI enhances other technology on farms, particularly where there are automated systems with live sensor feeds. Robots, drones, software systems, IoT systems, automated vehicles, 3D printers and many more will all benefit from powerful AI. AI will become the brain that runs all of these moving pieces, and ensure they work perfectly together.

Some common uses of machine learning are listed in the larger review, but generally in Agriculture use it integrates with AI use cases.

Future development
Artificial intelligence is moving toward becoming more general. As we perfect AI software we will be able to create systems that emulate human cognitive ability more closely, which will allow a powerful general AI to emerge. This could become a virtual person on the internet, performing any computerised task that a person can do. With the aid of robotics, this AI could even take physical form and perform physical tasks. While this kind of AI may not be on the near term horizon, it is not unreasonable to predict that in a few years it will be possible to replace a general purpose office employee, such as an administrator, with an AI. Already, there are AI personal assistants which help people schedule meetings such as Kono AI[47].

Other areas where AI is advancing is through big data analytics and prescriptive modelling. As the adoption of autonomous vehicles and IoT grows, our cities and their infrastructure could be actively managed by a powerful artificial intelligence. Traffic, lighting, power and emergency services could all be intelligently coordinated by an AI that recognises and predicts demand for infrastructure such as road space or energy and plans the supply accordingly for optimal efficiency. For example, it could clear a path for emergency services when a disaster occurs[48].

In conclusion, AI will continue to develop rapidly, and repetitive and routine tasks, especially those that are computerised will almost certainly be the domain of AI. Even areas requiring high qualifications such as analytics and statistics will be dominated by AIs. While this has obvious implications for many people's skills becoming redundant, the economic growth potential is huge. Governments and businesses, including farms, need to deeply understand the impact of AI on employment, in order to put measures in place to upskill populations into areas that are least affected by AI, or new areas that emerge as a consequence of AI.

8. IOT

Synergistic technologies

- ICT, Big Data
- Sensors
- ML and AI
- Robotics
- UAV tech
- Smart Farming

Definition and application in agriculture

The Internet of Things (IoT) refers to any object that is connected to the internet. In the past, we would only have thought of computers and more recently smartphones as being connected to the internet. However, in today's economy there are a multitude of connected sensors and devices, from thermostats in homes, to wristwatches, cars, lights and many other items. Internet connected things can communicate and react with each other, without the need of human intervention. This is creating a truly vast array of networks and sensors, which also may be directly applicable in the agricultural environment (also see sensors review).

Current uses

Current use in agriculture is linked to any sensor connected to the internet, able to produce data which can then be analysed using techniques already discussed under the different data acquisition and analysis technologies. The Oxnard region in California, known for strawberry production, is not only battling water shortages due to the ongoing California drought, but also salinity issues stemming from depleted water sources, saltwater intrusion, urban and agricultural use, and treated water discharged into waterways. In order to maximise efficiencies from an increasingly scarce resource, El Rio Farms implemented a network of sensors in order to monitor soil conditions and implement precision agriculture.

Pal Halstead, Operations Manager at El Rio said their strawberry operation was able to cut water use by about 27%, thanks to precision irrigation practices such as drip irrigation and "smart" soil tension monitoring sensors. The system allows a high level of optimisation in water usage. The system is also able to reduce damage due to frost by automatically activating wind machines should the temperature recorded through sensors, drop below a certain level.

An internet connected soil sensor, source: Edyn.

In South Africa Jozeph du Plessis a grain producer from Schweizer-Reneke in North West, cultivates dryland crops on 3 600ha. He has practised precision farming since 2001. Du Plessis rotates his main crop maize, with soya beans and sunflowers. He started his precision programme with yield monitors and satellite imagery. In 2002 he surveyed his lands on a 1ha grid overlay, mapping the physical properties and chemical status of the soil. Spatial features were digitised with Agleader's spatial management system. Computerised models calculated the potential maize yield using calculated soil water holding capacity. Jozeph replaced low potential areas with pasture. Nutrient levels in each hectare were analysed and built up systematically to optimal levels, which meant that the soil could be used at its true potential.

Du Plessis uses a neutron moisture meter to monitor soil moisture in identified positions before planting. To manage low water content detected on some lands he implements a fallow system. A third of the cultivated area is left fallow for a season to conserve water. The farm also plans to introduce variable planting rates. These innovations have increased average maize yield from 2,98t/ha in 2000 to 7,01t/ha in 2012. Water use efficiency increased from 185mm rain per ton of maize produced to 91mm rain per ton of maize produced, calculated from a mean five-year rainfall.[49]

Future development

Infrastructure

In our report on ICT, we document the upcoming rollout of Low Power Wide Area (LPWA) networks specifically to cater for IoT devices. Such is the importance placed on IoT that Mobile Network Operators are installing low power wireless networks to capture the increasing demand for IoT connectivity. IoT in agriculture is limited by current connectivity in outlying regions. LPWA will go a long way to solving these issues, providing infrastructure that has been specifically designed for IoT to service sensors distributed across farms.

Weather prediction

90% of all crop losses are due to weather. With an IoT platform that can integrate IoT and weather data, farmers would be able to build predictive weather modeling driven by machine learning. This can provide the insights that help farmers to make strategic decisions on planting crops and take necessary actions to prevent the damage caused by extreme weather. With weather data, farmers can then adjust irrigation systems to save water and prevent pesticide waste by predicting rain.[50]

Supply Chain

IBM Research's Precision Agriculture is aiming to help farmers use data to make precise decisions from planting, growing, harvesting, to transporting food. The ability to monitor and track the route of food delivery can not only save food waste but enable food safety. Up to 40% of food is wasted in the U.S., which is estimated to cost approximately $165 billion each year. 50% of the food waste happens during distribution. To define the best route to transport food with the information of weather and all environmental conditions is a critical step to prevent food waste. Moreover, food companies now monitor the production and delivery process to control the quality of food. People can know where their food came from due to the transparent food supply chain.

Disintermediation

By connecting farmers with real-time pricing data, intermediary agents are likely to come under strain as farmers cut out the middleman to unlock better margins by selling directly to retailers. Technology companies such as Aggregator, are building platforms where groups of small farmers can achieve negotiating power through collective volume. By connecting retail outlets with farms and digitizing produce exchanges, this connected network will remove a great deal of friction in the market. This will benefit farmers as they receive better pricing, however, intermediary agents will be severely disrupted as technological innovation increases market efficiency.

9. 3D and 4D Printing

Synergistic technologies

- Food design
- Sensor technology
- Smart materials
- Biofabrication

Definition and application in agriculture

3D printing is used to describe manufacturing that builds products from a 3D design by depositing materials layer by layer. It is also called additive manufacturing, however this term describes a professional production technique which is clearly distinguished from conventional methods of material removal. The type of additive manufacturing method will determine what material is able to be used, but almost anything that can be modelled in 3D and made of plastics, metals or even organic matter. 4D printing adds a fourth dimension to 3D printed objects: movement. It aims to produce objects which shift in shape or change tension in response to an energy source such as heat or movement.[51] It works by 3D printing with multiple materials and embedding movements into the 3D printed object so that with a bit of energy, it pulls itself into shape, much like proteins automatically folding in living cells.

While 3D printing is not currently as directly applicable to farming as other technologies, such as robotics, it is being used in some agricultural operations. Most additive manufacturing methods are used upstream in agricultural equipment manufacturing.[52] 3D printing and 3D printed foods, meats and vegetables could have a large impact on agriculture (refer to biofabrication).

Current uses

Prototyping in agricultural engineering, cost reduction of certain components (zero tooling, re3duced labour and enabling design complexity).

Equipment manufacturers are using 3D printing which has brought down the cost of agricultural machinery and resulted in faster development of new equipment.[53] 3D printed equipment is emerging in the field of hydroponics, with open source equipment and designs used.[54]

The rapid prototyping of tools and replacement parts for farmers in remote areas are also possible. The alternative is parts which would need to be imported at great cost.[55] This also reduce waiting and downtime.

Future development

In future 4D printing would enable self-assembling and repairing products as well as smart materials that are able to perform basic computations. While this technology is not commercially available, good progress is being made in the field.

10. Renewables

Synergistic technologies
- Smart water
- Waste management and recycling

Definition and application in agriculture
One definition of renewables is "any naturally occurring, theoretically inexhaustible source of energy, as biomass, solar, wind, tidal, wave, and hydroelectric power, that is not derived from fossil or nuclear fuel"[56].

Agriculture is intricately tied with energy. Agriculture is responsible for approximately 2.4% of electricity consumption in South Africa[57] and about 3% of global energy consumption[58]. Because of its intensive fossil energy use, global agriculture contributes between 14% and 30% of the world's greenhouse gas (GHG) emissions[59]. Increasing agricultural production will increase emissions which, in turn, will impact the industry negatively. Mitigating climate change may require reducing agricultural production. Agriculture is therefore seemingly faced with a double-edged sword. But agriculture is fortunately capable of also providing solutions. Much potential exists for the generation of energy and production of fuel from agriculture. This chapter will provide an overview of the agriculture-energy nexus.

Firstly, the industry will experience an increased demand for agricultural products for the production of biofuels. Caution, in this respect, should be taken to avoid biofuels to impact on food production. At the same time, renewable energy can reduce the environmental impact of agriculture substantially while also making farming much more competitive.

Cost is of paramount importance in any industry. The declining cost of renewable energy is therefore a major driver for the increased adoption of the technologies. Many farmers make use of diesel engines to provide electricity on their farms. In many instances, renewable sources can reduce the need for diesel fuel and hence reduce costs substantially.

Current uses
Many renewable energy technologies are well suited for smaller installations as would be the case in agricultural applications, regardless of whether it is at large or small-scale farming. Technologies that are worthwhile in terms of cost savings are the following technologies:

Micro wind - Wind energy is one of the oldest renewable sources of energy. Wind pumps have been used extensively by farmers in drier regions of South Africa to pump water for animals from underground sources. Micro wind is very easy to set up, and typically can operate with very low wind speeds. Most of the Western Cape is suitable for wind energy (refer to accompanying review). Wind energy has many benefits. In a water scarce environment, it is important to note that wind energy does not require any water to operate. Wind energy also has low operational costs, although it is not as low as for solar PV. Furthermore, wind energy is the energy technology with the quickest energy payback, meaning it offsets the energy that it took to make the turbine in the shortest time. Lastly, wind energy is old technology, and hence micro-wind turbines can be serviced and repaired by most people with a rudimentary understanding of electric dynamos/ motors. Unfortunately the benefits of wind energy are offset by the disadvantages. Without battery backup, wind energy is unable to provide uninterrupted energy, or dispatchable (i.e. can be turned on or off, or can adjust their power output accordingly to an order) energy. This makes it unsuitable for applications that need a constant supply of power such as lighting or refrigeration. Battery backup is becoming cheaper, making wind energy ideal for applications that has sufficient wind but no grid connection.

Solar Photo-Voltaic (Solar PV) - Agriculture is the second biggest non-utility-scale user of solar PV in South Africa. In November 2016, Greencape[60] found the total capacity of PV to be just over 30 MW. Adoption of PV in all sectors were driven by, amongst other factors, the electricity shortages in 2015. Agri-businesses like dairy need a constant and stable supply of energy and are severely impacted by power outages[61]. The Northern Cape and Western Cape have very high levels of solar irradiation, making it ideal for solar energy applications such as solar PV. It should be noted that extreme heat is counterproductive for solar PV as the efficiency of panels decline at very high temperatures[62]. Solar PV is an ideal solution for applications that require energy at daytime or when it is hot (such as cooling for warehouses and packhouses) or applications where the time of use is unimportant and only required for some hours of the day (such as pumps to fill water-troughs). One study found that solar PV on an apple packhouse resulted in a 15 per cent saving on electricity[63]. Although a diesel-driven water pump is cheaper than a PV-based alternating current (AC) pump, diesel pumps are expensive to maintain and require constant monitoring and refuelling. PV pumps can easily be controlled through smart-phone technology and requires little additional attention. One issue with PV-pumps though is that the pump should not run without water for any extended period. Solar pumps are ideal for arid areas.

The saving attainable through the use of solar PV and other renewables will continue to increase with declining cost of PV, and the increase in the price of electricity from Eskom (see accompanying review). Solar PV is not a mature technology like hydro, and costs are expected to continue declining. Smaller systems are more expensive, but have typically the same components. Once installed, solar PV has the lowest maintenance expenses of any renewable energy technology. The fact that it has no moving parts, means that the only maintenance that remains is to clean the panels sporadically (a bigger expense in drier regions). Unless the panels are cleaned with water, solar PV requires no water. On the downside, solar PV requires space. Panels do not work in the shade, which implies that panels must be set so that the panels do not cause a shadow on other panels. Fortunately, agricultural environments usually have space available on shed rooftops or in unused fields.

Although solar PV is also more predictable than wind, without battery backup, it is restricted to providing electricity only in daytime. Hence, electricity production from solar is much lower in winter than in summer, reinforcing the early point that it is ideal for cooling (not needed in winter). There is however already a narrowing cost difference between PV with and without battery storage. Battery storage allows a much wider array of applications of solar PV, such as security lights, power supply for computer systems and heating applications. However, it should be noted that heating needs should ideally be met with solar thermal applications.

Solar thermal - solar thermal installations are a relatively low-tech but high efficiency technologies. Solar thermal technologies include many different technologies, but it typically involves the heating of water, which in turn may be used for food processing, greenhouse heating or even for under-floor heating. But solar thermal application also includes solar fruit driers, space heating and sometimes also cooling. Solar thermal is a broad term that is used to describe application that produce heat rather than electricity.

Solar water heating (SWH) or solar geyser systems often use panels (or collectors) through which water circulates. The warm water can then be used for applications that require hot water. SWH systems can also be used for pre-heating of water where steam may be needed. SWH technology is a mature technology and is well understood (compared to PV). There are therefore many providers of technology, and the cost is much lower for heating than it would be if one would use solar PV to heat water. In that respect, solar thermal collectors are far superior.
A second and similar technology uses mirrors to heat water or another carrier for the energy in order to provide steam. This is sometimes referred to as Concentrated Solar Power (CSP). However, CSP is often expensive and requires scale. It is therefore not suitable for smallholding farmers.

Solar thermal applications have relatively short payback periods, but this could depend on the supplier, the particular technology, etc. However, it must be said that the low technical knowledge required for solar thermal means that it holds far greater potential for job creation among previously disadvantaged communities. Maintenance for solar thermal systems may vary, but it would typically be higher than that of solar PV due to the presence of water. At the same time, the low tech need for maintenance services could be a significant job creator in rural areas. A further future application of solar thermal energy is for desalination of seawater. As with the previous example, desalination can be done during daytime and does not require an uninterrupted source of electricity. A greenhouse in Australia will produce 15 000 tonnes of tomatoes using no soil, pesticides, fossil fuels or groundwater[64].

Biomass - agriculture is both a potential producer and consumer of biomass-based energy. Energy can be extracted from biomass in a number of ways, and can be delivered in a number of forms (refer to accompanying review), i.e. bio-digester applications.

Heat pumps and exchangers - heat pumps and heat exchangers are often also mentioned as renewable energy technologies. These technologies extract heat from one environment and release it into another. Such technologies can therefore either heat or cool a space or water. Heat pumps are regarded as more efficient for heating than pure solar technologies and it does not require sunshine, but rather uses ambient heat. However, heat pumps still require electricity to operate, unlike some solar geysers.

Micro hydro (also refer to Smart Water section) - micro-hydro represents a relatively poorly exploited renewable energy technology in South Africa. Yet, micro-hydro provides reliable and despatchable power at a price that competes well with solar and wind[65]. The Western Cape has some of the best resources for hydro-power in South Africa (refer to accompanying review). The capacity for a stream to generate hydro-power is based on the flow and drop in the stream at the point of generation. An increase in either variables increases the potential.

Storage technology - one of the biggest criticisms against wind and solar energy is the intermittent nature of supply. Storage capacity and the economics of storage plays a major role. Combining renewable technologies with deep cycle lead-acid batteries enable the expansion of potential uses. Such applications could include water pumps, security lights, electrical fences, communication, and remote control and monitoring.

Partnering with Independent Power Producers (IPPs) - one last aspect of energy to consider in the agricultural sector is the role played in providing space for Independent Power Producers (IPPs) on farm-land. Apart from generating their own power, farmers can earn substantial rent from IPPs that require sites with particular characteristics.

Future development

Most of the previously mentioned technologies are in the early adoption phase, and set to develop in future as costs are driven down.

11. Smart Water

Definition and application in agriculture

Water technology has a significant role to play in alleviating some of the impacts of the drought in agriculture. The 4th IR could potentially greatly increase water efficiency and productivity, and alleviate some of the impacts of the current drought. This piece identifies available climate-smart agricultural technological innovations in the Western Cape, evaluates their potential for addressing the ensuing water crisis and explores how they might affect water use in agriculture in the future.

Top Nine Smart Water Technologies for Western Cape Agriculture

Item	Rank	Comment
Remote Sensing	1	Access to information
Smart monitoring of water	2	Reduces waste
Cell phones for weather forecasts	3	Provide useful information to even small holders
Seasonal hydrological forecasting	4	Very important for water budgeting
Unmanned aerial vehicles (UAVs)	5	Detects problems normally not visible
Intelligent irrigation	6	Reduce water use and management costs
Solar power for irrigation	7	Reduces cost of irrigation significantly
Aquifer recharging	8	Vulnerable to contamination
Waste water treatment technologies	9	Still too expensive

Current uses

Remote Sensing - *t*he FruitLook project is reviewed in the accompanying piece, but there are also many other platforms (i.e. Sentinel satellite data or UAV survey data) that can be very useful in reducing irrigation, but also potentially to monitor water resources.

Smart Water Monitoring

Water is lost every day in developing countries through aging infrastructure in agriculture. Leaks not only cause water loss but also increase the likelihood of pollutants contaminating the water. Existing water meter solutions are often manually read by officials, and the information takes long to be recorded. There are feedback delays by several weeks. Smart meters address these challenges by allowing for electronic and real-time metering[66].

Monitoring technologies can go a long way to improve the integrity of water supply networks. Electronic instruments, such as pressure and acoustic sensors, connected wirelessly in real time to centralised and cloud-based monitoring systems can detect and pinpoint leaks quickly. Many water meters are now able to communicate with the municipality or user, monitor Consumption patterns, dispense prepaid water and provide leakage alerts[67].

Some of the drawbacks of implementing this technology are the costs of importing the technology. Cellular meters are seen as the most viable in Africa because it is able to

Synergistic technologies

- Climate/weather
- Smart farming
- Renewables
- Waste management and recycling

meter without traditional network infrastructure or traditional manual reading. GreenCape also argues that there is a strong case for developing water companies with business models that incorporate audits and monitoring, shared savings, capital investment solutions for technology and smarter utility management[68].
A different type of smart metering technology in the South African agricultural water sector is the Water Administration System (WAS)[69]. This system, which has been developed over nearly two decades, simplifies water release calculations with the use of smart loggers, connected to an internet platform. This reduces water losses and the overall demand of the irrigation scheme, which improves water availability at catchment level. It also as a result improves financial management of the scheme.[69]

Cellphones for Weather Forecasting
Information Communication Technology can alleviate some of the costs of supplying water infrastructure in Africa. Basic mobile phones have been used provide farmers in Africa with daily information on effective agricultural practices, market prices and weather forecasts using text and voice messages[70]. In semi-arid areas, small farmers especially are confronted with difficulties in selecting crops in response to different weather conditions. Total crop failure can have devastating consequences for their futures. Having information about the expected weather conditions, helps them to be better informed about the upcoming season and plan what crops they want to grow[71].

More advanced phone-based information systems have also been developed in South Africa to give farmers access to everything from weather forecasts, to advice about seeds, fertilisers, crop information etc, at the touch of their fingertips (see for example http://www.manstratais.co.za). This type of technology is useful for extension officers, but is generally either still too expensive, or not refined enough for farm-level use[72].

Unmanned Aerial Vehicles (UAVs)
UAVs are reviewed elsewhere, but just to mention here that applications can vary from routine checks of dam levels and suspected water leaks, to the monitoring of crop fields with high spatial and temporal resolution remote sensing.

Intelligent Irrigation
Many intelligent irrigation systems have been developed with Water Research Commission funding over the past 4 decades in South Africa. There are soil-based approaches, atmospheric-based approaches through biophysical modelling of the soil-crop-atmosphere system, thermodynamic limits to the amount of water that can evaporate from a cropped surface under particular environmental conditions and modelling approaches that are more mechanistic, generic or crop specific, with pre-programmed (e.g. irrigation calendars) or real-time output[73].

Drip Irrigation is one that has taken off in the Western Cape. It works from the philosophy that plants only need a few regular drips direct to the root system. Each plant gets exactly the right amount of water that it needs in the right location. The savings on water, costs and on the devastating effects of drought, is potentially large[74].

The Chameleon soil moisture sensor and the FullStop wetting front detector are two other intelligent irrigation tools that are being explored in Sub-Saharan Africa. The first represent soil water, nitrate and salt levels in the soil by displaying different colours. The second provides an indication of over irrigation and an opportunity to assess the water quality leaving the root zone.

These tools form the basis of an experiential learning system for small-scale irrigators. Manufactures said farmers quickly learned from the tools and changed their management within a short time. The cost of implementing a learning system was expected to be small fraction of building or revitalising irrigation schemes[75].

Seasonal Hydrological Forecasting
South Africa's dependence on dam-based storage of water, coupled with its variable climate, underlines the importance for seasonal forecasts of water resources (predictions of climate and water resources issued three to six months into the future), and the mainstreaming of these forecasts into water resources management.

Ensemble hydrological predictions are normally obtained by combining hydrological models with ensembles of atmospheric forecasts produced by numerical weather prediction models. To be of practical value to water users, such forecasts should not only be sufficiently skilful, they should also provide information that is relevant to the decisions end users make [76].

The cosmic ray probe, an above-ground sensor, uses the low-energy cosmic-ray neutrons above soil level to detect moisture as deep as 0,5 m over a 34 ha footprint. It is understood that soil moisture estimates are useful for predicting weather, modelling climate and mitigating disaster. The development of the probe has enabled the measurement of soil water at big enough scales to validate weather modelling. A cosmic array network is expected to improve the quality of soil moisture data used by the SA Weather Service in its national Flash Flood Guidance (FFG) system[77].

Solar Power for Irrigation (also refer to renewable energy)
The use of renewable energy sources has the potential to decrease the cost of irrigation. A recent study looked at maize production from cultivation and concluded that replacing grid electricity with renewable energy in irrigation significantly reduced costs and environmental impacts of South African maize production[78].

PV-powered water pumping technologies are useful because they require almost no maintenance over the course of the lifetime of the technology. One of the drawbacks of the technology are, however, that initial investment costs are high and sometimes too much to bear for small-scale farmers. If the requirements of the crop are understood and an extensive site survey is done to analyse the working conditions of the system, then cost savings are said to be easier to achieve. The high cost and imported nature of PV technology are thought to be overcome by solar thermal water pumping technologies that have greater possibility of local production, low investment cost, easy maintenance and lower carbon footprint[79].

Aquifer Recharge
Managed aquifer recharge as a water management technology for agriculture has some key advantages, i.e. it reduces evaporation. Managed aquifer recharge is the prime use of water quality management in Atlantis, on the West Coast of the Western Province. The layout of the town allows for the separation of storm water from the residential and industrial areas as well as separate treatment of domestic and industrial wastewater. This permits safe artificial recharge of the various water quality portions at different points in the aquifer, either for recycling or for preventing seawater intrusion[80]. However, aquifers in South Africa are vulnerable to pollution because most usable groundwater is found within 60 metres below the surface and 80 percent of South Africa's aquifers are fractured, making them porous[81].

Waste Water Treatment Technologies
Waste water treatment technologies are an important source of additional

water in times of drought. However, in agriculture, due to the volumes of water and the distance from sources of contaminated water required, they are often prohibitively expensive. In the accompanying review, desalination[82], nanotechnology, phycoremediation and phytoremediation are all discussed.

Future development

All of the smart water technologies discussed in this chapter are theoretically useful to reduce water stress in agriculture in the Western Cape within the next decade. Their overall impact in the end, however, will be largely qualified by four key factors, the affordability of the technology, its geographical viability, how complicated the technology is for farmers to use and the perceived risks that it presents to society at large.

Remote sensing technology in the Western Cape that is available for free for fruit-farmers is a highly effective technology because it is cost effective and easy to use. It provides farmers with free access to satellite information about how well their crops are growing and how much water they are using. Cellular technology, in terms of its application in smart water monitoring and weather forecasting, has the potential to go the same way by providing both large and small farmers with early warning systems to adapt to unforeseen events.

Drones or Unmanned Aerial Devices, on the other hand are a more expensive technology that requires a high level of discernment and training to interpret the data at a farm level. If this can be simplified and made more accessible, it could vastly extended the management capabilities of farmers, enabling them to detect problems not normally visible to the human eye.

A number of intelligent irrigation systems have been devised ranging from the drip system to the soil water sensors, that if implemented can potentially reduce water use significantly in agriculture. Researchers, however, emphasis the need to improve the user-friendliness of these various systems to ensure take up by farmers.

Water treatment technologies in agriculture have not yet taken off, for various reasons. With regards to desalination, the cost of the electricity required to run such plants is prohibitive. The introduction of solar energy desalination has the potential to make this technology much more cost effective within an agricultural context.

Nanotechnology is still perceived as high risk to the possibilities of nanoparticles escaping and contaminating water in farming. The relatively high cost of implementing the technology is another barrier. Similarly, managed aquifer recharge is seen as high risk in South Africa because most are just 60 metres below the surface and are located in fractured porous rock.

12. Nanotechnology

Definition and application in agriculture

Nanotechnology is the engineering of functional systems at the molecular scale. In its original sense it refers to the projected ability to construct items from an atomic level up using techniques and tools being developed today to make complete, high performance products[83]. It is generally accepted to be technologies at the scale of 1-100 nanometers. One nanometer is a billionth of a meter, or 10^{-9} of a meter (a sheet of newspaper is about 100,000 nanometers thick and if a marble was 1 nanometer, a meter would be the size of the earth.

Agriculture	Food Processing	Food Packaging	Supplements
• Single molecule detection to determine enzyme/ substrate interactions • Nanocapsules for delivery of pesticides, fertilizers and other agrichemicals more efficiently • Delivery of growth hormones in a controlled fashion • Nanosensors for monitoring soil conditions and crop growth • Nanochips for identity preservation and tracking • Nanosensors for detection of animal and plant pathogens • Nanocapsules to deliver vaccines • Nanoparticles to deliver DNA to plants (targeted genetic engineering)	• Nanocapsules to improve bioavailability of neutraceuticals in standard ingredients such as cooking oils • Nanoencapsulated flavor enhancers • Nanotubes and nanoparticles as gelation and viscosifying agents • Nanocapsule infusion of plant based steroids to replace a meat's cholesterol • Nanoparticles to selectively bind and remove chemicals or pathogens from food • Nanoemulsions and –particles for better availability and dispersion of nutrients	• Antibodies attached to fluorescent nanoparticles to detect chemicals or foodborne pathogens • Biodegradable nanosensors for temperature, moisture and time monitoring • Nanoclays and nanofilms as barrier materials to prevent spoilage and prevent oxygen absorption • Electrochemical nano-sensors to detect ethylene • Antimicrobial and antifungal surface coatings with nanoparticles (silver, magnesium, zinc) • Lighter, stronger and more heat-resistant films with silicate nanoparticles • Modified permeation behavior of foils	• Nanosize powders to increase absorption of nutrients • Cellulose nanocrystal composites as drug carrier • Nanoencapsulation of neutraceuticals for better absorption, better stability or targeted delivery • Nanocochleates (coiled nanoparticles) to deliver nutrients more efficiently to cells without affecting color or taste of food • Vitamin sprays dispersing active molecules into nanodroplets for better absorption

Current uses

In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition. In the "top-down" approach, nano-objects are constructed from larger entities without atomic-level control, similar to additive vs subtractive manufacturing (see 3D printing) (See the figure for use cases in agricultural industries (source: Nanowerk).

Agricultural use cases typically involve the shrinking of current applications of plant protection products, minimize nutrient losses in fertilization, and increase yields through optimized nutrient management[84]. Other uses which offer promise is in IoT and sensor technology, where nanosensors can be used to optimise farming conditions as discussed in the AI and Machine Learning sections.

The development of intelligent nanosystems for the

Synergistic technologies

- Robotics
- Smart materials
- Biofabrication

immobilization of nutrients and their release in soil may help to minimise leaching and improve uptake. Nano materials could improve structure and function of pesticides by increasing solubility, enhancing resistance against hydrolysis and photodecomposition, and/or by providing a more specific and controlled-release toward target organisms.[85]

There are already soil-enhancer products that promote even water distribution, storage and consequently water saving[86]. It appears if high costs involved in developing nanotechnology restricts large scale commercial adoption by farmers due to the lower margins achieved in agriculture.

Future development

Further from textile advances which may benefit agriculture as well, medicinal and computing advances in future, it seems that a cost reduction of the useful applications for agriculture may be the best advancement for the future of these technologies in agriculture.

13. Bioinformatics

Synergistic technologies

- Smart farming
- Genetics
- Sensor technology
- IT and IT Infrastructure

Definition and application in agriculture

Bioinformatics is both an umbrella term for the body of biological studies that use computer programming as part of their methodology, as well as a reference to specific analysis "pipelines" that are repeatedly used, particularly in the field of genomics. Common uses of bioinformatics include the identification of candidate genes and nucleotides (SNPs). Often, such identification is made with the aim of better understanding the genetic basis of disease, unique adaptations, desirable properties (especially in the agricultural species), or differences between populations. In a less formal way, bioinformatics also tries to understand the organisational principles within nucleic acid and protein sequences, called proteomics[87]. The field of bioinformatics has evolved such that it now primarily involves the analysis and interpretation of various types of data. This includes nucleotide and amino acid sequences, protein domains, and protein structures[88].

The genome sequencing of the plants and animals has also provided benefits to agriculture. Tools of bioinformatics are playing significant role in providing the information about the genes present in the genome of these species. These tools have also made it possible to predict the function of different genes and factors affecting these genes. The information provided about the genes by the tools makes the scientists to produce enhanced species of plants which have drought, herbicide, and pesticide resistance in them. Similarly, specific genes can be modified to improve the production of meat and milk. Certain changes can be made in their genome to make them disease resistant.

Bioinformatics has become an important part of many areas of biology. In experimental molecular biology, bioinformatics techniques such as image and signal processing allow extraction of useful results from large amounts of raw data. In the field of genetics and genomics, it aids in sequencing and annotating genomes and their observed mutations. It plays a role in the text mining of biological literature and the development of biological and genetic data to organize and query biological data. It also plays a role in the analysis of gene and protein expression and regulation. Bioinformatics tools aid in the comparison of genetic and genomic data and more generally in the understanding of evolutionary aspects of molecular biology. At a more integrative level, it helps analyse and catalogue the biological pathways and networks that are an important part of systems biology. In structural biology, it aids in the simulation and modelling of DNA, RNA and protein[89,90,91] , including biomolecular interactions[92,93,94] .

The sequencing of the genomes of plants and animals will provide enormous benefits for the agricultural community. Bioinformatics tools can be used to search for the genes within those genomes that are useful for the agricultural community and to elucidate their functions. This specific genetic knowledge could then be used to produce stronger, more drought, disease and insect resistant crops and improve the quality of livestock making them healthier, more disease resistant and more productive.

Current uses

Crop breeding. Insect Resistance. Improved Nutritional quality. Plant-pathogen interactions. Better understanding of and interaction with agriculturally important microorganisms. Animal production and animal health. Control of infectious diseases in animals.

Future development

Improvement for plant resistance against biotic and abiotic stresses. Weather prediction Increased cultivation of crops in poorer soils. Renewable energy applications. Faster detection of disease outbreaks at an early stage globally (not limited by geography). Faster elucidation of causes of disease outbreaks. Risk analysis or a prediction of the future.

14. Aquaculture

Definition and application in agriculture

Aquaculture, (also known as fish or shellfish farming) refers to the breeding, rearing, and harvesting of plants and animals in all types of water environments including ponds, rivers, lakes, and the ocean. Researchers and aquaculture producers are "farming" all kinds of freshwater and marine species of fish, shellfish (crustaceans), molluscs, algae (phytoplankton, microphytes, or planktonic algae) and aquatic plants. Aquaculture produces food fish, sport fish, bait fish, ornamental fish, crustaceans, molluscs, algae, sea vegetables, and fish eggs.

Aquaculture includes the production of seafood from hatchery fish and shellfish which are grown to market size in ponds, tanks, cages, or raceways. Stock restoration or "enhancement" is a form of aquaculture in which hatchery fish and shellfish are released into the wild to rebuild wild populations or coastal habitats such as oyster reefs. Aquaculture also includes the production of ornamental fish for the aquarium trade, and growing plant species used in a range of food, pharmaceutical, nutritional, and biotechnology products[95].

Current uses

Recirculation systems or closed fish systems (energy-efficient and produce less waste)

Future development

Increased interest in the re-use of residual flows, such as the remains of processed fish products, offal and shells of mussels and oysters; Advanced water purification systems with no required for the addition of chemicals. The further intensification of aquaculture due to the application of advanced biotechnology

Synergistic technologies

- Biorefinery and biofuels
- Synthetic biology
- Genetics
- Protein transition
- Sensor technology
- Renewable energy

15. Biorefinery and biofuels

Definition and application in agriculture
Biorefining is the sustainable processing of biomass into a spectrum of marketable bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat)"[96]. By producing several different products, a biorefinery makes use of the various components in biomass as well as their intermediates therefore maximizing the value derived from the biomass feedstock through several bio-processes. A biorefinery could, for example, produce low-volume, but high-value, chemical or nutraceutical products, and a low-value, but high-volume liquid transportation fuel such as biodiesel or bioethanol through a conversion process[97].

Current uses
Starch Based Biorefineries: Wet & Dry Mills; Increase ethanol production by access to residual starch & increased protein in co-products; Fractionation of the feedstock to access the high value products prior ethanol production; Fractionation of residues in Dry Mills for new co-products from lignin; Fractionation of grain and residues, introduction of energy crops in dry mills.

Future development
Integrated Industrial Biorefinery: multiple feedstocks fractionated to high value products for economics and fuel production drive scale. Products are chemical intermediates, solvents, plastics, bio-plastics, building blocks for construction, adhesives, paints, dyes, pigments, identification of new microorganisms, new genes and enzymes from the microbial biodiversity for carbon flux manipulation, increase in substrate uptake, tolerance of toxic substances, and generation of new compounds Use of algae to produce fuel; refining of water; refining of waste water and manure into high-value products[98].

Synergistic technologies
- 3D printing
- 4D printing
- Smart materials
- Genetics and Biotechnology
- Nanotechnology
- Sensor technology
- Transport technology

16. Conservation technology (food preservation technology)

Definition and application in agriculture

Food preservation is a process of maintaining the original quality or existing state of food by treatment(s) that will prevent its spoilage or deterioration[99]. It implies putting microorganisms in a hostile environment to cause their death[100].

The term **food preservation** refers to any one of several techniques used to prevent food from spoiling. The following are the general methods of food preservation:

- **application of heat**, such as canning and preserving, pasteurization, evaporation, sun-drying, dehydration and smoking;
- **application of cold**, as ill cold storage, refrigeration and freezing;
- the **use of chemical substances** such as salt, sugar, vinegar, benzoic and lactic acids;
- **fermentation**, examples being acetic, lactic, alcoholic;
- such **mechanical means** as vacuum, filtration and clarification processes, devices or agents for preventing chemical deterioration or bacteriological spoilage (the use of oil, paraffin and water glass are included here);
- **natural preservation** techniques;
- **controlled atmosphere** techniques (containers);
- **combinations** of two or more of the above.

Current uses

The main benefit of conservation the application of food conservation technologies the inactivation of food-borne pathogens, natural toxins and enzymes as is normally required by Food Safety Legislation in all jurisdictions of the globe. Other key benefits of food conservation extracted from the literature are:

- To facilitate improved digestibility and bioavailability of nutrients (increase nutritional value);
- To improve sensory quality, such as taste, texture and flavour for the consumer;
- To exploit the functional health benefits of food, and gain access to the benefits of probiotics, prebiotics, Maillard reaction products (MRPs), flavonoids, for example;
- To introduce diversity into diets, and reduce dependence on the seasonal availability of foods;
- To reduce time to prepare and supply food to the market[101]

Future development

One-person food packages, and 3-D printing of food.

Synergistic technologies

- 3D printing
- 4D printing
- Genetics
- Synthetic biology
- Metabolomics
- Proteomics

17. Food design

Definition and application in agriculture

The term Functional Foods was first introduced in Japan in the mid-1980s and refers to processed foods containing ingredients that aid specific bodily functions in addition to being nutritious. Functional foods may therefore be defined as "*Natural or processed foods that contains known or unknown biologically-active compounds; which, in defined, effective non-toxic amounts, provide a clinically proven and documented health benefit for the prevention, management, or treatment of chronic disease*"[102], *and can be classified into three groups, namely: a) Functional foods that naturally contain a component that offers additional benefits to the consumer. b) Processed foods in which a component is added to the food to give it additional benefits c) Food in which the nature of the functional ingredients has been altered.*

Current uses

Products with less fat, sugar or salt without affecting the taste, structure and (eating) experience;
Products with a different structure, e.g. less grainy or easier to chew;
Products with a specific aesthetic attraction, e.g. smell, shape and colour, so that food becomes a different (eating) experience.

Future development

3D printing may enable households to design their own food, and print it;
Units of nutrients (cubes, gel or powder);
Personalised foods (based on nutrigenomics, which investigates the interaction between diet and development of diseases, derived from an individual's genetic profile)

Synergistic technologies

- Genetics
- Bioinformatics
- Waste management and recycling
- Synthetic biology

18. Genetics

Definition and application in agriculture
Genetic engineering, also called genetic modification, is the direct manipulation of an organism's genome using biotechnology. It is a set of technologies used to change the genetic make-up of cells, including the transfer of genes within and across species boundaries to produce improved or novel organisms. New deoxyribonucleic acid (DNA) is obtained by either isolating and copying the genetic material of interest using molecular cloning methods (DNA or RNA techniques) or by artificially synthesizing the DNA either randomly, or targeted to a specific part of the genome. A construct is usually created and used to insert this DNA into the host organism, or directly through micro-injection, macro-injection and micro-encapsulation techniques. As well as inserting genes, the process can also be used to remove, or "knock out", genes.

An organism that is generated through genetic engineering is genetically modified (GM) and the resulting entity is a genetically modified organism (GMO). Genetic engineering therefore alters the genetic make-up of an organism. The resulting organism is called transgenic. If genetic material from the same species or a species that can naturally breed with the host is used the resulting organism is called cis-genic.[103]

Agricultural genetics is the applied study of the effects of genetic variation and selection used to propagate desired and useful traits in animals and crops. These traits can be inherited by subsequent generations of crops and animals, to ensure continued benefit. The discipline of agricultural genetics uses genetic markers to guide this breeding.

Current uses
Insect resistance;
Herbicide tolerance;
Virus resistance;
Delayed fruit ripening;
Foods with improved nutritional value;
Increased profits;
Use of marginalised land;
Tolerance to biotic and abiotic stresses;
Pharmaceuticals and vaccines from transgenic plants;
Genetic modification of animals
Applications in technology development for research purposes (Molecular diagnostics, Tissue culture and Genetic engineering).

Future development
Improved abiotic stress (e.g. water efficient maize).
GM crops specifically developed for small-scale farmers.
Crops with enhanced nutritional content, e.g. sorghum with increased levels of lysine, Vitamin A, iron and zinc.
Crops with increased yields.
Weed & insect control.
Human vaccine production and antibodies in plants.
Animal gene modification

Synergistic technologies

- Synthetic biology
- Biorefinery and biofuels
- Protein transition
- Food design
- Bioinformatics

19. Protein transition

Definition and application in agriculture
Protein transition has become synonymous with meat substitutes, in response to population explosions, environmental concerns around global warming due to, amongst other methane gas production by animals and the prediction of a global population of 9.5 billion people by 2015[104].
The current average meat consumption is 42 kg per person per year globally[105], indicating that that the meat production sector has expanded 3-fold since 1960, and is expected to reach a demand of 300 million metric tons in 2020[106].

According to the World Bank[107], the demand for meat around the globe is projected to increase by 56% between 1997 and 2020[108]. Meat demand in the developing world is projected to rise from 65 million tons in 1995 to 170-200 million tons in the year 2020[109]. According to a prediction by the FAO[110], the consumption of meat in the year 2030 could be as high as 100 kg per person per year in developed countries[111]. It was also projected[112] that the total amount of meat consumption around the world may be 72% higher in 2030 than consumed in 2000 following current consumption patterns[113].

There are three broad categories of alternatives to meat:

I. Meat alternatives – protein sources identified and used as meat alternatives include plants and fungi (mycoproteins)[114].
II. Cultured meat, or *in vitro* meat – meat derived from tissue and cells grown in a laboratory setting[115,116].
III. Genetically modified organisms - animals that have had their genome artificially altered in the laboratory
Cloned animals are possibly a fourth category of artificial meat. This report will focus on cultured meat, or *in vitro* meat.
Replacing meat from livestock with meat cultures in laboratories involves involves growing protein cells from a culture of animal stem cells, or the whole muscle is synthesised *de novo* in a laboratory. The principles of tissue engineering are applied.

Current uses
Currently at research stage:
Insect burgers and vegetarian 'butcher' meat already on the market (these products look like meat, but are made from the proteins of mushrooms, soya or dairy products.
Chicken nuggets and croquettes - contain a mix of meat and 'alternative proteins'.
Meat Substitutes from plants and mycoproteins

Future development
GMO cloning of meat (animals that are genetically modified to produce food and feed).
Diet makeovers, i.e. insect-based protein diets.
Artificial meat based on cell and tissue culture cells produced at commercial scale.

Synergistic technologies

- 3D printing
- Genetics
- Synthetic biology
- Aquaculture
- Renewable energy

20. Synthetic Biology

Definition and application in agriculture

Synthetic Biology (SB) is the design of biological systems and living organisms using engineering principles, with the objectives of (1) contributing to basic research on the fundamental mechanisms of life itself (2) deploying biology as a technology for constructive purposes and (3) extending or modifying the behavior of organisms and engineer them to perform new tasks [117,118,119]. In achieving its objectives, SB combines scientific disciplines and is generally understood to involve the deliberate design of biological systems, using standardized components that have been created in a laboratory[120]

SB goes beyond the transfer of pre-existing individual genes, encompassing a broader range of genetic engineering strategies, from the tinkering of the genetic code itself to the complete synthesis of microorganisms, including the design of novel proteins and metabolic pathway engineering. Depending on their specific objectives, the engineering effort of SB projects may focus on different scales: DNA regulatory elements, genes/proteins, genetic circuits and metabolic pathways, whole genomes, cells or even larger systems such as microbial consortia[121]. Two different approaches may be distinguished: the modification of existing cells, or the complete construction of artificial systems.

The major enabling technologies are (i) DNA synthesis (a topic covered elsewhere in another report in this project), (ii) and DNA sequencing (iii) DNA amplification (iv) computational modelling (iv) reconstruction and (v) the ability to model and design genetic circuits and metabolic pathways, and (vi) measurement[122].

Current uses

Biomass yield increase (although still sub-optimal).
Speciality chemicals synthesis.
Biosensor applications, biomaterials, plastics and textiles.
Multi-enzyme pathways for the in vitro production of complex fine chemicals such as unnatural monosaccharides for the pharmaceutical industry

Future development

New crops with desirable traits such as salt-tolerance, drought-tolerance, and pest-resistance;
By manipulating genes, brand-new foods can be created with new properties or flavours;
Development of new gene-delivery technologies will enable the development of new seed products with multiple genetic traits;
New types of pesticides which are environmentally friendly;
Optimised seed stocks to produce effective crops in difficult and complex environmental conditions;
Man-made cells that are capable of self-assembly and self-repair and able to reproduce;
Synthesis of micro-organisms with novel traits;
Integration of novel feedstocks with novel processes development of enzymes which can break down a much wider range of biomass into useful forms;
Development of plants whose whole biomass is readily convertible;

Synergistic technologies

- Genetics
- Bioinformatics
- Biorefinery and biofuels

Reduction of CO_2 levels by the development of artificial leaf technology.

21. Vertical Agriculture

Definition and application in agriculture
Controlled Urban Agriculture (CUA), or Controlled Environment Agriculture (CEA) includes any form of agriculture where environmental conditions (such as, light, temperature, humidity, radiation and nutrient cycling) are controlled in conjunction with urban architecture or green infrastructure[123].

Vertical farming can be defined in general terms as a system of commercial farming whereby plants, animals, fungi and other life forms are cultivated for food, fuel, fibre or other products or services by artificially stacking them vertically above each other, such as in a skyscraper (multi-storeyed building), used warehouse, or (stacked) shipping container(s). The concept anticipates the cultivation of fruits, vegetables, medicinal, fuel producing plants and other plant products in the cities and their sales directly within the cities, thereby reducing the transportation costs and efficient utilization of land and water resources[124] .

More modern versions of vertical farming use indoor farming techniques and Controlled-Environment Agriculture (CEA) technology, where all environmental factors are controlled, using sophisticated IT (Information Technology) platforms. These facilities utilize artificial control of light, in particular LED lighting, environmental control (humidity, temperature, gases) and fertigation. Some vertical farms use techniques similar to greenhouses, where natural sunlight can be augmented with artificial lighting and metal reflectors[125] to manipulate plant physiological processes.

Current uses
Continuous crop production - Vertical farming technology can ensure crop production continuously throughout the year in non-tropical regions, in an efficient manner, superior to that of land-based farming irrespective of the environmental conditions. In vertical farming, the growing cycles are consistent and reliable, allowing commercial growers to commit to delivery schedules and supply contracts. In terms of quantity, a single indoor acre (0.41 hectares) of a vertical farm may produce yield equivalent to more than 30 acres (12.1 hectares) of farmland, when the number of crops produced per season is considered. The land productivity of vertical farming is more than twice as high and faster as traditional agriculture. For the same floor area, vertical eco-farm systems multi-level design provides nearly 8 times more growing area than single level hydroponic or greenhouse systems or open field system[126].

Future development
Adaptive LEDs
Water purification and desalination
Vertical agriculture will allow production much closer to the consumer, thus cutting transport cost.
Big data capabilities (linear programming, non-linear optimization, machine-learning, artificial neural networks, cluster analysis.
Atmospheric capture of water.
Super seeds.

Synergistic technologies
- IT & IT infrastructure
- Smart farming
- Sensor technology
- Aquaculture

22. Waste management and recycling

Synergistic technologies

- Bio-refinery and bio-fuels
- Renewable energy

Definition and application in agriculture

Waste can be described as any matter, whether gaseous, liquid or solid, originating from any residential, commercial or industrial area, which is superfluous to requirements and has no further intrinsic or commercial value[127].

In South Africa, the Department of Environmental Affairs defines waste as:

"… any substance, whether or not that substance can be reduced, re-used, recycled or recovered:

- *That is surplus, unwanted, rejected, discarded, abandoned or disposed of*
- *Which the generator has no further use of for the purposes of production*
- *That must be treated or disposed of"*

Agricultural wastes can be defined as the residues from the growing and first processing of raw agricultural products such as fruits, vegetables, meat, poultry, and crops. This includes natural (organic) and non-natural wastes produced from arming activities such as dairy farming, horticulture, seed growing, livestock breeding, grazing land, market gardens, nursery plots and forestry.

The agricultural waste can come in several forms, such as slurries or sludge, solids, and liquids. Because agricultural and food industry residues and wastes are seasonal care should be taken to dispose of this waste from the environment, or have in place systems to manage the waste from interfering with other environmental and ecological systems. This is because the pollution potential of agricultural waste is high over an extended period, contaminating water (surface and underground) and soil resources with a host of contents, some of which are organic chemicals and pathogens from animal excrement[128].

Current uses

Waste to fuel technology

Agricultural waste composting;

Food processing

[1] De Wilde, S. 2016. *The Future of Technology in Agriculture*. [Online] Available: https://stt.nl/stt/wp-content/uploads/2016/05/ENG-Toekomstverkenning-agri-food-Web.pdf [Accessed: 22 October 2017].
[2] Guerrini, F. 2015. The Future Of Agriculture? *Smart Farming*. [Online] Available: https://www.forbes.com/sites/federicoguerrini/2015/02/18/the-future-of-agriculture-smart-farming/#1d56905e3c42 [Accessed: 15 October 2017].
[3] Macaskill, C. 2017. Precision farming. *Agrihandbook - Services and Technologies section*. [Online] Available: http://www.agrihandbook.co.za/index.php/book/services-technologies/precision-farming [Accessed: 22 October 2017].
[4] King, J., "Automatic Weather Station." [Online]. Available: http://www.automaticweatherstation.com/index.html. [Accessed: 13-May-2017].
[5] Barnes, E. M. *et al.*, (2003) "Remote- and Ground-Based Sensor Techniques to Map Soil Properties," *Photogramm. Eng. Remote Sens.*, vol. 69, no. 6, pp. 619–630, Jun. 2003.
[6] Rodrigues, F. A., Bramley, R. G. V., and Gobbett, D. L., (2015) "Proximal soil sensing for Precision Agriculture: Simultaneous use of electromagnetic induction and gamma radiometrics in contrasting soils," *Geoderma*, vol. 243, pp. 183–195, 2015.
[7] Zazueta, F. and Xin, J., (1994) "Soil moisture sensors," *Soil Sci.*, 1994.
[8] Dinh, T. Le, Hu, W., Sikka, P., Corke, P., Overs, L., and Brosnan, S., (2007) "Design and Deployment of a Remote Robust Sensor Network: Experiences from an Outdoor Water Quality Monitoring Network," in *32nd IEEE Conference on Local Computer Networks (LCN 2007)*, 2007, pp. 799–806.
[9] GNSS in Africa. 2017. *Success 2 Project team, SBAS and Africa*. [Online] Available: http://www.gnss-africa.org/?page_id=23 [Accessed: 13-May-201
[10] Botha, M., "SANSA - Precision Farming trial findings: Satellite Based Augmentation System yields positive results." [Online]. Available: http://www.sansa.org.za/spaceoperations/resource-centre/news/268-precision-farming-trial-findings-satellite-based-augmentation-system-yields-positive-results. [Accessed: 14-May-2017].
[11] Linz, A., Ruckelshausen, A., and Wunder, E., (2014) "Autonomous service robots for orchards and vineyards: 3D simulation environment of multi sensor-based navigation and applications," *Precison Agric. …*, 2014.
[12] Sasani, S., Asgari, J., and Amiri-Simkooei, A. R., (2016) "Improving MEMS-IMU/GPS integrated systems for land vehicle navigation applications," *GPS Solut.*, vol. 20, no. 1, pp. 89–100, Jan. 2016.
[13] US Department of Commerce, N. O. and A. A., "What is LIDAR."
[14] Lu, Z., Hu, Z., and Uchimura, K., (2009) "SLAM estimation in dynamic outdoor environments: A review," *Intell. Robot. Appl.*, 2009.
[15] De Graef, V. and Vermeir, S., "Sensors For Food | Ondersteuning naar sensoren in de voedingssector." [Online]. Available: http://www.sensorsforfood.com/en. [Accessed: 13-May-2017].
[16] Pongnumkul, S., Chaovalit, P., and Surasvadi, N., (2015) "Applications of Smartphone-Based Sensors in Agriculture: A Systematic Review of Research," *J. Sensors*, vol. 2015, pp. 1–18, 2015.
[17] Ruiz-Garcia, L. and Lunadei, L., (2011) "The role of RFID in agriculture: Applications, limitations and challenges," *Comput. Electron. Agric.*, vol. 79, no. 1, pp. 42–50, 2011.
[18] Reagan, J. 2014. *Drone Definitions: Learning the Lingo of UAS*. [Online]. Available: http://dronelife.com/2014/09/29/drone-definitions-learning-uas/. [Accessed: 20-May-2017].
[19] Poponak, N., Porat, M., Hallam, C., Jankowski, S., Samuelson, A. & Nannizzi, M. 2016. *Drones: Flying into the Mainstream*. [Online] Available: http://www.goldmansachs.com/our-thinking/pages/drones-flying-into-the-mainstream.html [Accessed: 2 November 2017]
[20] Mazur, M. 2016. Six ways drones are revolutionizing agriculture. *States News Service*, 20 May.
[21] Sze, L.T. *et al.* 2015. High resolution DEM generation using small drone for interferometry SAR. In *2015 International Conference on Space Science and Communication (IconSpace)*, 366-369.
[22] Chamoso, P., Raveane, W., Parra, V. & González, A. 2014. UAVs applied to the counting and monitoring of animals. In *Ambient Intelligence-Software and Applications*, Springer, 71-80.

[23] Xu, J., Solmaz, G., Rahmatizadeh, R., Turgut, D. & Boloni, L. 2015. Animal monitoring with unmanned aerial vehicle-aided wireless sensor networks. *2015 IEEE 40th Conference on Local Computer Networks (LCN)*, 125-132.
[24] Macaskill, C. 2017. Drones. *The AgriHandbook – Services and Technologies*. [Online] Available: http://www.agrihandbook.co.za/index.php/book/services-technologies/drones [Accessed: 21 October 2017].
[25] Anthony King 2017
[26] Wikipedia. 2017. *Unmanned Aerial Vehicles*. [Online] Available: https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle [Accessed: 20 July 2005].
[27] Muller, N. 2017. Determining friend or foe : Smart technologies to enhance farm security – technology. Red Meat / Rooivleis. *AgriConnect*, 8(2), 74-79.
[28] Merriam Webster, 2017, Robotics, https://www.merriam-webster.com/dictionary/robotics
[29] Luis Emmi, Mariano Gonzalez-de-Soto et al., 2014, Science World Journal Vol 2014, New Trends in Robotics for Agriculture: Integration and Assessment of a Real Fleet of Robots
[30] Science World Journal - New Trends in Robotics for Agriculture: Integration and Assessment of a Real Fleet of Robots
[31] Science World Journal, New Trends in Robotics for Agriculture: Integration and Assessment of a Real Fleet of Robots Pg3
[32] Intorobotics - https://www.intorobotics.com/35-robots-in-agriculture/
[33] Agrobot, 2017, Products, http://www.agrobot.com/products.html and https://youtu.be/RKT351pQHfI
[34] Will Nicol, 2017, Automated agriculture: Can robots, drones, and AI save us from starvation?, Digital Trends, https://www.digitaltrends.com/cool-tech/automated-agriculture-can-robots-drones-ai-save-us-from-starvation/
[35] Cheeín, F.A.A. & Carelli, R., 2013. Agricultural Robotics: Unmanned Robotic Service Units in Agricultural Tasks. IEEE Industrial Electronics Magazi, http://ieeexplore.ieee.org/document/6603408
[36] Daniels, J. 2016. *Future of farming: Driverless tractors, ag robots.* [Online] Available: https://www.cnbc.com/2016/09/16/future-of-farming-driverless-tractors-ag-robots.html [Accessed: 23 October 2017].
[37] AgriLand. 2017. *Electric John Deere tractor runs for 4 hours on a charge.* [Online] Available: http://www.agriland.ie/farming-news/electric-john-deere-tractor-runs-for-4-hours-on-a-charge/ [Accessed: 2 November 2017].
[38] Gopi, C.Y. 2011. *Messages from the farm.* [Online] Available: https://www.youtube.com/watch?v=eEj0gVV44V0 [Accessed: 29 October 2017].
[39] Merriam Webster. 2017. *Artificial intelligence.* [Online] Available: https://www.merriam-webster.com/dictionary/artificial%20intelligence [Accessed: 22 October 2017].
[40] Copeland, M. 2016. *What's the difference between artificial intelligence, machine learning, and deep learning?* [Online] Available: https://blogs.nvidia.com/blog/2016/07/29/whats-difference-artificial-intelligence-machine-learning-deep-learning-ai/ [Accessed: 22 October 2017].
[41] AIA. 2014. *Computer vision vs machine vision.* [Online] Available: https://www.visiononline.org/vision-resources-details.cfm/vision-resources/Computer-Vision-vs-Machine-Vision/content_id/4585 [Accessed: 1 November 2017].
[42] Rouse, M. 2010. *AI (Artificial intelligence).* [Online] Available: http://searchcio.techtarget.com/definition/AI [Accessed: 22 October 2017].
[43] SAS. 2017. *Machine learning*. [Online] Available: https://www.sas.com/en_za/insights/analytics/machine-learning.html [Accessed: 28 October 2017].
[44] SAS. 2017. *Machine learning*. [Online] Available: https://www.sas.com/en_za/insights/analytics/machine-learning.html [Accessed: 28 October 2017].
[45] Tech Navio. 2017. *Artificial intelligence in Agriculture.* [Online] Available: https://www.technavio.com/blog/industrial-artificial-intelligence-agriculture-disruptive-technology-holds-future-food-supply [Accessed: 31 October 2017].

[46] Cosgrove, E. 2017. *How to build artificial intelligence that's smarter than a farmer.* [Online] Available: https://agfundernews.com/build-artificial-intelligence-indoor-farm.html [Accessed: 1 November 2017].
[47] Kono. 2017. https://kono.ai/
[48] Del Prado, G.M. *18 artificial intelligence researchers reveal the profound changes coming to our lives.* [Online] Available: http://www.businessinsider.com/researchers-predictions-future-artificial-intelligence-2015-10/#pieter-abbeel-says-robots-will-keep-us-safer-especially-from-disasters-1 [Accessed: 1 November 2017].
[49]Coleman, A. 2013. *Precision farming – a global perspective*. [Online] Available: https://www.farmersweekly.co.za/agri-technology/farming-for-tomorrow/precision-farming-a-global-perspective/ [Accessed: 23 October 2017].
[50] Angela Huang, 2016. *Transforming the agricultural industry*. [Online] Available: https://www.ibm.com/blogs/internet-of-things/agricultural-industry/ [Accessed: 3 October 2017].
[51] Alice Klein, 2017, 4D printing makes objects that assemble themselves when heated, New Scientist, https://www.newscientist.com/article/2127713-4d-printing-makes-objects-that-assemble-themselves-when-heated/
[52] Jodie Wehrspann , 2013, Farm Industry News, http://www.farmindustrynews.com/farm-equipment/3-d-printing-technology-impact-agriculture
[53] Clare Scott, 2016, 3D Printing and Other High-Tech Solutions Could Create Lots of New Jobs in Agriculture, https://3dprint.com/115833/3d-printing-agriculture-jobs/
[54] Scott J Grunewald, 2015, 3Dponics is Modernizing Urban Agriculture Further With New 3D Printed Cube Garden, https://3dprint.com/66460/3dponics-urban-agriculture/
[55] Tyler Koslow, 2016, Myanmar Farmers Utilize MakerBot 3D Printers to Create Their Own Tools, https://3dprint.com/149881/myanmar-makerbot-farming/
[56] Dictionary.com – "renewable energy" definition.
[57] Zyambo, S. 2013. *Shedding light on energy efficiency in South African households.* [Online] Available: https://www.slideshare.net/FrostandSullivan/energy-efficiency-south-african-residential-sector [Accessed: 1 November 2017].
[58] South African National Department of Minerals and Energy. 2009. *South African Energy Balance:2006.* Pretoria: South African National Department of Minerals and Energy.
[59] Reynolds, L. & Wenzlau, S. 2012. Climate-friendly agriculture and renewable energy: Working hand-in-hand toward climate mitigation. [Online] Available: http://www.renewableenergyworld.com/articles/2012/ 12/climate-friendly-agriculture-and-renewable-energy-working-hand-inhand-toward-climate-mitigation.html [Accessed: 1 November 2017].
[60] Greencape. 2017. *Energy services: 2017 market intelligence report.* [Online] Available: http://www.greencape.co.za/assets/Uploads/GreenCape-Energy-Services-MIR-2017-electronic-FINAL-v1.pdf [Accessed: 28 October 2017].
[61] Greencape. 2017. *Agriculture: 2017 market intelligence report.* [Online] Available: http://www.greencape.co.za/assets/Uploads/GreenCape-Agri-MIR-2017-electronic-FINAL-v1.pdf [Accessed: 30 October 2017].
[62] Radziemska, E. 2003. The effect of temperature on the power drop in crystalline silicon solar cells. *Renewable Energy,* 28(1), 1-12.
[63] Janse van Vuuren, P. 2016. *Solar photovoltaic (PV) systems on packhouses: The business case for an apple packhouse.* [Online] Available: https://goo.gl/VF7qjx [Accessed: 1 November 2017].
[64] Klein, A. 2016. *First farm to grow veg in a desert using only sun and seawater.* [Online] Available: https://www.newscientist.com/article/2108296-first-farm-to-grow-veg-in-a-desert-using-only-sun-and-seawater/ [Accessed: 28 October 2017].
[65] Nel, C. 2015. *Good riddance to Eskom: Generate your own power!* [Online] Available: http://www.farmersweekly.co.za/agri-technology/useful-products/good-riddance-to-eskom-generate-your-own-power/ [Accessed: 30 October 2017].
[66] Nel, P.J.C., Booysen, M.J. & van der Merwe, B. 2014. *ICT-enabled solutions for smart management of water supply in Africa.* Proceedings of the First International Conference on the Use of Mobile ICT in Africa, Stellenbosch, 9-10 December.

[67] Henley, W. 2013. *The new water technologies that could save the planet.* [Online] Available: https://www.theguardian.com/sustainable-business/new-water-technologies-save-planet [Accessed: 30 October 2017].
[68]Green Cape. 2017. *Market intelligence report.* [Online] Available: https://www.greencape.co.za/assets/Uploads/GreenCape-Water-MIR-2017-electronic-FINAL-v1.pdf [Accessed: 1 November 2017].
[69] Water Administration System (WAS). Undated. [Online] Available: https://www.wateradmin.co.za/ [Accessed 1 November 2017].
[70]Van Vark, C. 2012. *Empowering farmers through SMS.* [Online] Available: https://www.theguardian.com/global-development-professionals-network/2012/nov/27/farmers-mobile-phones-sms-agriculture [Accessed: 1 November 2017].
[71] Churi, A.J., Mlozi, M.R.S., Mahoo, H., Tumbo, S.D. & Casmir, R. 2013. A decision support system for enhancing crop productivity of smallholder farmers in semi-arid agriculture. *International Journal of Information and Communication Technology Research*, 3(8), 238-248.
[72] Manstrat Agricultural Intelligence Solutions. Undated. [Online] Available: http://www.manstratais.co.za/ [Accessed 24 October 2017].
[73] Annandale, J.G., Stirzaker, R.J., Singels, A., van der Laan, M. & Laker, M.C. 2011. Irrigation scheduling research: South African experiences and future prospects. *Water SA*, 37(5), 751-764.
[74] Netafim. Undated. [Online] Available: www.netafim.co.za [Accessed 24 October 2017].
[75] Stirzaker, R., Mbakwe, I. & Mziray, N.R. 2017. A soil water and solute learning system for small-scale irrigators in Africa. *International Journal of Water Resources Development*, 33(5), 788-803.
[76] Climate Systems Analysis Group. 2017. *Seasonal hydrological forecasting: Current state of play.* [Online] Available: http://www.wrc.org.za/Knowledge%20Hub%20Documents/Water%20Wheel/Magazine/WW%20Sept_Oct%202017_web.pdf [Accessed: 28 October 2017].
[77] Joubert, R. 2014. Cosmic probe sheds light on soil moisture. *Farmers Weekly*, 30 January.
[78] Wettstein, S., Muir, K., Scharfy, D. & Stucki, M. 2017. The environmental mitigation potential of photovoltaic-powered irrigation in the production of South African maize. *Sustainability*, 9(10), 1772.
[79] Hughes, B., O'Connor, D., Kaiser, J. & Calautit, S. 2018. A review of sustainable solar irrigation systems for Sub-Saharan Africa. *Renewable and Sustainable Energy Reviews,* 81(1), 1206-1225.
[80] Bugan, R.D.H., Jovanovic, N., Israel, S., Tredoux, G., Genthe, B., Steyn, M., Allpass, D., Bishop, R. & Marinus, V. 2016. Four decades of water recycling in Atlantis. *Water SA*, 42(4), 577-594.
[81] Closas, A. & Molle, F. 2016. *Groundwater governance in Sub-Saharan Africa*. [Online] Available: https://www.researchgate.net/profile/Alvar_Closas/publication/318825406_Groundwater_governance_in_Sub-Saharan_Africa/links/59807ab20f7e9bd660eb480a/Groundwater-governance-in-Sub-Saharan-Africa.pdf [Accessed: 22 October 2017].
[82] Li, X., Xu, W., Tang, M., Zhou, L., Zhu, B., Zhu, S. & Zhu, J. 2016. Graphene oxide-based efficient and scalable solar desalination under one sun with a confined 2D water path. *Proceedings of the National Academy of Sciences*, 113(49), 13953-13958.
[83]Centre for Responsible Nanotechnology,2008 ,http://www.crnano.org/whatis.htm
[84] Nanowerk, 2014, Nanotechnology in agriculture, https://www.nanowerk.com/spotlight/spotid=37064.php
[85] Leonardo F. Fraceto et al.,Nanotechnology in Agriculture: Which Innovation Potential Does It Have?, Frontiers, https://www.frontiersin.org/articles/10.3389/fenvs.2016.00020/full
[86] Nanowerk, 2014
[87] "Bioinformatics". Encyclopædia Britannica.com. Retrieved 17 April 2017.
[88] Attwood, T.K., Gisel, A., Eriksson, N.E., Bongcam-Rudloff, E., 2011. Concepts, Historical Milestones and the Central Place of Bioinformatics in Modern Biology: A European Perspective. Bioinformatics – Trends and Methodologies. InTech. Retrieved 8 Jan 2012.
[89] Sim, A.Y., Minary, P., Levitt, M., 2012. Modeling nucleic acids. Current Opinion in Structural Biology. Nucleic acids/Sequences and topology. 22 (3): 273–278.
[90] Dawson, W.K., Maciejczyk, M., Jankowska, E.J., Bujnicki, J.M., 2016. Coarse-grained modeling of RNA 3D structure. Methods. Advances in RNA Structure Determination. 103: 138–156

[91] Kmiecik, S., Gront, D., Kolinski, M., Wieteska, L., Dawid, A.E., Kolinski, A., 2016. Coarse-Grained Protein Models and Their Applications. Chemical Reviews. 116: 7898–936
[92] Wong, K.C., 2016. Computational Biology and Bioinformatics: Gene Regulation. CRC Press (Taylor & Francis Group)
[93] Joyce, A.P., Zhang, C., Bradley, P., Havranek, J. J., 2015. Structure-based modeling of protein: DNA specificity. Briefings in Functional Genomics. 14 (1): 39–49
[94] Spiga, E., Degiacomi, M.T., Dal Peraro, M., 2014. Karabencheva-Christova, T. ed. Chapter Three - New Strategies for Integrative Dynamic Modeling of Macromolecular Assembly. Biomolecular Modelling and Simulations. 96. Academic Press. pp. 77–111
[95] NOAA Website: www.oceanservice.noaa.gov
[96] IEA (International Energy Agency), 2008. Bioenergy Task 42 on Biorefineries. Minutes of the third Task meeting, Copenhagen, Denmark.
[97] Wikipedia definition
[98] Paes, B.G., Almeida, J.R.M., 2014. Genetic improvement of microorganisms for applications in biorefineries. Chemical and Biological Technologies in Agriculture, 1:21. (and references therein).
[99] International Food Information Service (IFIS)., 2005. Dictionary of Food Science and Technology. Blackwell Publishing UK.
[100] Oladapo A. S., Akinyosoye F. A., Abiodun O. A., 2014. The Inhibitory effect of different Chemical Food Preservatives on the Growth of Selected Food Borne Pathogenic Bacteria. African Journal of Microbiology Research. Vol 8(14), 1510-1515.
[101] Inetianbor, J. E., Yakubu, J. M. and Ezeonu, S. C., 2015. Effects of food additives and preservatives on man - a review. Asian Journal of Science and Technology Vol. 6, Issue 02, 1118-1135
[102] Martirosyan, D.M., Singh, J., 2015. A new definition of functional food by FFC: what makes a new definition unique? Functional Foods in Health and Disease, 5(6):209-223
[103] Karp, G (2002) cell and molecular biology: concepts and experiments. 3rd ED., New York, Wiley p 785
[104] United Nations. 2015 Revision of World Population Prospects, United Nations. Available online: https: //esa.un.org/unpd/wpp/publications/files/keyfindingswpp2015.pdf (accessed on 25 April 2016).
[105] UNEP GEAS (2012) http://www.unep.org/pdf/unep-geas_oct_2012.pdf. Accessed 19 September 2014.
[106] Alexandratos, N., Bruinsma, J., 2012. World Agriculture Towards 2030/2050. ESA Working Paper no. 2012:12–03
[107] De Haan, C, Van Veen, T.S., Brandenburg, B., Gauthier, J., Le Gall, F Mearns, R., 2001. Livestock development. Implications for rural poverty, the environment, and global food security, World Bank Report Washington D.C, USA, 23241
[108] Vinnari, M., 2008. The future of meat consumption-Expert views from Finland. Technological Forecasting and Social Change 75(6): 893-904.
[109] Cinar, M.U., 2015. Impact of livestock genomics on food security and sustainability. Paper presented at the Regional workshop on sustainable management of food security, Istanbul, Turkey.
[110] FAO (2003) World agriculture: Towards 2015/2030. An FAO perspective. Rome (EP Ltd Edn). London, UK.
[111] Grunert, K.G., 2006. Future trends and consumer lifestyles with regard to meat consumption. Meat Sci 74(1): 149-160.
[112] Fiala, N., 2008. Meeting the demand: An estimation of potential future greenhouse gas emissions from meat production. Ecological Economics 67(3): 412-419.
[113] Datar, I., Betti, M. 2010. Possibilities for an in vitro meat production system. Innovative Food Science & Emerging Technologies 11(1): 13- 22.
[114] van der Spiegel, M., Noordam, M. Y., van der Fels-Klerx, H. J., 2013. Safety of Novel Protein Sources (Insects, Microalgae, Seaweed, Duckweed, and Rapeseed) and Legislative Aspects for Their Application in Food and Feed Production. Comprehensive Reviews in Food Science and Food Safety, 12, 662-678.

[115] Post, M. J., 2012. Cultured meat from stem cells: challenges and prospects. Meat Science, 92, 297-301.
[116] Stephens, N., Kramer, C., Denfeld, .Z, Strand, R. (Eds), 2015. What is in vitro meat? Ditto press
[117] de Lorenzo, V., Danchin, A., 2008. Synthetic Biology: discovering new worlds and new words. EMBO Rep 9, 822-827.
[118] Endy, D., 2005). Foundations for engineering biology. Nature 438, 449-453.
[119] Andrianantoandro, E., Basu, S., Karig, D.K., Weiss, R., 2006) Synthetic Biology: new engineering rules for an emerging discipline. Mol Syst Biol 2: 0028
[120] Jones, G., Mayer, M., 2010. Acb, briefing paper no. 20, Synthetic Biology in Africa: recent developments.
[121] Brenner, K., You, L., and Arnold, F. H., 2008. Engineering microbial consortia: a new frontier in SB. Trends Biotechnol 26, 483-489.
[122] Garang, B.N., Onkware A. O., 2016. Redirecting the Wheels of Natural Progression: Review of SB and the African Biotechnology Revolution. Bioengineering and Bioscience 4(2): 11-19
[123] Despommier, D. (2013). Farming up the city: the rise of urban vertical farms. Trends in biotechnology, 31(7), 388-389.
[124] www.verticalfarms.com.au
[125] Wikipedia
[126] Sarkar, A., Majumder, M., 2015. Opportunities and Challenges in Sustainability of Vertical Eco-Farming: A Review. Journal of Advanced Agricultural Technologies Vol. 2, No. 2
[127] van Jaarsveldt, D., 2016. Short market analysis: Waste management and Recycling in South Africa, 2016Southern African – German Chamber of Commerce and Industry NPC
[128] Sarmah, A.K., 2009. Potential Risk and Environmental Benefits of Waste Derived from Animal Agriculture, In Agriculture Issues and Policies Series - Agricultural Wastes, Eds: Geoffrey S. Ashworth and Pablo Azevedo, ISBN 978-1-60741-305-9, Nova Science Publishers, Inc., New York.