Precision Agriculture

Producing More With Less

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Overview

Agriculture is an important part of the human development that is being enhanced with the use of technology. Due to high population growth rates, farmers are struggling to produce sufficient amount of crops to feed the whole world. This research paper discusses the current issues in agriculture such as soil degradation which is due to excessive use of chemical fertilizers. Today's farming practices contribute to global climatic changes by producing greenhouse gases like methane and carbon dioxide. The leading cause of deforestation is the need for more agricultural land, however malnutrition still remains one of the top leading causes of death. Even after great technical advancements, farmers fail to protect their crops from pest attacks. The solution to these problems is precision agriculture which is the practice of cultivation and crop production using technology. It helps to reduce the crop input such as water, pesticides, and fertilizers and helps produce high quality crops. There are four major precision agriculture technologies mentioned in the paper which are a) **Variable Rate Technology** that is used to control the crop input; b) **Unmanned Aerial Vehicle** which helps in monitoring the crop heath; c) **Global Positioning System** to understand the field details by accessing its exact coordinates; and d) **Geo Mapping** which helps to create informational field maps. These technologies benefit farmers economically and reduce the negative environmental impacts, however, they come up with high costs. There are certain barriers that farmers face in adopting the farming technology. Additionally, these barriers need to be understood and addressed properly to promote sustainable farming practice using precision agriculture. Technology has the power to help farmers produce more food using less resources that can support mankind in subsequent years.

Table of Content

1. Introduction to Agriculture **5**
2. Issues in Agriculture 6
2.1. Soil degradation 7
2.2. Deforestation 8
2.3. Climate change 9
2.4. Pest attack 10
2.5. Food scarcity 11
3. Introduction to Precision Agriculture 12
4. Current technologies in Precision Agriculture **13**
4.1. Variable rate technology (VRT) 14
4.1.A. Map based VRT 14
4.1.B. Sensor based VRT 16
4.1.C. Manual VRT 16
4.1.1. Benefits 17
4.1.2. Considerations 18
4.2. Unmanned Aerial Vehicle (UAV) **18**
4.2.A. Hyperspectral and multispectral sensors 19
4.2.B. Digital camera 21
4.2.C. Thermal and multiple sensors 21
4.2.1. Benefits 22
4.2.2. Considerations 22
4.3. Global Positioning System (GPS) **23**
4.3.A. Equipment Guidance System 24
4.3.B. Field Mapping 25
4.3.C. Precision Crop Input Applications 26
4.3.1. Benefits 26
4.3.2. Considerations 26
4.4. Geo Mapping **27**
4.4.A. Soil maps 27

4.4.B. Yield maps 28
4.4.1. Benefits.. 29
4.4.2. Considerations.. 29
5. Barriers in adoption of Precision Agriculture 29
5.1. Information Barrier 30
5.2. Poor quality agricultural input 32
5.3. High Price 33
6. Conclusion 34
Works Cited 35

"The ultimate goal of farming is not the growing of crops, but the cultivation and perfection of human beings." – Masanobu Fukuoka ("10 memorable")

1. Introduction to Agriculture

Many archaeologists and palaeontologists have claimed that the practice of agriculture originated around 10,000 years ago (Mason). It was a period of transition when the hunter-gatherer societies started to domesticate the crops. This period is marked as the first Agricultural Revolution in the history of mankind. From approximately 8,000 BC to AD 1600, many civilizations worked towards developing better ways of crop cultivation. The irrigation systems evolved and global food trade became prominent. Over the years, people had access to more food sources that led to an increase in world population. The global community reached to about 700 million in 1750. Consequently, the demand of food started to increase again and hence modern farming methods were introduced during the 18th century to combat this issue. This introduction of technology into the agricultural sector came to be known as the "British Agricultural Revolution". The production of food increased rapidly as farmers began to use fertilizers and pesticides for better crop quality. One of the key development of the revolution was the Norfolk four-field crop rotation which originated in the early 16th century. It is the practice of growing various types of crops in the same area and in sequential seasons ("Agricultural Revolution"). It helped the farmers to get rid of the fallow year and feed their livestock all year-round using the fodder crops. The Industrial Revolution helped reinforce the mechanization of agriculture. Farmers began to use threshing machines to separate seeds from the stalks. Ploughs were continuously upgraded and the adoption of seed drills rapidly increased. The third revolution of

Fallow year

The plowed land that is left idle for a season to conserve soil moisture ("fallow").

Fig. 1. **A central figure in the "green revolution", Norman Ernest Borlaug** from: "Norman Borlaug - Biographical". *Nobelprize.org*, Nobel Media AB 2014. Web, 12 Aug 2018, http://www.nobelprize.org/nobel_prizes/peace/laureates/1970/borlaug-bio.html.

agricultural industry is known as the Green Revolution that started in the 1940s. American scientist named Norman Borlaug researched and developed a disease resistant high-yield variety of wheat (Briney). This resulted in auxiliary production of wheat leading Mexico to begin exporting the crop by 1960s. Due to the success of food production in Mexico, the technologies of Green Revolution were adopted worldwide. For instance, India produced a new variety of rice, IR8, to fight mass famine during the 1960s using the research of Borlaug and Ford Foundation (Briney). Collecting data and making farming decisions based on that data had become a crucial part of the agriculture by 1970s. On the contrary, Green Revolution also received some criticism from the world. Due to high food availability, population started to grow faster in some countries like India and China. Whereas poor countries like Africa did not benefit significantly from the Green Revolution due to the “lack of infrastructure, governmental corruption, and insecurity in nations” (Briney). This gave rise to many problems that were caused due to crop cultivation and within the agriculture sector.

2. Issues in Agriculture

The boost in fertilizer use had made the Green Revolution possible. The revolution also gave rise to the expansion of farming land around the world. Currently “11 percent (1.5 billion ha) of the globe's land surface (13.4 billion ha) is used in crop production (arable land and land under permanent crops)” (“Crop Production”). The increase in agricultural practices around the world has resulted in environmental issues such as climate change and deforestation. On the other hand, food shortage still prevails in countries like Central African Republic, Chad and Sierra Leone due to inefficient farming methods and limited resources. This section discusses the current issues in agriculture.

2.1. Soil Degradation

Soil acidification

The process where the soil pH decreases over time that leads to a dramatic decline in crop and pasture production. ("Soil acidification")

Eutrophication

The process by which a water body becomes enriched in dissolved nutrients (such as phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen ("Eutrophication")

Crops like corn, wheat and cotton receive their nutrients from the soil which eventually causes deterioration of soil quality ("Fertilizers"). The use of fertilizers is essential for the crop production and maintaining nutrient rich soil. Over the years, a vast variety of chemical fertilizers have been developed mainly including potassium, urea and phosphate fertilizers. However, they are causing negative environmental impacts like eutrophication and soil acidification. The movement of phosphorus fertilizers is the major reason for eutrophication "particularly in fresh-water systems" (Hedlin). The accumulation of trace minerals like cadmium (Cd) in the soil due to the use of phosphorus fertilizers can cause long term soil degradation (Hedlin).

Fig. 2. **Eutrophication** from: "Eutrophication of Waterways." *HSC Chemistry*, https://goo.gl/images/siosqB.Accessed 8 August 2018.

2.2. Deforestation

The increasing need of land for agricultural purposes contributes to deforestation and loss of biodiversity. It is a major issue in tropical rainforests as they are the home to most of the world's biodiversity, for example 17% of the Amazon forest has been lost in last 50 years ("Deforestation"). The cutting of forest trees to make agricultural land leads to soil erosion and loss of minerals. It is believed that "Agriculture is the largest single cause of deforestation and severe forest degradation" ("Forest conversion"). Deforestation is a big contributor towards global warming as well. The forest trees consume majority of the carbon dioxide in the atmosphere that is reduced and causing rise in the Earth's temperature.

Fig. 3. **Deforestation** from: Curley, Jeri. "How Does Deforestation Affect the Air?" *Sciencing*, 16 May 2018, https://sciencing.com/deforestation-affect-air-10632.html. Accessed on 9 August 2018.

2.3. Climate Change

The change in climatic conditions is a global concern in today's world. Many scientists claim that the rise in Earth's temperature is due to the expansion of greenhouse effect ("Blanket"). Several harmful gases contribute to greenhouse effect such as methane that is produced during farming. The cultivation of rice and the "manure management associated with domestic livestock" ("Blanket") create this active greenhouse gas. Another powerful greenhouse gas, nitrous oxide is "produced by soil cultivation practices, especially the use of commercial and organic fertilizers" ("Blanket"). The manufacturing of fertilizers and food transportation utilizes fossil fuels which produces excessive amount of carbon dioxide. It is also a contributor to the greenhouse effect.

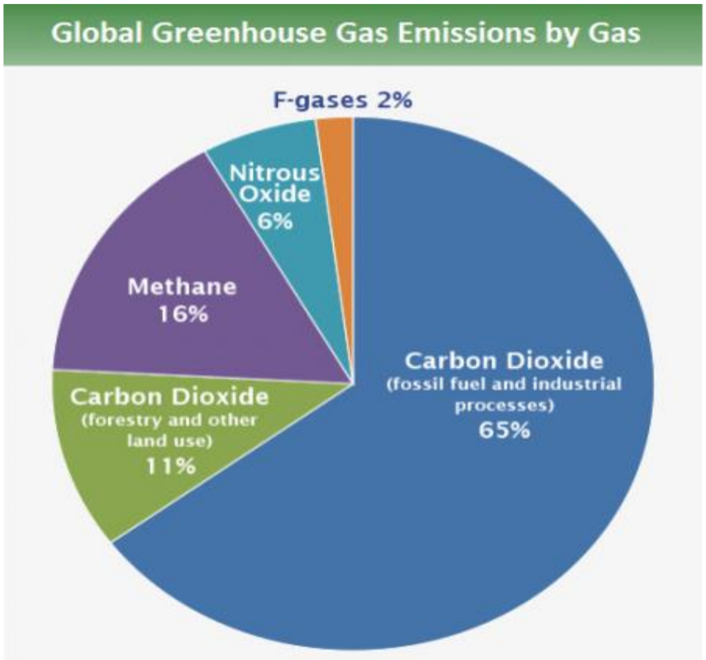

Fig. 4. **Global greenhouse gas emissions** from: *Global Greenhouse Gas Emissions Data.* United States Environmental Protection Agency, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data . Accessed on 7 August 2018.

2.4. Pest Attack

Fig. 5. **Red palm weevil** from: "Red Palm Weevil (Rhynchophorus ferrugineus)." June 2008, https://www.iberia-natur.com/en/insekten/palmr.html. Accessed 29 July 2018.

It is said that pest attacks are "responsible for destroying one fifth of the world's total crop production annually" (Sallam 2). Some of the most harmful pests include Red Palm Weevil that are the worst known pests for palm trees; Mediterranean Fruit Fly which has been recorded to infect over 300 types of fruits; and Asian Citrus Psyllid that causes one of the most destructive bacterial citrus disease worldwide. It is a serious issue for small-scale as well as large-scale farmers as the crops can be damaged even after harvest. Any broken or cracked grain is an opportunity for pests and mould to grow (Sallam 4). There are two major group of insects that cause post-harvest crop destruction: "Coleoptera (beetles) and Lepidoptera (moths and butterflies)" (Sallam 10).

Fig. 6. **Mediterranean fruit fly** from: Bauer, Scott. "Mediterranean fruit fly." *News, ABC,* 2 May 2016, http://www.abc.net.au/news/2014-08-01/mediterranean-fruit-fly/5640920 . Accessed 28 July 2018.

Fig. 7. **Asian citrus psyllid** from: "Are Asian citrus psyllids afraid of heights? New study may provide clues for stopping them." *ScienceDaily*, Entomological Society of America, 20 January 2015. www.sciencedaily.com/releases/2015/01/150120090236.htm. Accessed 1 August 2018.

2.5. Food Scarcity

Regardless of the strong agricultural industry, farmers fail to produce sufficient amount of food to feed the whole world. According to the United Nations, one of the top leading causes of death in the world is malnutrition. Despite that, in many countries farmers still cultivate crops using traditional farming methods. The lack of knowledge and resources is one of greatest hurdle to agricultural technology adoption. The world needs more food and the only way to accomplish this goal is through agricultural technology. The future of environmental friendly farming is precision agriculture.

Fig. 8. **Children in Nigeria suffering from malnutrition** from: Bakare-Ogunnubi, Bilkis. "Malnutrition and child survival in Nigeria." *Guardian Women*, The Guardian, 09 July 2016,https://guardian.ng/guardian-woman/malnutrition-and-child-survival-in-nigeria-2/. Accessed 6 August 2018.

3. Introduction to Precision Agriculture

Fig. 9. **Precision agriculture** from: "Agriculture and Technology." http://agriculturalinformation4u.com/. Accessed 7 August 2018.

Precision agriculture also known as precision farming is the practice of using technology for crop cultivation to produce high quality crops. It abides smart farming practices to ensure profitability and sustainability of the environment. According to the United Nations, there were approximately 815 million undernourished people in 2016 and this number is increasing, annually. Hence, the goal of precision agriculture is to use less resources, produce more food and fight global food scarcity. The environmental factors affecting the development of crops vary from place-to-place, for example not all parts of the land receive equal amount of sunlight or have the same level of moisture. Thus, the initial step towards adopting the precision farming practices is to monitor the soil health, nutrient levels and moisture content of the land. The data is collected using GPS, in-field monitors, sensors, drones and geo maps. Satellites and drones are used to obtain the real-time images of individual plants; "information from those images can be processed and integrated with sensor and other data to yield guidance for immediate and future decisions, such as exactly what fields to water and when or where to plant a particular crop"(Rouse). Farmers can easily identify the crops that need more attention using the data collected from the fields. Precision agriculture also saves crucial resources like time and money. The traditional farming practices are unable to detect any pest attacks on time which result in majority of the crops being destroyed. But precision farming methods alert the farmers at the first instance of a pest attack which helps them save million dollars worth of crop. Hardware traps are fixed on the field that catches pest and submit real time data to the field monitoring software. The lack of appropriate infrastructure and expensive equipment was a barrier in the adoption of precision agriculture during the 1990s. However, nowadays "mobile apps, smart sensors, drones and cloud computing makes precision agriculture possible for farming cooperatives" (Rouse).

4. Current technologies in Precision Agriculture

The technology used in agriculture has evolved rapidly in the past two decades. It helps to reduce the human labor required for farming tasks like pesticide spraying, seeding, application of fertilizers, checking soil quality and monitoring pest attacks. The technology is improving constantly to assist farmers with better agricultural practices. Mentioned below are few of the most commonly used precision agricultural technologies.

4.1. Variable Rate Technology (VRT)

The VRT includes any technology that lets a farmer vary the rate of crop input such as water, pesticides and fertilizers "to achieve site-specific application rates of inputs" ("Variable-Rate").

DGPS receiver

Differential GPS involves the cooperation of two receivers, one that's stationary and another that's roving around making position measurements ("Differential GPS").

It combines a variable rate (VR) control system with application equipment that allows the control of input application rate at a precise time and location. It helps a farmer to take care of each plant individually. The VRT system incorporates other components "such as a DGPS receiver, computer, and variable rate application (VRA) software and controller" to work (Fulton et al. 1). There are three different approaches that can be used to implement VRT that are map-based, sensor-based, and manual.

4.1.A. Map Based VRT

It is the most commonly used technique because it is affordable for farmers to develop field maps. The soil testing analysis and other crop information derived using drones and GPS is used to create different field maps. Crop producers and consultants can develop electronic maps also known as prescription maps using information based on following factors:

- Soil type and texture
- Remote sensing
- Terrain features (slopes, elevation, etc)
- Field scouting data
- Soil electrical conductivity
- Crop and location-specific data (Fulton et al. 3).

Maps are beneficial to check moisture level, nutrient quality, crop and soil health. Regardless of the actual map type, these systems must be capable of determining the location of the machine within the field and control the desired application rate by reading the prescription maps (Grisso et al. 1).

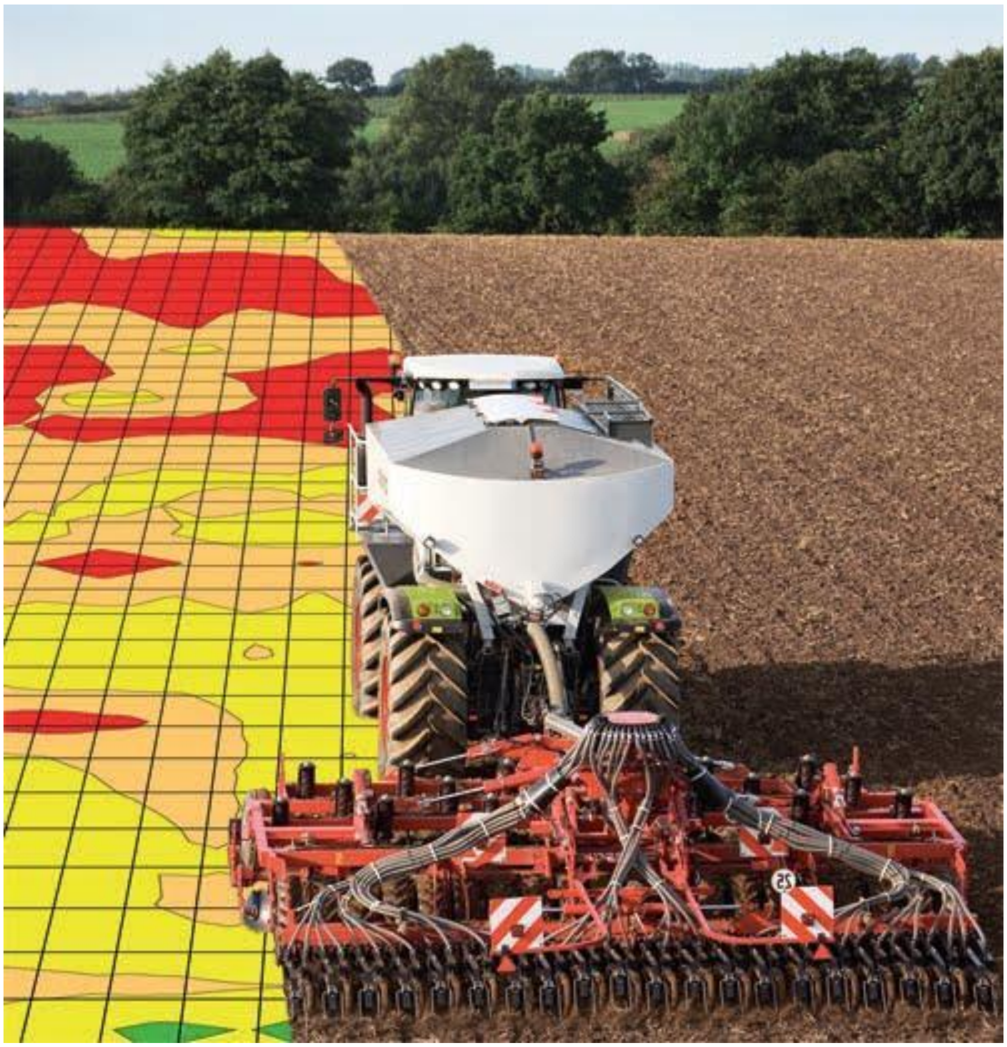

Fig. 10. **Map based VRT** from: CEMA aisbl - European Agricultural Machinery. "Precision Farming: key technologies & concepts." *CEMA*, http://cema-agri.org/page/precision-farming-key-technologies-concepts. Accessed 18 may 2018.

4.1.B. Sensor based VRT

This method allow the farmers to apply variable rate of input without any prior mapping or crop information. Real-time sensors evaluate the soil and crop properties on the go. The information obtained is then processed and used immediately to control the variable rate technology. The sensor based VRT system does not require any positioning system. However, the collected data can be stored and used later to create prescription maps for site specific crop management exercises (Grisso et al. 2). This technology is developed recently and is still under improvement phase.

4.1.C. Manual VRT

The manual control for variable rate of input is the method where the operator is responsible for changing the rates of application (Fulton et al. 1). This method is usually adopted by poor farmers where they cannot afford the better approaches to VRT. This technique helps many farmers save the cost of crop input resources. It requires the farmers to analyze the crop and change the input rate accordingly. Manual approach to VRT requires more time and labor.

Fig. 11. **Manual VRT** from: Hirschfeld, Marin. *Farmer Health: A Case Against Pesticides*, Cabi, February 19, 2016,https://blog.plantwise.org/2016/02/19/farmer-health-a-case-against-pesticides/. Accessed 29 July 2018.

4.1.1 Benefits

VRT can be used for the controlled application of fertilizers, pesticides, manure, seeding, tillage and irrigation (Fulton et al. 2). These systems can provide multiple benefits such as:

- It can minimize the use of fertilizers and pesticides thereby reducing harmful environmental impacts such as eutrophication.
- It increases crop quality and production by applying chemicals only when needed.
- It helps reduce farm labor and cost due to site specific input application.
- It leads to “Improved in-field equipment efficiency” (Fulton et al. 4).

4.1.2. Considerations

Farmers must consider the following facts before investing into Variable Rate Technology (Fulton et al. 4).

- The machinery is complex and requires good knowledge to use it effectively.
- It requires good management of the equipment- calibration and proper maintenance.
- The machinery can become difficult to operate and rely on, increasing the frustration of the user.
- The user needs to determine how to develop the prescription maps.
- The user needs to develop over goals for using VRT like reduced input, increased crop yield, etc.

4.2. Unmanned Aerial Vehicle (UAV)

The most commonly used UAVs in agriculture nowadays is a drone. It flies by itself using a GPS and is equipped with a point and shoot camera (Opfer). Farmers fly their drones over the crop field to collect real-time field imagery that is used to evaluate the soil and crop quality. Agricultural drones also include infrared technology which is very helpful in detecting healthy and damaged crops. The farmers use it to spot bacterial or fungal infection growing on the crops. Drones play a vital role in livestock monitoring and crop dusting/spraying. The crop spraying drones are able to carry large liquid storage reservoirs that can operate autonomously and more safely (Margaritoff). Sensors are a crucial part of the drones.

Fig. 12. **Drone used for crop spraying** from: Leonetti, Allan. *Agriculture Drone Market driven by Increasing automation in the agriculture process*, DIY Drones, November 29, 2016, https://diydrones.com/profiles/blogs/agriculture-drone-market-driven-by-increasing-automation-in-the. Accessed 2 August 2018.

Hence, following are the sensors available for drones that are used by farmers at present:

4.2.A. Hyperspectral and Multispectral Sensors

The images captured using these sensors "help in creating Normalized Difference Vegetation Index (NDVI) maps" (Sylvester 3). These maps let farmers precisely differentiate between soil and crops, detect plants under stress and access different crops and crop stages. The fundamental principle of NDVI relies on the fact that crops reflect back a huge amount of light in the near infrared (NIR) (Sylvester 3). For example when a plant gets stressed or dehydrated, it reflects less NIR light but the same amount of visible range.

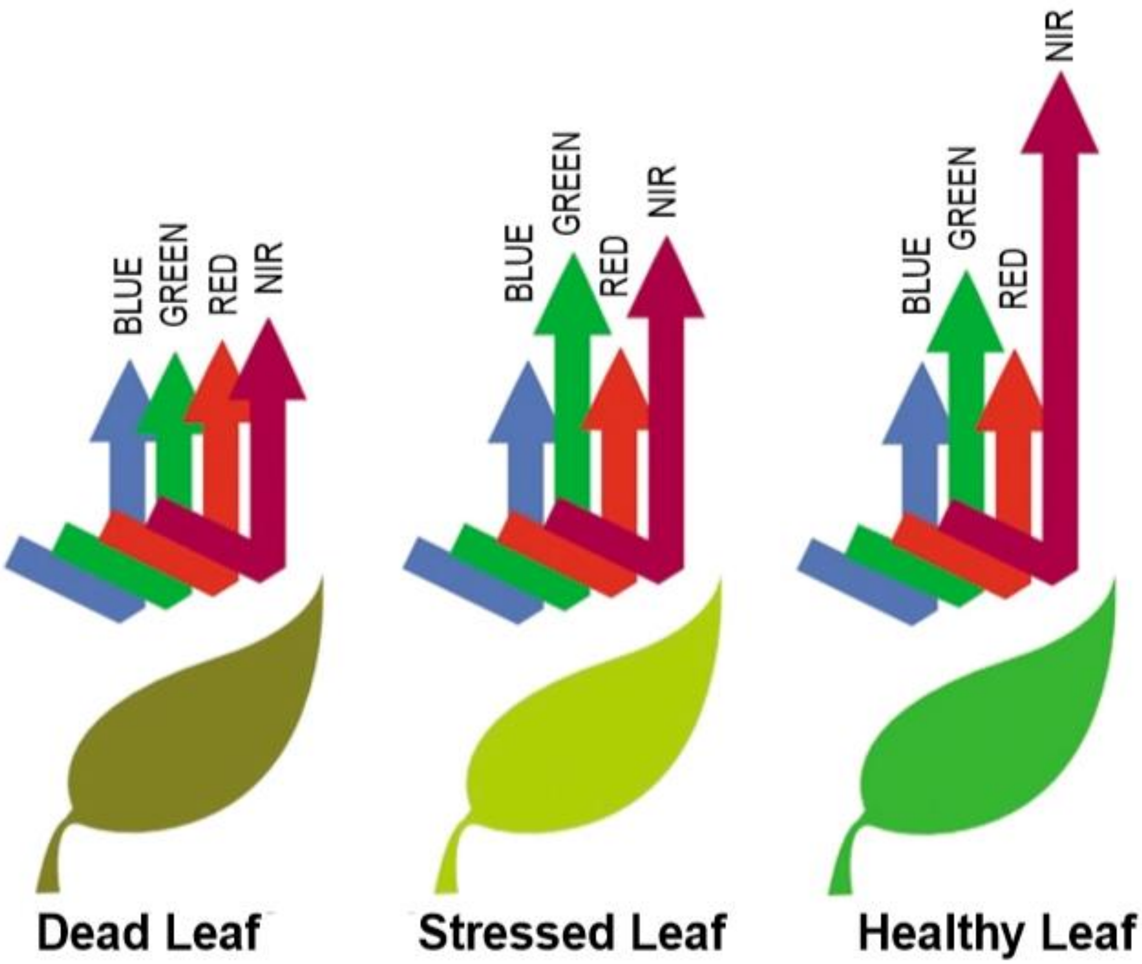

Fig. 13. **Fundamental principle of NDVI relies on the reflection of infrared (NIR)** from: *E-AGRICULTURE IN ACTION: DRONES FOR AGRICULTURE,* Food and Agriculture Organization of the United Nations, 2018, http://www.fao.org/3/I8494EN/i8494en.pdf. Accessed 16 July 2018.

4.2.B. Digital Camera

A camera applies multiple corrections to the image for light sensitivity, white balance, dark pixel noise, etc. Camera's aperture and shutter speed are carefully selected to achieve the correct exposure value calculated from the measured luminance sensors (Hunt Jr. and Daughtry). There are some performance features that need to be considered before choosing a digital camera for UAV ("Digital Cameras"). These factors are:

- Superior image quality
- High resolution
- Image format (RAW format must be acquired)
- Reliable camera shutter
- Fast frame rate
- Standard data interface

4.2.C. Thermal and multiple sensors

The thermal sensors are either accurate and expensive or cheap and inaccurate which is why they are not used as much as other UAV sensors. The two main goals for thermal remote sensing are: "detect spatial variability of incipient water stress; and manage irrigation more effectively" (Hunt Jr. and Daughtry). When plants have sufficient water, the rate of transpiration is high and temperature of leaves is low to balance their energy fluxes. With the water stress in plants, the transpiration rate decreases and temperature becomes higher to maintain the energy balance. The thermal sensors map the spatial variability of transpiration and water stress.

Transpiration

The process by which plants give off water vapor through openings in their leaves ("transpiration").

4.2.1. Benefits

Field monitoring and increased yield: It helps the farmers to analyse the field crops and soil that helps increase the crop production by identifying problems before they happen. This leads to higher crop health awareness.

Save time: Drones can be set up and send to fields within minutes. It helps the farmers to conduct regular field checks quickly and precisely.

Plan for the future: The use of drones enable producers to create geo maps that can be used to make future crop decisions (Margaritoff).

Measure mould: It helps the farmers to identify any kind of bacterial or fungal infection and save the crop before complete destruction.

Implement VRT: Drones help to apply pesticides and fertilizers in a variable rate and at accurate locations using GPS.

4.2.2. Considerations

- The power consumption and battery life is a big issue with drones. Many manufacturers are working on creating drones that can run on solar energy.
- Drones can sometimes have issues with the communication range during harsh weather conditions. Most wireless sensors in agriculture support a relatively shorter communication range.

- Cost is another major factor while considering UAVs. The user needs to cover hardware as well as software cost of the equipment.
- Using drones require good knowledge of the equipment and software. The collected data needs understanding and user analysis.
- Huge amounts of data is collected using UAVs which needs proper infrastructure, storage capacity and security. Producers need base stations to monitor field changes by analysing data patterns (Jawad et al.).

4.3. Global Positioning System (GPS)

Fig. 15. **Global Positioning System (GPS)** from: "Top 10 Tips to Consider Before Buying an Agriculture Guidance System." *Farm Management*, https://www.farmmanagement.pro/top-10-tips-to-consider-before-buying-an-agriculture-guidance-system-2/. Accessed 6 August 2018.

The development of agricultural technology cannot exist without GPS. The global positioning system is used to map the crop field using latitudes and longitudes that enable UAVs to work precisely on the fields ("key technologies & concepts"). It allows the farmers to understand the dynamics of each crop rather than generalizing the requirements of the whole field. The accuracy of GPS allow the farmers to create field maps with precise "field area, road locations and distances between points of interest" ("Agriculture"). The geographic information system (GIS) is used to capture, store, analyse and present spatial and geographic data. The GIS and GPS work together to assist site-specific farming. GPS is used for a variety of field application, some of which include:

4.3.A. Equipment Guidance System

The guidance system consists of two components: a light-bar or screen to show machine's deviation from the intended position; and a GPS receiver to locate the position. The light-bar guided automated steering system helps to work at accurate locations of the field. The guidance systems identify an "imaginary A-B starting line, curve or circle for parallel swathing using GPS positions and a control module" (Nowatzki et al.). The module takes into account the equipment width and use GPS to guide it "along parallel, curved, or circular evenly spaced swaths" (Nowatzki et al.). This GPS receiver needs to operate at a higher frequency (position calculations are usually 5 to 10 times per second) than a regular GPS receiver that is designed to record positions for yield monitoring.

Fig. 16. **Equipment Guidance System** from: "Grass-Guide GPS system offers guidance on a budget." *ZoomLion*, 21 March 2016, http://knowledge.agriculturemachinerybusiness.com/AgriculturalMachineryNews_60_17713_1.html. Accessed 18 July 2018.

4.3.B. Field Mapping

The GPS technology is used to locate and map different regions of the field. It is highly effective in detecting variations and landmarks such as rocks, pit holes, poorly drained regions, power lines and tree rows. With the help of GPS, field maps are able to show exact position of plants that are affected by any disease or pest attack. This technology is much needed for bigger farms than the smaller ones, as it is hard to analyse bigger farms visually (Nowatzki et al.). Various datasets collected using GPS are added as map layers in GIS for better evaluation of the crops.

4.3.C. Precision Crop Input Applications

The variable rate technology requires a GPS to locate the crops that need more crop input. GPS technology assist the variable input rate technology by providing a field map based on GIS maps or real time sensors. Global Positioning System is useful with many other agricultural practices as well. Some of other uses include yield monitoring systems, precision plowing, soil sampling, harvesting, farm planning and river mapping.

4.3.1. Benefits

- It eliminated the need for human flaggers and increases spraying efficiency.
- It enables future site-specific field preparation with accurately monitored yield data.
- It assist farmers to work during low visibility conditions like dust, fog or darkness.
- It provides precise field navigation that minimizes redundant input application and skipped areas.
- It guides the farmer and farm equipments with right directions and help complete tasks in shortest possible time.
- It provides crop analysis that helps save input cost and labor.

  (“Agriculture”)

4.3.2. Considerations

- The infrastructure for GPS and GIS is mandatory to run the system effectively.
- The field area must have a good internet connection and cellular coverage for the GPS to work.

- The machinery and equipment must be well connected with GPS system to perform precision agricultural practices.
- The connected systems requires proper knowledge to run them effectively, otherwise it can confuse the user.
- The regular supply of power is needed to monitor crops using GPS.

4.4. Geo Mapping

Most of the precision agricultural technologies either collect data to create a field map or use a geo map to perform their tasks. Also known as precision maps, this technology works by using multiple in-field sensors and GPS technology to analyse factors like pesticide requirement, soil moisture content and other crop data. Geo maps are a crucial part of the agricultural decision making process as they convert all the essential field information into a digital format which makes it readable for the farmers. It helps the farmers to be well informed about their field rather than guessing about the crop quality. Geo mapping creates a wide variety of field maps depicting the soil quality, water content and nutrient levels that help farmers to get insights of the yield ("Precision Agriculture Technology"). However, there are two widely used precision maps.

4.4.A. Soil Maps

Geo-referenced soil maps can be collected using various methods. One way is to divide the crop field into grids and sample individual grid block. The more samples, the more accurate soil map farmer will have. Another approach is to take samples of fields in the zones that were designated by previous precision maps ("Precision Maps"). In both the cases, location of the samples is recorded which means they are geo-referenced. This is helpful in representing soil fertility levels in any zone. These maps can be used to cross refer other types of maps such as nutrient level and pest attack. Geo maps are also connected with other farming technology namely VRT, UAV and automated steering system.

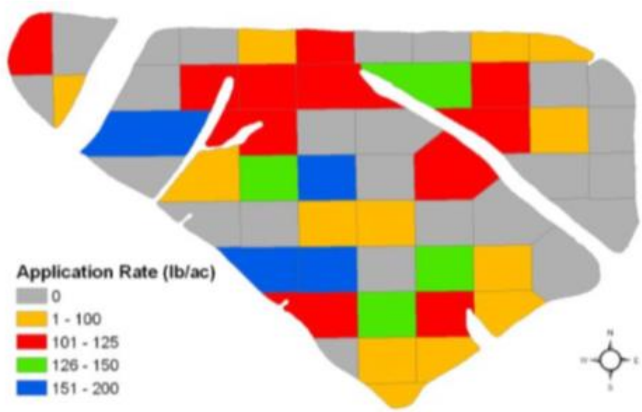

Fig. 17. **Grid-based prescription map** from: Fulton, John, Christian Brodbeck et al. *PRECISION AGRICULTURE SERIES TIMELY INFORMATION Agriculture, Natural Resources & Forestry:Overview of Variable-Rate Technology*. Alabama Precision Ag Extension, January 2009, https://sites.aces.edu/group/crops/precisionag/Publications/Timely%20Information/Overview%20of%20Variable-Rate%20Technology.pdf .Accessed 27 June 2018.

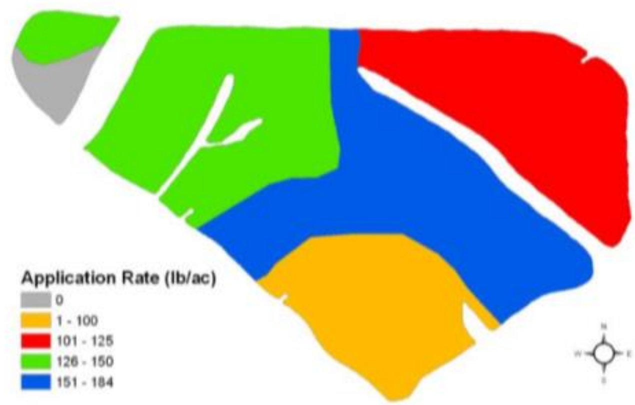

Fig. 18. **Zone-based prescription map** from: Fulton, John, Christian Brodbeck et al. *PRECISION AGRICULTURE SERIES TIMELY INFORMATION Agriculture, Natural Resources & Forestry:Overview of Variable-Rate Technology*. Alabama Precision Ag Extension, January 2009, https://sites.aces.edu/group/crops/precisionag/Publications/Timely%20Information/Overview%20of%20Variable-Rate%20Technology.pdf .Accessed 27 June 2018.

4.4.B. Yield Maps

These maps are targeted on crop yield, for example comparing different field zones by their amount of crop production ("Precision Maps"). These maps are helpful to make farmers understand the relationship between crop yield and field conditions. Similar to soil maps, these maps can be layered with other field maps to get crop insights. They are also combined with other technologies like VRT to help farmers retrieve more harvest in less cost.

4.4.1. Benefits

- Geo maps provide details of the field showing least to most productive land.
- They help the farmers to understand their field better in terms of soil nutrient content, fertiliser and pesticide requirements and crop quality.
- They guide the farmers to make future precision agricultural decisions.
- They help to understand where exactly to use the other technologies such as VRT and UAV.
- They connect all the field information together in one readable maps.

4.4.2. Considerations

- The technology itself is not much useful without other precision agricultural technology that will use maps.
- The user must have a thorough knowledge to understand and analyse the maps.
- These maps can have errors if sensors are not placed accurately.
- Geo maps require costly investment in technology that will process collected information and create maps.

5. Barriers in adoption of Precision Agriculture

Precision agricultural practices have enormous potential to drive economic growth and sustainable food production, but adoption still remains low in many countries (Jack and Tobias 1). With approximately 26.5% of the world population working in the agricultural sector, it is important to introduce the smart farming methods to fight the current issues in agriculture globally and raise the living standards of the poor farming workers. Natural resources like water is diminishing each day but the world still needs more food. However, the increase in food productivity can only be achieved using technology. Even though farmers are promoted to use precision farming practices, there are some barriers to its adoption. The following section discusses some barriers that farmers face.

5.1. Information Barrier

The biggest reason that blocks the farmers from using precision technology is the lack of information on how to use it. Over the past two decades, governments of many countries and numerous NGOs have invested in campaigning to let farmers understand why they “need to be aware of the existing technology, its benefits and how to use it” (Jack and Tobias 1). The information should be updated, accurate and tailored towards individual farmers. It is very important that farmers get information at the right time from credible sources. The information provided to the farmers should also focus on overcoming their “behavioral biases like forgetfulness, procrastination and risk aversion” (Jack and Tobias 7).

Fig. 19. **Farmer in India** from: Ventures, Unitus. “Farm IT: Mobiles in the Mud.” *Unitus Ventures*, 13 May 2014, https://unitus.vc/updates/farm-it-mobiles-in-the-mud/. Accessed 21

SMS advice for farmers in India (Jack and Tobias 3)

Recently a mobile based service was provided to cotton farmers in India. The toll-free hotline provided agricultural advises, information regarding weather and crop conditions via voice mails. The experiment was a successful receiving calls from 80% of the farmers within 2 years. Statistics revealed that an average farmer used the service for over 2.5 hours making approximately 20 calls. The farmers with access to the agricultural information were more likely to follow the advice resulting in better yield results and reduced use of chemical pesticides. The experiment also revealed differences in adoption of the service showing lesser usage by poorer and less educated farmers, even though the service was designed to be accessible to illiterate farmers. It was estimated that each dollar spend had yielded $10 back, still farmers were not willing to pay enough for the service. This displayed the need for subsidies to promote the adoption of technology.

5.2. Poor quality agricultural input

The low quality of crop input is a major barrier especially for poor farmers in the third world countries. Farmers use low quality seeds, fertilizers and pesticides with farming technology; and later when the harvest does not show any improvement, farmers blame the technology to be useless. A research supported by the IGC and the Swedish Research Council depicts a purchase of urea fertiliser and hybrid maize seeds from random stores across Uganda. The seeds were used for testing and obtained yields reported that purchased seed bags were diluted with “only half the seeds being hybrid (the other half were traditional seeds)” (Jack and Tobias 4). Whereas the urea fertilizers were sent to the laboratory for examination to verify its composition. The reports showed that it had “33% less nitrogen content than advertised” (Jack and Tobias 4). Hence the manipulated crop input causes unexpected yield results. The authentic inputs would have yielded an average return above 50% but due to the exploited resources only 1% of the crop yielded return over 10%.

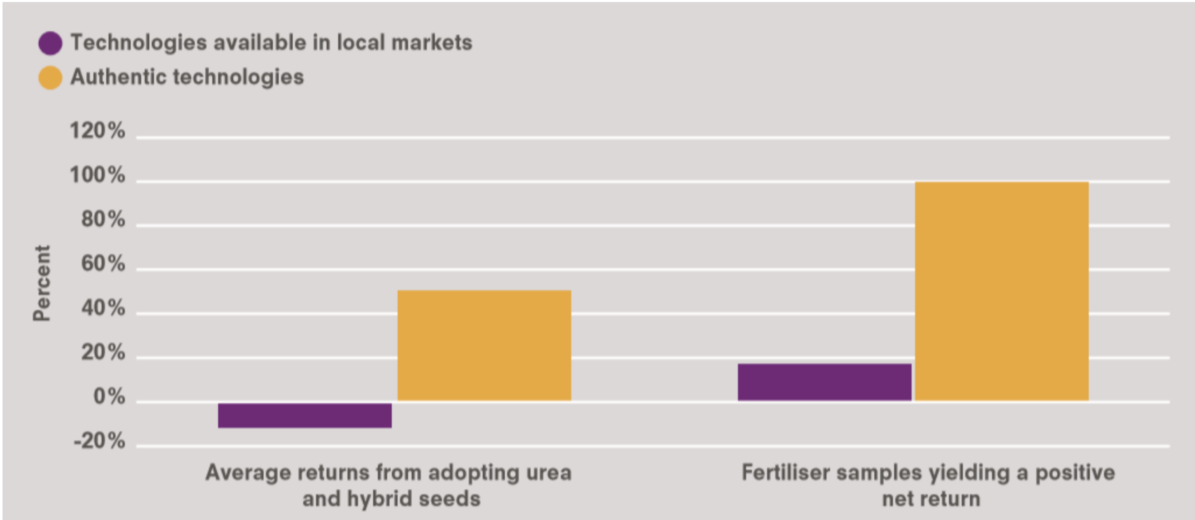

Fig. 20. **Average return from authentic vs manipulated crop inputs** from: Jack, Kelsey and Julia Tobias. *Seeding success: Increasing agricultural technology adoption through information*, December 2017, IGC, https://www.theigc.org/wp-content/uploads/2017/12/IGCJ5833-Agriculture-growth-brief-171214-Web.pdf. Accessed 16 July 2018.

5.3. High Price

The adoption of precision farming is observed mostly within the financially stable farmers who are capable of investing into the infrastructure and equipment. The basic requirements for practicing smart farming methods include a GPS, variable rate technology, in-field sensors, unmanned aerial vehicles, geo maps and a monitoring base. The cost of such high tech machinery causes an obstacle for many poor farmers. There are other cost affecting factor such as power supply, strong internet connection and cellular coverage which are needed to run these equipment.

6. Conclusion

Precision agriculture is a stepping stone towards sustainable food production in the future. Many research studies have proven exponential growth in the crop production using precision agricultural practices. There are many other agricultural advancements which are currently in use and some are under development such as mobile applications, fruit harvesters and agricultural robots. Scientists and agronomists around the world are working to convert all farming practices into tech operated tasks which will require limited human assistance. However, many poor farmers around the world are unable to access precision farming tech. The issue is that farmers are scared to invest their hard earned money into something they don't know anything about which is due to their illiteracy. One of the possible solutions to help them overcome technical barriers could include awareness campaigns that are targeted to provide the farmers with basic knowledge of farming technology. Local governments, NGOs and wealthy investors must take an action towards supporting farmers financially as well as to educate them on how to use the equipment. Thus farmers need to understand that if they want to stand strong against the competition then they need to adopt the upcoming agricultural technologies. With the successful adoption of farming technology, big issues like world hunger and global climate changes can be sustained.

Works Cited

Goddard, Tom. “What Is Precision Farming?” Alberta Agriculture and Forestry, 18 Feb. 2014, www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag1951?opendocument. Accessed 6 August 2018.

“10 Memorable Farming Quotes from Famous Figures.” MACHINEFINDER, 17 Feb.2017, blog.machinefinder.com/19688/10-memorable-farming-quotes-famous-figures. Accessed 1 August 2018.

“3 Ways Specialty Crop Farmers Can Protect with Ag Tech.” SPENSA,www.spensatech.com/ebook/protecting-specialty-crop-yields/protecting-specialty-crop-yields.pdf. Accessed 6 July 2018.

“30 Uses or Applications of GPS in Agriculture.” Grind GIS-GIS and Remote Sensing Blogs, Articles, Tutorials, 8 Jan. 2018, grindgis.com/blog/30-uses-of-gps-in-agriculture. Accessed 8 August 2018.

“Agriculture.” GPS, www.gps.gov/applications/agriculture/. Accessed 6 August 2018.

Borneman, Elizabeth. “Use of GIS in Agriculture ~ GIS Lounge.” GIS Lounge, GIS Lounge, 10 Mar. 2014, www.gislounge.com/use-gis-agriculture/. Accessed 3 August 2018.

“Boundless World History.” Lumen, Open SUNY Textbooks,courses.lumenlearning.com/boundless-worldhistory/chapter/the-agricultural-revolution/. Accessed 2 July 2018.

Briney, Amanda. “All You Wanted to Know About the Green Revolution.”ThoughtCo, ThoughtCo, 16 Apr. 2018, www.thoughtco.com/green-revolution-overview-1434948. Accessed 7 August 2018.

Chappine, Patricia. “The Agricultural Revolution: Timeline, Causes, Inventions & Effects.” Study.com, study.com/academy/lesson/the-agricultural-revolution-timeline-causes-inventions-effects.html. Accessed 1 July 2018.

“Climate Change Causes: A Blanket around the Earth.” NASA, 8 Aug. 2018,climate.nasa.gov/causes/. Accessed 8 August 2018.

“Crop Production and Natural Resource Use.” Fao.org, FAO of the UN, www.fao.org/docrep/005/y4252e/y4252e06.htm. Accessed 18 July 2018.

“Deforestation.” WWF, World Wildlife Fund,www.worldwildlife.org/threats/deforestation. Accessed 2 August 2018.

“Digital Cameras in Unmanned Aerial.” LUMENERA SOLUTION SHEET, www.lumenera.com/media/wysiwyg/documents/casestudies/UnmannedAerialVehicles.pdf. Accessed 27 July 2018.

“Employment in Agriculture (% of Total Employment) (Modeled ILO Estimate).” The World Bank, data.worldbank.org/indicator. Accessed 7 August 2018.

“Fertilizers | Uses, Benefits, and Chemical Safety Facts.” ChemicalSafetyFacts.org, 13 June 2018, www.chemicalsafetyfacts.org/fertilizers/. Accessed 6 August 2018.

“Food.” United Nations, www.un.org/en/sections/issues-depth/food/. Accessed 6 August 2018.

“Free Image on Pixabay - Tractors, Mower, Tractor, Pasture.” PIXABAY,pixabay.com/en/tractors-mower-tractor-pasture-3571452/. Accessed 6 July 2018.

“Global Greenhouse Gas Emissions Data.” EPA, Environmental Protection Agency, 13 Apr. 2017, www.epa.gov/ghgemissions/global-greenhouse-gas- emissions-data. Accessed 12 August 2018.

"Grangetto's Farm and Garden Supply, Landscape Supplies, Agriculture Supplies, Irrigation Supplies, Plant Nursery Supplies, Garden Supplies." Pest Alerts, www.grangettos.com/main/pest-alerts.html. Accessed 5 August 2018.

Hedlin, R.A., et al. "Fertilizer." The Canadian Encyclopedia,www.thecanadianencyclopedia.ca/en/article/fertilizer/. Accessed 6 August 2018.

"History of Precision Agriculture." Delmar Cengage Learning Companions -Nursing Fundamentals: Caring & Clinical Decision Making,www.delmarlearning.com/companions/content/140188105X/trends/history_pre_agr.asp. Accessed 4 August 2018.

Hunt, E. Raymond, and Craig S. T. Daughtry. "What Good Are Unmanned Aircraft Systems for Agricultural Remote Sensing and Precision Agriculture?" International Journal of Remote Sensing, Mar. 2017, pp. 1–32., doi:10.1080/01431161.2017.1410300. Accessed 19 July 2018.

Jack, Kelsey, and Tobias Julia. "Seeding Success: Increasing Agricultural Technology Adoption through Information." International Growth Centre, Dec.2017, www.theigc.org/wp-content/uploads/2017/12/IGCJ5833-Agriculture-growth-brief-171214-Web.pdf. Accessed 6 August 2018.

Jawad, Haider Mahmood, et al. "Energy-Efficient Wireless Sensor Networks for Precision Agriculture: A Review." Advances in Pediatrics., U.S. National Library of Medicine, 3 Aug. 2017, www.ncbi.nlm.nih.gov/pmc/articles/PMC5579920/. Accessed 8 August 2018.

Margaritoff, Marco. "Drones in Agriculture: How UAVs Make Farming More Efficient." The Drive, 13 Feb. 2018, www.thedrive.com/tech/18456/drones-in-agriculture-how-uavs-make-farming-more-efficient. Accessed 30 June 2018.

Mason, Matthew. "History of Agriculture." EnvironmentalScience.org,www.environmentalscience.org/history-agriculture. Accessed 6 August 2018.

Mazur, Michal. "Six Ways Drones Are Revolutionizing Agriculture." MIT Technology, 22 July 2016, www.technologyreview.com/s/601935/six-ways-drones-are-revolutionizing-agriculture/. Accessed 10 August 2018.

McKenzie, Shawn. "A Brief History of Agriculture and Food Production:"Https://Www.saylor.org/Site/Wp-Content/Uploads/2015/07/ENVS203-7.3.1-ShawnMackenzie-ABriefHistoryOfAgricultureandFoodProduction-CCBYNCSA.pdf,Saylor, 2007, www.saylor.org/site/wp-content/uploads/2015/07/ENVS203-7.3.1-ShawnMackenzie-ABriefHistoryOfAgricultureandFoodProduction-CCBYNCSA.pdf. Accessed 10 August 2018.

"Fallow." Merriam-Webster, www.merriam-webster.com/dictionary/fallow. Accessed 10 July 2018.

"Eutrophication." Merriam-Webster, www.merriam-webster.com/dictionary/eutrophication. Accessed 10 August 2018.

"Transpiration." Merriam-Webster, www.merriam-webster.com/dictionary/transpiration. Accessed 10 August 2018.

Myers, Kristen. "The World's Ten Hungriest Countries." Concern, 12 Oct. 2017,www.concernusa.org/story/worlds-ten-hungriest-countries/. Accessed 10 August 2018.

Nowatzki, John, et al. "GPS Applications in Crop Production." EXtension, 28 Sept.2011, articles.extension.org/pages/9672/gps-applications-in-crop-production. Accessed 12 August 2018.

Opfer, Chris. “How Are Drones Changing Agriculture?” HowStuffWorks, 8 Mar.2018, science.howstuffworks.com/environmental/green-science/are-drones-changing-agriculture.htm. Accessed 15 July 2018.

“PRECISION AGRICULTURE SERIES TIMELY INFORMATION Agriculture, Natural Resources & Forestry .” Alabama Precision AG Extension, Jan. 2009, sites.aces.edu/group/crops/precisionag/Publications/Timely Information/Overview of Variable-Rate Technology.pdf. Accessed 10 August 2018.

“Precision Agriculture Technology.” FARMS, www.farms.com/precision-agriculture/technology/. Accessed 10 August 2018.

“Precision Farming - Producing More with Less.” Precision Farming – Producing More with Less | CEMA - European Agricultural Machinery, CEMA, www.cema-agri.org/page/precision-farming-producing-more-less. Accessed 19 June 2018.

“Precision Farming Tools: Variable-Rate Application.” Virginia Cooperative Extension, pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/442/442-505/442-505_PDF.pdf. Accessed 1 August 2018.

“Precision Farming: Key Technologies & Concepts.” CEMA, cema-agri.org/page/precision-farming-key-technologies-concepts. Accessed 5 July 2018.

“Precision Maps.” FARMS, www.farms.com/precision-agriculture/precision-maps/. Accessed 10 August 2018.

“Acidification.” Queensland Government,www.qld.gov.au/environment/land/soil/soil-health/acidification. Accessed 11 August 2018.

Rouse, Margeret. “What Is Precision Agriculture? - Definition from WhatIs.com.”WhatIs.com, whatis.techtarget.com/definition/precision-agriculture-precision-farming. Accessed 10 June 2018.

Sallam, Mohamed N. “INSECT DAMAGE: Damage on Post-Harvest.” FAO,www.fao.org/3/a-av013e.pdf. Accessed 14 July 2018.

Schmaltz, Remi. “What Is Precision Agriculture and How Is Technology Enabling It?” AgFunderNews, 17 July 2018, agfundernews.com/what-is-precision-agriculture.html. Accessed 3 August 2018.

Steele, Dale. “Analysis of Precision Agriculture.” Statistics Canada, Apr. 2017,static.agcanada.com/wp-content/uploads/sites/3/2017/05/Final-Report-Analysis-of-Precision-Agriculture-Adoption-and-Barriers-in-western-Canada-April-2017.pdf. Accessed 18 June 2018.

Sylvester, George. “E-Agriculture In Actions: Drones for Agriculture.” Food and Agriculture Organization of the United Nations, http://www.fao.org/3/I8494EN/i8494en.pdf. Accessed 9 July 2018.

“Differential GPS.” TRIMBLE, www.trimble.com/gps_tutorial/dgps-how.aspx. Accessed 12 August 2018.

“What Is Forest Conversion?” WWF,wwf.panda.org/our_work/forests/deforestation_causes/forest_conversion/. Accessed 11 August 2018.

Geo Spatial Media. “What Is Precision Agriculture? What Is the Meaning of Precision Farming?” YouTube, 20 Nov. 2017, www.youtube.com/watch?v=WhAfZhFxHTs. Accessed 12 August 2018.