A Spatial Decision Support System To Address Precision Agriculture Adoption Challenges

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Declaration

I declare that the work described in this dissertation is, except where otherwise stated, entirely my own work, and has not been submitted as an exercise for a degree at this or any other university. I further declare that this research has been carried out in full compliance with the ethical research requirements of the School of Computer Science and Statistics.

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Abstract

Agriculture is the primary indigenous industry in Ireland and is playing an important role in the nation's economic recovery. Precision Agriculture presents opportunities for Irish agriculture to gain competitive advantage and expand production to meet national targets. The adoption of Precision Agriculture has been low until now due to cost and complexity barriers. This study presents a spatial decision support system that seeks to address challenges facing the adoption of Precision Agriculture. The research question is 'would an intuitive decision support system incorporating remote sensing data, mapping interfaces, crowdsourced data and external data sources address challenges facing the adoption of Precision Agriculture?'.

A mixed methods research methodology was employed for the purposes of this study. A survey was circulated to Precision Agriculture stakeholders in Ireland. Survey participants were asked to evaluate features of the developed spatial decision support system and to indicate if the system would be useful for addressing challenges regarding the adoption of Precision Agriculture. Interviews were held with a number of key stakeholders to gain further insight on the barriers to adoption, the technologies driving Precision Agriculture, the drivers for adoption, methods of increasing adoption and the outlook for Precision Agriculture going forward.

The findings of the research are that the spatial decision support system would be useful for addressing challenges facing the adoption of Precision Agriculture. The system features rated highly by survey respondents included the crowdsourcing feature and the application's responsive design. Key drivers for the greater adoption of Precision Agriculture identified were increased profitability, knowledge transfer groups, financing and mobile applications. Key technologies driving Precision Agriculture were found to be high precision positioning systems, broadband, remote sensing and sensors. The outlook for the adoption of Precision Agriculture was found to be positive once barriers to adoption are addressed.

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Abbreviations

API Application Program Interface

CAP Common Agriculture Policy

CSA Climate Smart Agriculture

CTF Controlled Traffic Farming

DAFM Department of Agriculture, Food and the Marine

EIP-AGRI European Innovation Partnership for Agricultural Productivity and Sustainability

ESA European Space Agency

EU European Union

FMIS Farm Management Information Systems

GIS Geographical Information Systems

GNSS Global Navigation Satellite System

GPS Global Positioning System

IOT Internet of Things

ISO International Organization for Standardization

IT Information Technology

JRC Joint Research Centre

M2M Machine To Machine

NASA National Aeronautics and Space Administration

NDVI Normalized Difference Vegetation Index

OADA Open Ag Data Alliance

OGC Open Geospatial Consortium

PA Precision Agriculture

PFA Precision Farming Application

PLF Precision Livestock Farming

PV Precision Viticulture

RDP Rural Development Policy

RFID Radio Frequency Identification

RTK Real Time Kinematic

SNAP Sentinel Application Platform

SSM Site Specific Crop Management

SWOT Strengths-Weaknesses-Opportunities-Threats

TAM Technology Acceptance Model

UAV Unmanned Aerial Vehicle

VRT Variable Rate Technology

1 Introduction

Technology is having a major impact on workplaces with disruptive technologies transforming work practices and delivering enhanced productivity. The rate of technological change is forecast to grow exponentially in the coming years (Brynjolfsson and McAfee, 2014). Precision Agriculture (PA) presents opportunities for farmers to leverage new technologies to drive efficiencies and maximise profits. The Joint Research Centre (JRC) of the European Commission defines PA as a “whole-farm management approach which aims to maximise return on investment and reduce environmental impacts by using remote sensing, information technology, proximal data gathering and satellite positioning data” (Zarco-Tejada et al., 2014).

1.1 Rationale for this Study

“Smart and digital agriculture holds many promises for a more sustainable, productive, and competitive EU farm sector. We have seen solutions that have the potential to significantly improve resource efficiency, animal health, carbon footprint and farmers' position in the supply chain. But we have yet to witness a wider uptake in the broader farm community. Developing new solutions is not in itself enough - encouraging sufficient uptake is an issue we must address” (Hogan, 2016).

A number of reports and workshops have recently highlighted the potential for PA to positively impact agriculture but the adoption of PA has been low and uneven across Europe. The EU Commissioner for Agriculture, Mr Phil Hogan recently delivered a speech on the potential of PA technology to protect the environment and enable farms to become smarter, more productive and more efficient. Mr Hogan noted that technologies were available to achieve these goals but uptake in the agricultural community has been low. Agriculture was identified as the last industry where information technology is not widely adopted, driving efficiencies and production gains (Hogan, 2016).

Teagasc’s Technology Foresight 2035 Report anticipates an exponential growth of technological innovation in Irish agriculture over the next two decades. The report identified precision and digital technologies, human and soil microbiota, plant and animal genomics, food chain transformation and food processing technologies as important technologies that will drive growth in the Irish agribusiness sector. Farmers will be using PA technologies such as networked autonomous vehicles, robotic milking and robotic harvesting machines, tractor based sensing, drones, micro-satellites and sensors that are connected via the Internet of Things (IOT) to produce extensive datasets which can be analysed by farmers to drive effective decision making. PA adoption was reported to be low in Ireland due to the cost and complexity of the technologies (Teagasc, 2016).

The European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) is one of five partnerships established by the European Union (EU) to drive research and innovation in key areas. The EIP-AGRI Focus Group on Precision Farming recently published a report on the benefits of PA and recommendations for implementing PA in the EU. A recommendation for increasing adoption of PA among medium and small farmers was the development of tools that are easy to use, robust and affordable. Additional recommendations were the need to increase the sharing of data, usage of open-data and development of technical solutions that combine maps with other data sources to enable management decision making (Bahr et al., 2015).

The JRC recently published a report on PA in Europe and described how PA can deliver benefits such as improved crop and field measurements, efficient application of inputs and enhanced decision making. Barriers to the adoption of PA were reported to be high start-up costs, a risk of insufficient return on the investment, infrastructure and institutional constraints, knowledge and technical gaps, the lack of local technical expertise and cultural perception. A number of recommendations were made to increase PA adoption within the EU including the provision of free and accurate data for use by PA applications. Free data generated by Global Navigation Satellite System (GNSS) services and the Copernicus remote sensing programme were highlighted as important sources of data for PA applications. Additional recommendations included researching the benefits of using PA data for crowdsourcing farm data, researching better methods of raising PA awareness, disseminating knowledge and technology transfer (Zarco-Tejada et al., 2014).

This study presents a spatial decision support system that seeks to address the low adoption of PA technologies in line with the recommendations of the EIP-AGRI and JRC reports. Key features of the developed Precision Farming Application (PFA) include crowdsourcing, mobile and desktop delivery, usage of open data and integrated datasets presented on an intuitive map interface.

1.2 Background

Agriculture is an important element of rural life and the economy in Ireland with 140,000 farmers producing a gross agricultural output of €6.18 billon and agri-food exports of €10.3 billion in 2013 (DAFM, 2014). The Food Wise 2015 strategy outlines the targets and actions required to maximise the performance of the Irish agricultural industry over the coming decade. Key areas identified that require strategic action to deliver growth were human capital, competitiveness, market development and innovation. The importance of PA technologies for strategic change was recognised in these areas.

Figure 1.1 below displays a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis of Irish agriculture from the Department of Agriculture, Food and the Marine's (DAFM) Food Wise 2025 strategy (DAFM, 2016). The SWOT analysis establishes the current strengths and weakness in Irish agriculture and identifies threats and opportunities that must be addressed to maximise the potential of Irish agriculture.

FIGURE 1.1 A SWOT analysis of Irish agriculture (DAFM, 2016).

Strengths of agriculture in Ireland include grass based sustainable production systems, access to the EU single market and a strong research eco-system. Threats going forward for agriculture in Ireland are challenging green house and air emission targets, supply chain disruption due to potential disease or food safety risks, biodiversity loss, reduced water quality and price volatility. Weaknesses include access to finance, land mobility and lack of scale. Opportunities for Irish agriculture are increasing demand for quality food, Ireland's green image in key markets and expansion in key farming sectors.

Technology is driving competitive advantage in agriculture. A key theme of the 2016 World Economic Forum was the fourth industrial revolution or Industry 4.0. Disruptive technological developments such as nanotechnology, biotechnology, robotics and the IOT are creating new opportunities that will change how humans work with machines (Wolter et al., 2015). Ireland has a strong Information Technology (IT) sector with indigenous and multinational companies working together on advanced technologies. Opportunities exist to combine the skills of indigenous IT companies with experienced agribusiness stakeholders into a mutually beneficial domestic PA technology ecosystem that would develop and deliver innovative PA technologies.

Food security is becoming an increasingly important issue with the United Nations predicting a global population of 9.7 billion by 2050. The demand for food will increase in line with population growth and the rise of incomes (UN, 2015). The competition for land will be intense in the future as agriculture, housing, energy, transport and environmental industries compete to control a finite asset. Environmental sustainability will be an important consideration as climate change, industrial growth and population pressures impact freshwater supplies and air quality. Climate change will bring more extreme weather events, higher temperatures, more flooding events and increased crop loss. The cost of agricultural inputs such as fertiliser and fuel are projected to rise as the supply of fossil fuels reduces (Tilman et al., 2002).

Bongiovanni and Lowenberg-DeBoer described agricultural sustainability as "the intersection of the disciplines of ecology, economics and sociology" (Bongiovanni and Lowenberg-DeBoer, 2004). Sustainable agriculture is economically viable, improves the quality of life for farmers and the wider society, enhances environmental quality and supplies food to feed growing populations. Farmers will need to produce more food with fewer resources to feed the increased future population. PA offers farmer's solutions which utilise multiple technologies to maximise food production, improve quality, reduce risk, increase profits and safeguard the environment. PA integrates remote sensing, IT, sensors, big data and geographical information systems (GIS) to provide valuable insights that enable effective decision making.

Figure 1.2 below illustrates Bongiovanni and Lowenberg-DeBoer's disciplines of agricultural sustainability.

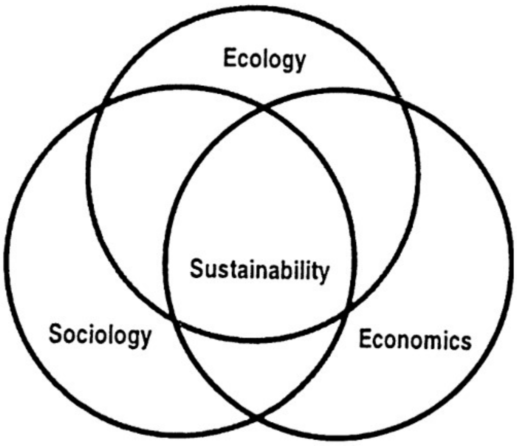


FIGURE 1.2 : The Disciplines of Agricultural Sustainability (Bongiovanni and Lowenberg-DeBoer, 2004).

1.3 The Research Question

The research question is 'would an intuitive decision support system incorporating remote sensing data, mapping interfaces, crowdsourced data and external data sources address challenges facing the adoption of PA?'.

The objectives of this study are to explore:

- The role of technology in agriculture and the technologies driving PA
- The barriers and drivers for the adoption of PA
- The applications and benefits of PA
- To investigate methods of increasing PA adoption
- To determine if the developed PFA would be useful for addressing challenges regarding the adoption of PA technology

1.4 Why This Research Is Important

Agriculture is facing a number of challenges in the coming years and PA offers solutions to deal with these challenges. Research is required to understand the barriers facing the adoption of PA in Ireland and to find new methods of achieving the wider adoption of PA so that the benefits of PA technologies can be realised by more farmers and the wider community. The spatial decision support system that has been developed for this study incorporates features suggested by the recommendations of the EIP-AGRI and JRC reports.

1.5 To Whom Is It Important

This research is important to stakeholders in agribusiness such as farmers, suppliers of agricultural machinery, agricultural researchers, agricultural contractors, agricultural cooperatives, government agencies and food companies.

1.6 Scope

The scope of this research is the Irish agribusiness sector. The evaluation survey was circulated to 95 stakeholders in the agribusiness sector including farmers, farming organisations, suppliers and manufactures of high-tech farm machinery, employees in DAFM and companies working with geospatial and agri-tech technologies. 15 key stakeholders in the Irish agribusiness sector were contacted with requests for interviews.

1.7 Document Structure

Chapter 1 introduces the research and describes the rationale for the study, provides background information, describes the research question, explains why the research question is important and interesting, to whom it is important, the scope and boundaries of the study and a description of subsequent chapters.

Chapter 2 reviews important literature in the research field, critically analyses the works, covers the major theories in the research area and positions the research question in the context of the literature. Topics covered in the literature review include innovation and agricultural development, the fundamentals of PA, the benefits of PA, technologies driving PA applications, applications of PA, the adoption of PA, drivers for the adoption of PA, challenges to the wider adoption of PA and opportunities for increasing the adoption of PA.

Chapter 3 describes the methodology and fieldwork element of the research. The considered methodological approaches are described, the applied methodological approach is discussed and justified, limitations of the chosen methodological approach are explained and the collection of data via interviews and surveying is described.

Chapter 4 discusses the research findings and analysis. The data collected from the evaluation survey and interviews was analysed and interpreted, the analysis methodology described to show correct procedures were followed and the research findings were revealed.

Chapter 5 presents the research conclusions and areas for future work. The research claims are described, new findings are listed, an explanation is given for how the research answers the research question and advances the current state of knowledge, the generalisability and limitations of the research are addressed and possible future directions identified for research in this area.

2 Literature Review

2.1 Technological Innovations and Agricultural Development

Innovation has been a key driver of agricultural development since the first farmers started growing crops during Neolithic times. Drucker defined innovation as “the act that endows resources with a new capacity to create wealth” (Drucker, 2014). In the agricultural industry, innovation is the successful deployment of good ideas into practice on farms.

The first agricultural revolution took place 10,000 years ago in the Fertile Crescent with the transition from hunter gathering to farming. Agriculture enabled the development of permanent settlements, provided stable food sources and enabled the foundation of civilisations. The first farmers planted wild seeds and used digging sticks, hoes, spades, flint sickles, antler picks, grinding stones and pottery to collect, process and store the harvest (Suprem et al., 2013). The domestication of animals provided draught animals which led to the development of technologies such as dragging sledges, ploughs and wagons. Trade in farm produce developed over time and led to the exchange of ideas and technologies (Price, 2000). Progression into the bronze and iron ages brought technical innovations such as axes, pots, metal ploughs and rotary quern stones. Farming practices such as irrigation, the application of fertilisers and crop rotation were developed to increase harvests and improve field management.

The second agricultural revolution took place in tandem with the Industrial Revolution during the 18th century. Innovative technologies and practices that drove the Industrial Revolution were applied to the countryside. Increased production was achieved with less labour due to the introduction of mechanisation, motorisation, high yield crops, organic fertiliser usage, improved crop rotation techniques, selective breeding of animals and the development of improved plant varieties. The introduction of horse drawn sowing machines, grain binders, threshers, reapers and steam powered tractors allowed farmers to do more work in less time. The increased productivity on farms enabled the supply of more food to feed expanding populations in cities (Allen, 1999).

The third agricultural revolution is known as the Green revolution and took place in the 20th century with the development and adoption of chemical farming, more high-yield crops, multiple cropping, increased mechanisation, biotechnology and food manufacturing.

Chemical farming is used to describe the usage of inorganic herbicides, fungicides, pesticides and fertilisers on farms. The industrial production of nitrogen with the Haber-Bosch process enabled the manufacture of nitrogen fertiliser for farming. The addition of nitrogen dramatically improved crop performance but excessive application caused problems when nutrients leaked into the surrounding environment. Multiple cropping is a form of sustainable agriculture where farmers grow multiple crops in the same field. Benefits for the farmer include reduced risk of total crop failure, less plant diseases, increased biodiversity and less pest infestations (Borlaug, 2000). The introduction of gasoline and diesel tractors allowed farmers to carry out more farm work with fewer resources. Machinery manufacturers developed innovative buying plans to enable farmers to purchase new machinery on credit. Average farm sizes increased as smaller and less efficient farms were consolidated into larger farms.

The fourth agricultural revolution is currently underway with development and increasing adoption of plant and animal genomics, IT, Industry 4.0 technologies, microbiota technologies, advanced food processing technologies and PA technologies (Teagasc, 2016). Drivers for the fourth agricultural revolution include the need for Climate Smart Agriculture (CSA), the necessity to maximise production to meet the growing global population and the need for sustainable agriculture. CSA aims to reduce the production of greenhouse gases in agricultural production and adapt agricultural and food systems to deal with changing weather patterns. PA is leveraging technological innovations such as cloud computing, nanotechnology, Machine to Machine (M2M) communication, broadband, data analytics, sensors, global positioning devices and satellites to generate and process data that facilities effective and timely decision making by farmers. The convergence of technologies and datasets with PA can bring new insights and benefits to farmers (Barrera, 2011).

Industry 4.0 will positively impact PA and the fourth agricultural revolution with increased investment in the development of cyber-physical systems, sensors, IT, networking systems, robotics, big data, cloud computing and augmented reality (Wolter et al., 2015).
The decision by the U.S. government in 1983 to allow civilian usage of the Global Positioning System (GPS) was the first step in the development of PA. The free availability of GPS enabled guidance systems that can be fitted to tractors or harvesters for better navigation when planting, spraying and harvesting crops. GPS guidance systems remain the most widely adopted PA technology to date. The private sector is investing heavily in

PA technologies with specialist PA companies being purchased by well-established agricultural companies. Embodied PA innovations are predicted to become the most widely adopted due to ease of use (Lowenberg-DeBoer, 2015). The impact of the fourth agricultural revolution will be profound with the reduced need for farm labour and farmers spending more time working with PA systems. Farmers will need to be trained on business intelligence concepts to understand the PA data collection and reporting process. With the increasing usage of PA applications, farmers will become data managers and analysts (McBratney et al., 2005).

2.2 Fundamentals of Precision Agriculture

PA has evolved over time as technologies have progressed and innovative products have been developed. In 1996, Heuvel defined PA as "an application of an input across a field based upon some evaluation of the variability of need for the input" (Heuvel, 1996). PA at that time was primarily applied on arable farms with the use of site specific management (SSM) techniques. Farmers implementing SSM review the spatial and temporal variability of the crop and soil types in the field and adjust water supplies and the application of fertiliser, pesticides and herbicides to meet the needs of specific areas of the field. Spatial variability with SSM refers to the changes in crop performance in different areas of a field. Crops grow at different rates due to variable access to nutrients and water, crop diseases, disparate soil types and the impact of pests. Many fields contain multiple soil types with different requirements for nutrient management. Temporal variability with SSM refers to the changes that occur over time in a field. Comparing crop growth at similar stages over multiple seasons can identify areas of the field that are performing well and other areas requiring attention (Heuvel, 1996).

Over time, PA expanded into more sectors of agriculture such as livestock, viticulture, horticulture, fisheries and forestry. Khosla described the fundamentals of PA as the "five R's"; the Right source in the Right amount to the Right place at the Right time and in the Right manner. The right source refers to the selection of the appropriate element that will improve the agricultural product. Examples of the right source include identifying the correct nutrient that a crop needs to thrive or the appropriate feedstuff to supply to animals for optimal growth. The right amount of the input material applied to an area ensures the efficient usage of resources, reduced waste and cost savings. The right place refers to the need to apply inputs to the area of need. Fields are heterogeneous in nature with differences in soil properties and crop performance across fields. The right time allows for timely interventions that save resources and produce results. Sensors can be used to alert farmers of important events requiring attention such as cows calving or applying fertiliser at the optimal time during the crop growth season. The right manner is the method of application used to deploy the input resource. In terms of crop nutrients, the right manner may refer to the spraying or injection of nutrients (Khosla, 2010).

Gebbers and Adamchuk defined PA as “a set of technologies that combines sensors, information systems, enhanced machinery and informed management to optimize production by accounting for variability and uncertainties within agricultural systems”. PA allows farmers to actively manage the quality and quantity of agricultural produce and enables the monitoring of the food production chain. The site-specific management of fields and the individual management of livestock uses resources in an efficient manner that protects the environment, increases profits for farmers and ensures the sustainability of the food supply (Gebbers and Adamchuk, 2010). The EIP-AGRI focus group described PA as “a management concept focusing on (near-real time) observation, measurement and responses to inter and intra-variability in crops, fields and animals” (Bahr et al., 2015).

2.3 Technologies driving Precision Agriculture applications

PA developers bring many different technologies together to provide useful products to farmers. Technologies that are driving PA applications include sensors, high precision positioning systems, smartphones, broadband, cloud computing, automated steering systems, M2M communication, big data, geospatial systems, machine controls, remote sensing, variable rate technology (VRT), robotics, application programming interfaces (APIs), Unmanned Aerial Vehicles (UAV), decision support systems and Radio Frequency Identification (RFID).

Remote sensing data has been used for a number of years in PA applications to visualise land parcels and identify crop health indicators. The remote sensing industry is currently experiencing a period of rapid expansion with the proliferation of UAVs and micro satellites and the availability of open spatial data, high frequency data and high resolution imagery.

Low cost UAVs (also known as drones) are allowing more farmers to monitor their own crops with high resolution cameras and take actions to improve crop yields (Zarco-Tejada et al., 2014). Today's very high resolution satellite imagery can deliver sub-meter resolution. The WorldView-3 satellite is currently providing 30cm resolution imagery which brings increased accuracy to PA applications, enhanced decision making and more efficient operations. The availability of open and free remote sensing data from the United States' Landsat and the European Space Agency's Sentinel programs is widening the geospatial market and enabling the development of low cost PA solutions. The Landsat 8 satellite is imaging the globe every 16 days and the Sentinel 2 satellites have a combined revisit frequency of 5 days. The increased availability of this open data enables farmers to view their land at regular intervals, identify growth patterns and decide areas for resource allocation (Delegido et al., 2011).

A GIS combines geography and technology to provide users with mapping, analysis and reporting tools. Multiple datasets from sensors, crop yields, weather data and maps can be combined in map interfaces to enable enhanced decision making. Farm assets and utilities can be accurately mapped to allow farmers to plan crop layouts that maximise production when planting seeds. Farm assets can be managed centrally which helps farmers keep track of their assets, organise maintenance and plan for upgrades. Satellite and drone data can be analysed to determine crop growth and crop health in specific management zones. This data can be integrated into a GIS to generate geo-referenced yield maps, nutrient management plans and farm reports. A GIS enables enhanced decision making by delivering multiple integrated geo-referenced datasets and reports to farmers on intuitive map interfaces (Tayari et al., 2015).

Decision support systems are information technology systems that enable effective problem solving and decision making based on accurate and relevant data. Internet based decision support systems have increased the accessibility of decision making information, delivered cost savings for suppliers and reduced technological barriers to decision support system adoption (Shim et al., 2002). Farmers can access decision support systems on their farms with internet technologies and mobile devices to help the decision making process. Spatial decision support systems leverage the power of geospatial technologies to present relevant data on map based interfaces. Users can make effective decisions by running reports and combining multiple datasets on easy to use map interfaces. Farmers can use spatial decision support models such as irrigation scheduling and land usage models to visualise performance metrics and identify areas for attention (Arciniegas et al., 2013).

Internet technologies have facilitated the collection of data from multiple users in a process known as crowdsourcing. Farmers have been working together for many years to achieve cost savings and enhanced profits through agricultural cooperatives (Ortmann and King, 2007). Farmers can now supply data to PA applications which utilise crowdsourcing to collect data on supplier and market prices, monitor crop disease incidents, track severe weather events and gather information on crop damage. The integration of multiple external and internal data sources is a key driver of effective decision making. External APIs provide valuable business intelligence and analytics for users (Chen et al., 2012). Farmers can leverage external APIs that provide market price data, weather forecasts and fertiliser prices to plan future farm actions.

Machine control systems can automate the application of nutrients, navigation and harvesting on farms. VRT agro-chemical applicators can direct field equipment to apply the appropriate rate and mix of water, seeds, nutrients and chemicals at the required locations. Automatic guidance systems are used by farmers to control infield navigation to save on fuel and to make work easier and less tiring for farmers. Networked systems use distributed control to enable the delivery of nutrients to individual plants via plant sensors and actuators (Keicher and Seufert, 2000).

Low cost, real-time and robust sensors can detect animal behaviour, crop condition, soil texture, pest infestations and soil status indicators such as salt content, acidity, nitrogen and moisture levels. These sensors can be deployed in management zones within a field to enable the recording and analysis of data. The IOT is arriving on today’s farms with the proliferation of connected sensors and devices. Accurate and real time information from connected devices are a valuable resource for farmers. Farmers can analyse the collected data and make informed decisions. RFID tags on livestock allow farmers to monitor individual animals and enable automated machines to feed and milk animals. RFID tags can be placed on farm produce to track products through the production systems for traceability purposes (Hamadani and Khan, 2015).

High precision positioning systems such as GPS and Real Time Kinematic (RTK) enable the accurate positioning of tractors and harvesters for efficient navigation and resource allocation within land parcels. RTK uses a base station and satellite positioning to provide accuracy to 2cm. Farmers are reducing fuel costs and saving time with efficient navigation that eliminates the need for multiple passes of the same area (Teagasc, 2016). Big data is managing and extracting insights on farm performance from the large volumes of data created by the array of devices and sensors for PA applications. Big data is founded on the principles of volume, variety, velocity and veracity. Large volumes of real-time and legacy datasets from multiple sources are used to produce accurate reports. Combining multiple different sources of information together can bring new insights that drive effective decision making by farmers. Researchers are actively developing data management solutions to drive enhanced reporting and cost savings for farmers (Bronson and Knezevic, 2016).

2.4 Benefits of Precision Agriculture

The key benefits of PA for farmers are efficient farming practices, greater profits, increased production, better quality produce, reduced inputs, minimised risk, more data for better planning and decision making, enhanced soil fertility, labour savings, environmental sustainability, food security, traceability, automation of repetitive work and better animal welfare (Zarco-Tejada et al., 2014).

Increased farm profitability is an important benefit of PA for farmers. Griffin and Lowenberg-DeBoer reviewed 234 studies of PA published from 1988 to 2005 and found PA to be profitable for 68% of the cases studied (Griffin and Lowenberg-DeBoer, 2005). Arable farmers have traditionally used a whole field approach when planting seeds, applying fertiliser and spraying pesticides. PA allows the arable farmer to break a field down into smaller management zones based on crop yield rates and crop production factors such as pest presence, soil types and soil acidity levels. Farmers can use the knowledge gained from management zones to develop management plans and implement processes that ensure the best usage of resources to maximize output and profits (Zhang et al., 2002).

Dairy farmers can use PA applications to enhance profitability by monitoring individual livestock and making interventions at the right time to optimise outcomes. Sensors can record key aspects of livestock fertility and alert farmers when an animal is ready to reproduce. Dairy farmers can maximise the number of calves, produce more milk, save time and reduce artificial insemination costs by monitoring their livestock (Hamadani and Khan, 2015).

Farmers are constantly making important decisions that impact their business success. PA uses a continuous cycle of data collection, data analysis and application to maximise farm profits and protect the environment by managing land and livestock changes over time. The data collection process identifies areas of interest and records the required data. The data analysis process organises, queries and reports on the collected data. The farmer can make effective decisions based on the reports generated (Zacepins et al., 2012).

Farmers can improve the quality of their produce and increase profits by using PA technologies and practices that actively monitor production. Automated machine vision systems are being used in the fruit and vegetable sectors to monitor quality and grade produce. Chemicals for spraying and fertilizer in the production process can be applied to precise areas and recorded to reduce the amount of chemicals in the final product. Precise irrigation methods are reducing costs for farmers, delivering water to areas of need and producing better quality fruit and vegetable (Doruchowski et al., 2009).

Time and labour savings can be achieved through the automation of repetitive farming tasks. In the dairy sector, robotic milking can record valuable data on milking performance, save time for farmers, reduce the need for external labour, encourage greater production, better animal health and higher quality milk. Auto-steer systems on tractors and harvesters can reduce driver fatigue by automating the navigation of fields with satellite positioning. Automated feeding systems can provide livestock with feed at regular intervals and reduce the workload for farmers. Animals are less stressed with automatic feeding and lower ranking animals have more access to feed (Grothmann et al., 2010).

PA applications protect the environment by minimising the application of fertilisers and pesticides to crops and reducing the quantity of chemicals that drain into rivers and streams. Yield maps and crop health data is used to target specific areas that require the application of chemical fertilisers or pesticides. Farmers can record their usage of chemicals over time in specific locations to ensure efficient usage of resources and reduced environmental impact. The efficient navigation of fields with high precision positioning systems can reduce soil erosion, soil compaction and the production of greenhouse gases by farm machinery (Zarco-Tejada et al., 2014).

PA applications can continuously monitor animal health in real-time and alert farmers when intervention is required. Sensors can monitor livestock and their environment to detect changes in livestock positioning, feeding patterns, temperature, humidity and sounds. Pig farmers can monitor the health of their herds by reviewing the sounds produced by the herd. Early detection of coughing sounds can reduce disease transmission in the herd and save money on antibiotic purchases and veterinary fees. Feeding patterns can be monitored for individual animals and farmers can be alerted when particular animals are eating or drinking less (Banhazi and Black, 2009).

2.5 Applications of Precision Agriculture

Vineyards are often diverse environments with variable topology and microclimates. Vines grow and produce grapes at different rates depending on factors such as soil quality, access to water and nutrients, altitude and temperature. Precision viticulture (PV) applications are used to increase quality, record production levels, generate yield maps and identify zones requiring additional irrigation or fertiliser (Matese et al., 2015). Drones and satellite imagery are used to analyse the health of the vines using Normalised Difference Vegetation Index (NDVI) to identify areas that require attention. The NDVI uses the visible and near-infrared bands of multispectral imagery to display plant health information. Nutrients are applied to specific areas using the analysed data to reduce water usage and the cost of fertilisers.

Arable farmers use high precision positioning systems, VRT and Controlled Traffic Farming (CTF) to drive efficiencies for crop production and protect the environment. High precision positioning systems enable the accurate positioning of a farmer’s tractor in a field and facilitate the precise seeding of crops, higher planting density and the efficient application of pesticides, nutrients and herbicides. VRT allows farmers to vary the application of fertiliser on specific areas of the field according to the needs of the crop. CTF enables farm vehicles to accurately navigate fields which results in reduced operator fatigue and minimised crop damage (Vermeulen et al., 2010). Tractors and combine harvesters are large vehicles with the capacity to damage crops with poor operator direction (Suprem et al., 2013).

Livestock farmers are using Precision Livestock Farming (PLF) to monitor their herds and environment, detect diseases at an early stage, record growth, food intake and milk production (Wathes et al., 2008). Farmers can review the variation in performance within their herd and make the necessary input changes to achieve optimal results. Alerts can be setup to notify a farmer when a cow is going to calve. Time savings and better outcomes are achieved by applying technology to herd management. Horticulture farmers are using machine vision methods to record the size, shape, colour, external defects, sugar content and acidity of their products (Kondo, 2010).

PA is used in forestry to monitor growth, produce biomass estimates, identify diseased or infested trees, classify different species of trees and determine areas ready for harvesting. Remote sensing imagery captured by satellites and drones are analysed in geospatial systems at regular intervals to produce data that drives planning and decision making. NDVI maps can be used to identify tree health in specific areas. Harvesting machines fitted with high precision positioning systems can record their location and harvesting yields to ensure that a forest is managed appropriately (Zhang et al., 2002).

Real time information from PA applications will lead to changes in the monitoring and trading of crops. Government agencies and the financial markets will be aware of crop yields during the growing season rather than at the end of season. The pricing for crop markets will become more dynamic with fluctuations occurring as data is received during the growing season. Government agencies will be able to forecast crop yields more accurately with the increased volumes of crop performance data (Rasmussen, 2016).

2.6 Requirements for the successful implementation of Precision Agriculture

Murakami et al. studied the requirements for a successful implementation of a PA application. Key components were found to be scalability, low cost, support, integration and interoperability with the utilisation of open data standards, rule based workflows, automated and intuitive data processing methods, user control over analysis and processing functions, systems customised to meet farmer needs and an easy to user interface (Murakami et al., 2007). Farmers need systems that can grow over time as more PA applications are implemented. Low cost systems are needed as farmers are often unwilling to take a risk on expensive applications that may not deliver the expected benefits. Farmers require systems and applications with interfaces that integrate with legacy, current and future systems.

Farming is a diverse industry and PA applications must be customised to suit the particular needs of the farmer. Specific modules of PA applications can be supplied to the farmers based on their requirements. Rule based workflows allow farmers to deploy their business knowledge into a PA application. Standards and interoperability protocols ensure that systems with different technologies can communicate effectively. Intuitive interfaces ensure that farmers can use the system effectively with minimal training. Usable and automated data processing methods help the farmer manage the large volume of data generated by PA applications (Murakami et al., 2007).

Kitchen et al. found that stakeholders need to be educated on PA to fully realise the potential benefits of the PA technologies and practices. There has been rapid development in PA in the past decade and stakeholders need to be informed of technological advances and how these technologies can be applied on their own farms. Six learning steps were identified for stakeholders to improve their agronomic knowledge, information management skills and understanding of PA. The first learning step was described as understanding the idea of spatial data management, spatial variability and maps. At step two, the stakeholders gain an understanding of sensors and how sensors can be used for benefit in farming. Systems that use sensors were described as GPS, Yield Monitoring Systems, Remote Sensing and VRT systems.

Stakeholders learn IT skills at step three and become familiar with GIS technology. GIS were described as a fundamental decision making tool for PA systems. At step four, stakeholders become familiar with the factors that enable the identification of manageable yield influencing elements. Stakeholders learn how to analyse yield maps, study yield variation patterns and understand the difference between natural and management-induced variation. At step five, stakeholders learn how to develop and apply SSM plans. The final step shows stakeholders how to carry out strategic sampling and on-farm trials to test PA technologies and practices on their own farms (Kitchen et al., 2002).

2.7 The Adoption of Precision Agriculture

Agriculture develops as farmers adopt innovative technologies and practices that deliver competitive advantage. The rate and diffusion of PA technology adoption determines the impact upon farm production levels. Factors such as the farmer profile, farm type, economic conditions, complexity and cost of the technology influence the diffusion and speed of PA adoption (Zhang et al., 2002). Farmers go through a five stage decision making process when adopting PA technologies. In the Knowledge stage, the farmer learns about the new technology and its applications. At the Persuasion stage, the farmer develops an opinion on the new technology. The farmer makes a choice to adopt the innovation at the Decision stage. The Implementation stage is where the farmer puts the technology into use on their farm. The Confirmation stage is the final stage where the farmer seeks to validate the decision to adopt the technology (Rogers, 2010). Figure 2.1 below illustrates the five stage of the Innovation-Decision Process:

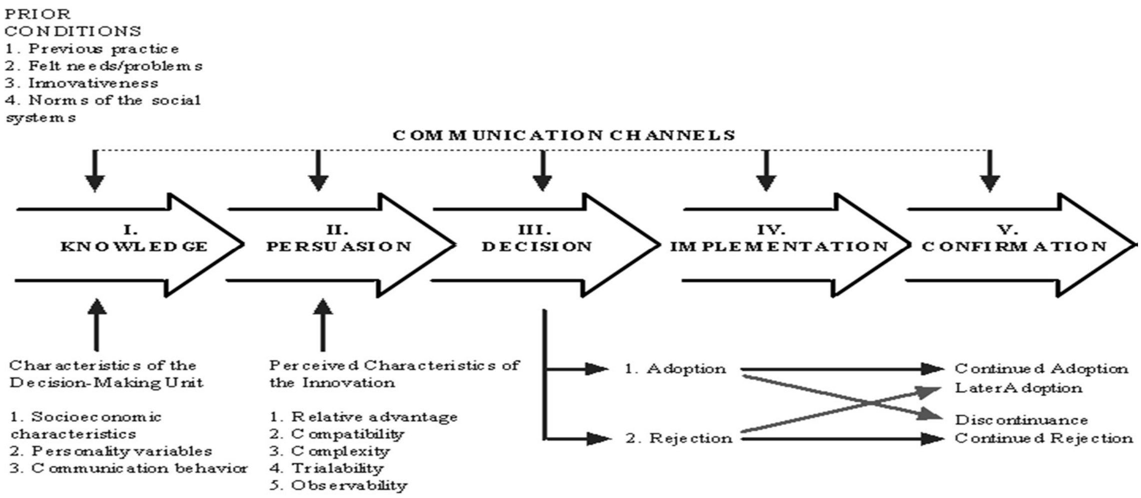


FIGURE 2.1: The five stages of the Innovation-Decision Process (Rogers, 2010)

Diederen et al. identified five stakeholder groups in the adoption life cycle of agricultural technology; the innovators, the early adopters, the early majority, the late majority and the laggards. The innovators are adventurous farmers who discover new technologies and pay a premium to evaluate the technologies. Innovators are a small but important part of a market. Early adopters are influential leaders who observe the innovators' findings and find practical usages for the new technology. They communicate the benefits of the technology to a wider audience. The early majority adopt technologies when they are certain that the product will be useful on their farm and there will be a good return on their investment. The late majority are doubtful of new technology and wait until the technology has achieved widespread adoption before deciding to invest. The laggards are happy to continue farming in the old way and adopt new technologies reluctantly. The diffusion of technology adoption can be illustrated on an S-Shaped Diffusion Curve as per Figure 2.2.

Structural characteristics such as solvency, a farmer's age, market position and farm size were found to be differentiators between the innovators and laggards. Early adopters and innovators were found to have the same structural characteristics but differed in behaviour patterns. Innovators were involved in innovation development and used external information sources more effectively than early adopters (Diederen et al., 2003).

Figure 2.2 below illustrates the diffusion of technology adoption on an S-Shaped Diffusion Curve:

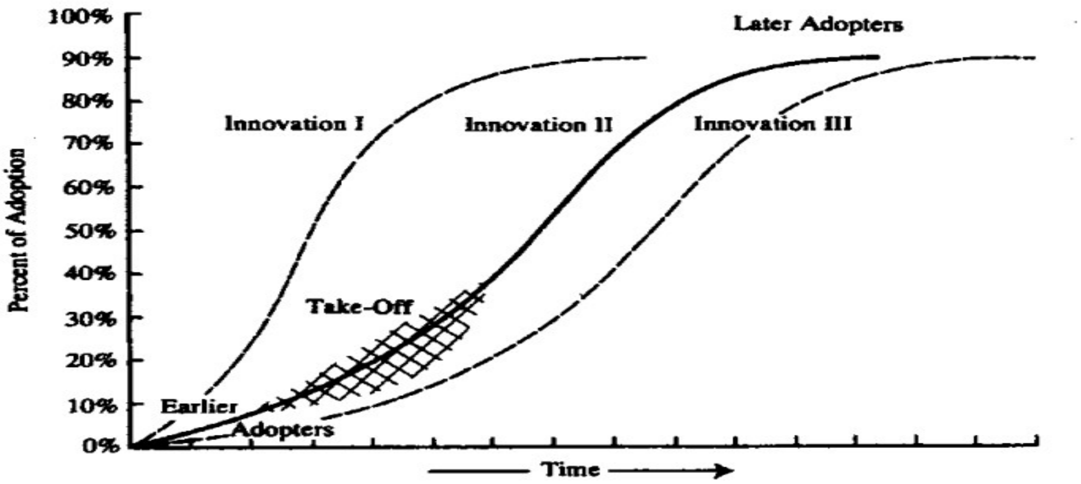


FIGURE 2.2 The diffusion of technology adoption (Rogers, 2010).

Rogers described the attributes of innovation that impact adoption as relative advantage, complexity, compatibility, trialability, and observability. Relative advantage of an innovation is the perceived improvement that the new innovation brings compared to previous technologies. The complexity of the innovation refers to the usability of the technology. Farmers are looking for technologies that are straightforward to use. The compatibility of the innovation refers to consistency with the existing systems in place on a farm, the farmer's needs, the farmer's values and past experiences. The trialability is the degree of testing and evaluation that a farmer can do with the new technology. The observability of an innovation is the extent that the effects of the technology are visible to stakeholders (Rogers, 2010).

Swinton and Lowenberg-Deboer studied the global adoption patterns of PA and found that adoption was higher in countries with large profitable farms, high wages and capital available for investment. Adoption rates were found to be uneven across regions and the decision to invest in PA was often tied to expensive farm machinery purchases. Early adopters of PA were large arable farmers with the resources to invest in the technologies and training required. Countries such as the United States, Canada, Australia and certain areas of Brazil and Argentina have large arable farming areas with high levels of PA usage (Swinton and Lowenberg-Deboer, 2001). Schimmelpfennig and Edel researched PA adoption in the United States and found mixed rates of adoption across the spectrum of PA technologies. Yield monitoring technology was achieving greater adoption but other technologies such as VRT and mapping were struggling to gain wider adoption (Schimmelpfennig and Ebel, 2011).

PA has not achieved widespread adoption in Europe due to high start-up costs, complexity, stakeholder awareness and training, data management issues and the size and diversity of farm structures. The average European farm is 16.1 hectares and many farmers cannot afford large investments in technology products. European countries with large arable regions and intensive farming such as France, England, Holland and Germany have higher levels of PA usage (Zarco-Tejada et al., 2014). The Teagasc Technology Foresight Report notes that the adoption of farming technology and management systems in Ireland has traditionally been low. Extensive research and investment is taking place to develop PA in Ireland to ensure higher adoption rates going forward (Teagasc, 2016).

2.8 Factors influencing the adoption of Precision Agriculture

Research shows the primary driver of PA adoption to be increased profitability and cost to be the primary barrier to PA adoption (Zarco-Tejada et al., 2014). Batte and Arnholt studied PA adoption and usage on Ohio farms and found economic benefit to be the principal driver of PA adoption. Secondary adoption drivers were environmental compliance, availability of increased information for better decision making and risk reduction. Farmers expressed frustration that PA was not a “turn-key” technology and there were many complex interactions to be interpreted to derive the benefits from PA. Batte and Arnholt found that research is required to develop low cost, robust and easy to use PA technology to drive increased adoption (Batte and Arnholt, 2003).

Tey and Brindal studied the adoption factors for PA and classified the factors found into seven categories; socioeconomic factors, agro-ecological factors, institutional factors, information factors, perception factors, behavioural factors and technological factors. Socioeconomic factors that influence the adoption of PA were found to be the farmer’s age, education, farming experience, attitude to risk, market conditions and access to information. Older farmers are less likely to adopt new technologies that require training and investment. Farmers with higher levels of education are more likely to adopt PA technologies as they often have a greater knowledge of best practice farming practices. Risk is associated with every investment and risk averse farmers are more likely to continue farming in the traditional manner. Market conditions influence the adoption of PA and farmers are more likely to invest in new PA technologies and equipment when market conditions are strong and the return on investment is high (Tey and Brindal, 2012).

Agro-ecological factors that influence adoption decisions include farm size, income, land tenure, environmental compliance and crop type. Larger farms with strong incomes are more likely to invest in PA. Farmers who are renting land are unlikely to significantly invest in PA technology due to uncertainty regarding future control of the land. Farmers growing crops planted in rows such as corn, cotton and soybeans were more likely to adopt PA than farmers growing vegetables, fruits and minor crops. Environmental compliance is becoming an increasingly important adoption factor as farmers need to meet strict environmental protection measures. The European Union's Common Agricultural Policy (CAP) 2014-2020 legislation emphasises the importance of environmental sustainability. 30% of payments to European farmers are linked to agricultural practices that protect the environment such as ecological focus areas, maintenance of permanent grassland and crop diversification (Zarco-Tejada et al., 2014).

Institutional factors were found to be government organisations and policies, distance from fertiliser and equipment suppliers and the farm's location. Government organisations have a major role to play in training and educating farmers on the technologies driving PA and the possible PA applications for their own farms. Well informed farmers who understand the benefits of PA are more likely to adopt the technologies. Distance from fertiliser and equipment suppliers is another adoption factor as farmers located far from suppliers will be in less contact with sales personnel that can inform farmers of the availability of new PA equipment and possibly convince the farmer to invest in the new technologies (Tey and Brindal, 2012).

Information factors included the use of consultants and access to information sources. Farmers who work with consultants receive information on the best practices for their farm and are more likely to adopt PA. Access to information sources such as industry and government publications allows a farmer to keep informed of the latest developments with farming. Perception factors were the farmer's view on the importance of PA and the profitability of PA. The farmer's attitude to PA is important as ultimately the farmer is the decision maker who adopts the appropriate technologies for their farm. A farmer who had a bad experience with early PA technologies may be reluctant to invest in new technologies.

Behavioural factors included the farmer's behavioural profile and intentions (Tey and Brindal, 2012).

Pierpaoli et al. reviewed the ex-ante and ex-post drivers that influence PA adoption. The ex-ante factors influence a farmer's decision to adopt PA for the first time and ex-post factors are the reasons and motives for a farmer who has already adopted PA. The adoption factors are grouped into financial resources, competitive and contingent factors and socio-demographic factors. The primary ex-ante adoption factor was found to be increased profitability. Other ex-ante adoption factor were described as the farm size, previous experience of PA, usefulness of the PA technologies, ease of use of the PA technologies, farmer's education, farm soil fertility, the farmer's management characteristics, the farmer's age, technical support and engaging in a trial of the PA technology. Farmers with the innovator's or early adopter's management characteristics were found to be more likely to adopt PA (Pierpaoli et al., 2013).

Davis developed the Technology Acceptance Model (TAM) framework to study the attitudes and behaviours that impact technology acceptance and adoption. TAM is an ex-ante behavioural model derived from the Theory of Planned Behaviour. The individual's opinions regarding a technologies ease of use and usefulness are factors that influence their attitude to adopting the technology (Davis, 1989). Figure 2.3 below displays the TAM:

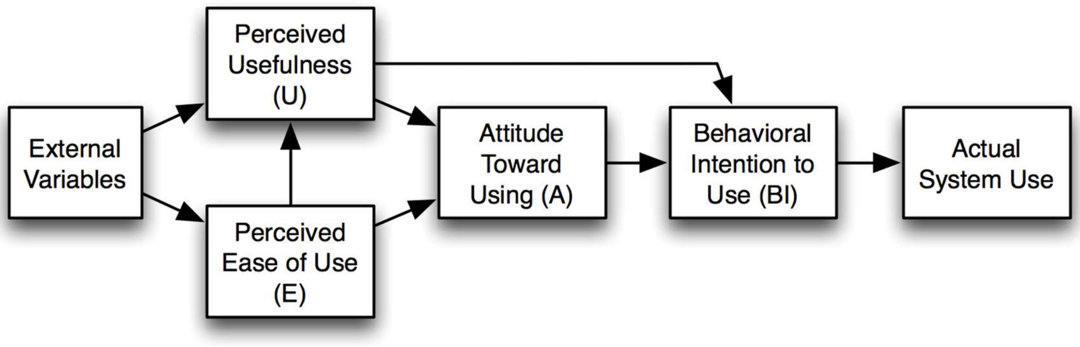


FIGURE 2.3: The TAM framework (Davis, 1989).

Technological factors found to be important adoption influences were the complexity of the PA technology, the type of technology to be adopted, farm irrigation structure and the usage of computers on the farm (Tey and Brindal, 2012). Technologies need to be understandable and usable to achieve widespread adoption by farmers. Many farmers are reluctant to adopt complex technologies due to the time and training required for usage. Farmers with previous experience of working with information technology are more likely to adopt PA technologies as they are familiar with computers. The type of technology influences adoption decisions as there are varying costs associated with different technologies and some technologies may be more familiar to farmers.

Figure 2.4 below displays the ex-ante adoption factors for PA:

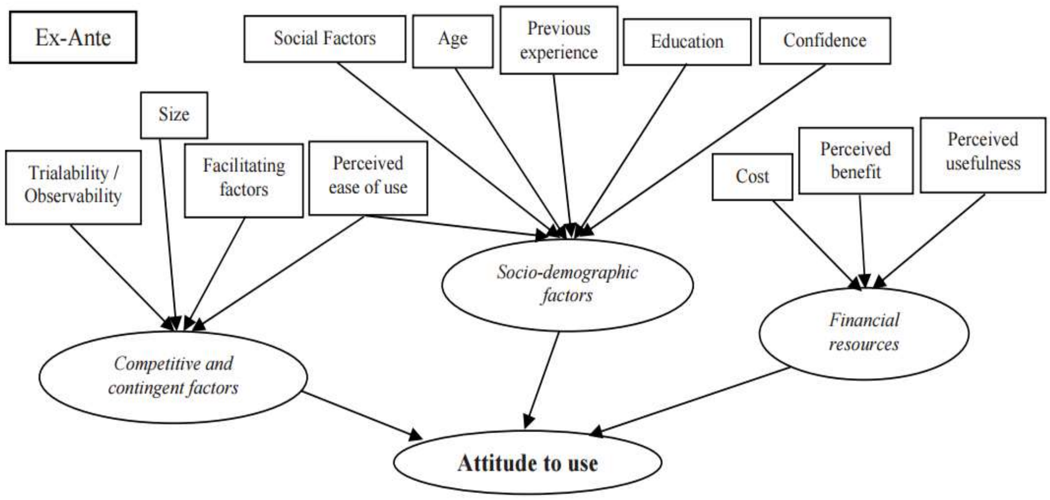


FIGURE 2.4 : The ex-ante adoption factors for PA (Pierpaoli et al., 2013).

Ex-post adoption factors include the farm size, quality of the farm's soils, farmer income, farmer education, access to information, costs savings, desire for higher profitability, land tenure and IT experience. The typical PA adopter was found to be an educated farmer seeking competitive advantage through better agricultural practices on their own large fertile farm. The primary ex-post driver for PA adoption was found to be farm size. Large farms with over 500 hectares can benefit from economy of scale when adopting PA. A secondary driver was the farmer's confidence with technology. Farmers with good technological skills were found to be more likely to adopt PA. Other ex-post drivers for PA adoption were a high income, the farm's location and the farmer's education (Pierpaoli et al., 2013).

Figure 2.5 below displays the ex-post adoption factors for PA:

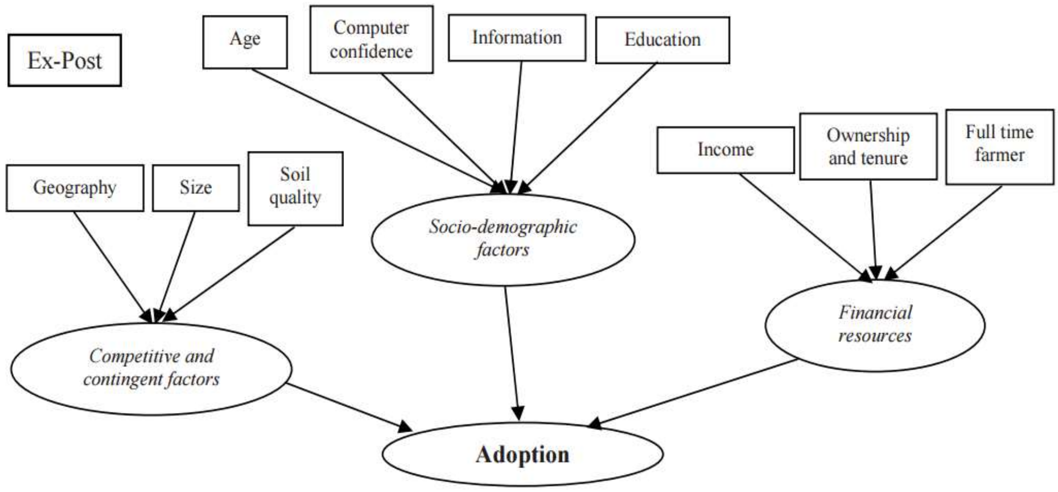


FIGURE 2.5 : The ex-post adoption factors for PA (Pierpaoli et al., 2013).

The adoption of PA has been constrained by a number of barriers such as cost, complexity and weak rural broadband infrastructure. The accessibility and speed of rural broadband will need to be improved to enhance internet connectivity between farm systems and external providers. PA applications use remote sensing data to identify crop health and development patterns. Remote sensing data is delivered in large files which require fast broadband connections for effective communication (McKinion et al., 2004). McBratney et al. found the lack of decision support systems to be a barrier to the adoption of PA. Farmers need decision support systems that enable effective decision making based on accurate and timely data (McBratney et al., 2005).

The lack of scale in Irish agriculture is a barrier to PA adoption. Irish farm have an average size of 32.7 hectares and are five times smaller than the average North American farms. The smaller farm sizes and incomes mean that farmers do not have resources or desire to invest in PA applications where the return on investment is unclear and start-up costs are often substantial. Smaller farmers are not willing to invest in technologies unless they can be sure of a sufficient return on investment (Normile and Leetmaa, 2004).

2.9 Opportunities for increasing the adoption of Precision Agriculture

The JRC and EIP-AGRI reports on the adoption of PA recommended a number of research areas for increasing PA adoption. Three of the EIP-AGRI recommendations were the increased usage of open-data and sharing of data, the development of “easy to use, robust and affordable PA tools” and technical solutions that combine maps with other data sources to enable management decision making (Bahr et al., 2015). The JRC report included recommendations for “free and accurate data products for PA applications”, crowdsourcing farm data and the need for better methods of raising PA awareness, disseminating knowledge and technology transfer (Zarco-Tejada et al., 2014).

Opportunities exist for raising the awareness of PA and knowledge transfer with print, television and radio media outlets, the use of social media platforms and organised training programs. Traditional media outlets have large audiences of farmers that can be informed about PA. Social media communication methods and platforms such as Facebook, Twitter, blogs and podcasts are being increasingly used by farmers to discuss and share knowledge regarding PA technologies and practices. Many farmers are using Youtube to learn about new agricultural practices and equipment. Organised training programs on PA and digital technologies would raise awareness of PA with farmers and equip farmers with the digital skills required to access digital resources (Roberts and McIntosh, 2012).

Farmers are looking for affordable, sturdy and accessible technologies that provide useful information for better decision making (Dehnen-Schmutz et al., 2016). Smartphones are a potential platform for increasing the adoption of PA. Smartphone adoption is growing in Ireland with 64% of Irish people owning a smartphone in August 2014 and 70% owning a smartphone in August 2015 (EIR, 2015). Smartphones are useful tools for farmers due to their affordability, mobility, ease of use, sensing capabilities and processing power. The mobility of smartphones enables farmers to carry out onsite analysis of crops and livestock. Smartphones have a range of sensors that can detect motion, position and the surrounding environment. PA applications can use these sensors on smartphones to capture valuable data for analysis.

Pongnumkul et al. identified the leading applications of smartphones in agriculture to be disease detection and diagnosis, fertiliser calculation, soil analysis, water quality analysis, crop inputs analysis, crop readiness analysis, land management, vehicle monitoring, human resource management, the localisation of farming information, agricultural market pricing and remote inspections. Key advantages of smartphones applications for agricultural purposes were cost savings, real-time reporting, the ability to leverage expert knowledge for analysis, geolocation data enabling the delivery of local information to farmers, easy to use interfaces and accurate analysis. The research found that GPS and cameras were the most commonly used sensors by agricultural smartphone applications (Pongnumkul et al., 2015).

Jespersen et al. analysed the use of crowdsourcing, social media, forums and other ICT tools for encouraging innovation in agriculture. Crowdsourcing was defined as “obtaining needed services, ideas, or content by soliciting contributions from a large group of people”. Farmers have been sharing among themselves for many years in local farming groups or co-operatives but the dissemination of agricultural research to farmers is weak. Crowdsourcing, social media and other ICT tools were found to have lots of potential for driving innovation in agriculture via the interaction and sharing of information by multiple stakeholders(Jespersen et al., 2014).

Integrated map based systems present opportunities for increased PA adoption. The availability of intuitive and low cost mapping interfaces such as Google Maps, Bing Maps and Apple Maps has enabled non-technical users to embrace geospatial technologies. Integrated map interfaces present spatial data to farmers in an accessible and visual manner that is easy to interpret and supports effective decision making. Farmers can record location information in the field and integrate multiple layers of data to review soil maps, crop growth, pest infestations, crop yields, identify underperforming field areas, manage farm assets and plan farm activities. Reports can be generated with mapping systems to provide timely performance indicators to farmers that enable effective interventions at the right time (Tayari et al., 2015).

Open data presents opportunities for greater adoption of PA with the availability of accurate and free data. Open data has been defined as “data that can be freely used, reused and redistributed by anyone". Open data enables improved public services, competitive advantage, transparency, increased participation, economic growth and job creation, enhanced transparency and accountability, increased innovation and increased citizen participation. Farmers using open data have access to free and accurate information that drives better planning and management decisions. Open data is driving innovation in agriculture with new disruptive technologies and practices driving competitive advantage for farmers. Initiatives such as the Open Agriculture Initiative and the Global Open Data for

Agriculture and Nutrition are developing open data sharing standards, APIs and open data communities to further the possibilities of open data (Carbonell, 2016).

The free availability of high resolution spatial data at regular intervals from the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) is driving innovative applications for PA. The ESA's Sentinel program is using a range of radar and multispectral imaging satellites to observe and capture data that can be used for PA applications. The Sentinel-2 satellites are especially useful for PA with data captured at 10 meter resolution on thirteen spectral bands and land monitoring capabilities such as crop type identification, land use, forestry species identification and water detection (Radoux et al., 2016).

Data standards can play an important role in increasing PA adoption by integrating different PA technologies. Organisations such as the International Organization for Standardization (ISO), Open Ag Data Alliance (OADA), and AgGateway have developed standards and policies to increase interoperability between disparate PA systems(Suprem et al., 2013). ISO 11783 was developed to enable standardised electronic communication between tractors, computers and farm machinery. Farmers can invest in ISO compatible equipment knowing that their purchase will integrate with their existing ISO compatible equipment. Ag-Gateway have developed connectivity standards such as the Standardized PA Data Exchange, PA Irrigation Leadership and the Fertiliser Tonnage Reporting XML schema. The OADA have developed open APIs to encourage data sharing among PA stakeholders (Whitacre et al., 2014).

EU agricultural policy has the potential to drive PA adoption with the CAP 2014-2020 committed to increasing farm income, enhancing agricultural competitiveness, supporting innovation, environmental protection and climate change reduction and adaptation. CAP policy is divided into Pillar 1 policy (direct payments and market related expenditure) and Pillar 2 policy (Rural Development). The CAP's Rural Development Policy (RDP) has objectives which support the adoption of PA such as support for innovation and knowledge transfer, increased competitiveness, promotion of innovative agricultural technologies, protection of agricultural ecosystems, efficient usage of resources and improving access to information and communication technologies (Zarco-Tejada et al., 2014).

3 Methodology and Fieldwork

3.1 Research Philosophy

Saunders et al. describe research philosophy as the development of knowledge and its nature. Researchers make assumptions at every stage of the research process and it is important to understand how these assumptions influence the questions, methods and findings. Research philosophy has a number of different branches including ontology, axiology and epistemology. Figure 3.1 below displays the research onion which Saunders et al. developed to illustrate research design. Researchers must consider each layer of the research onion as they develop a research design (Saunders et al., 2012).

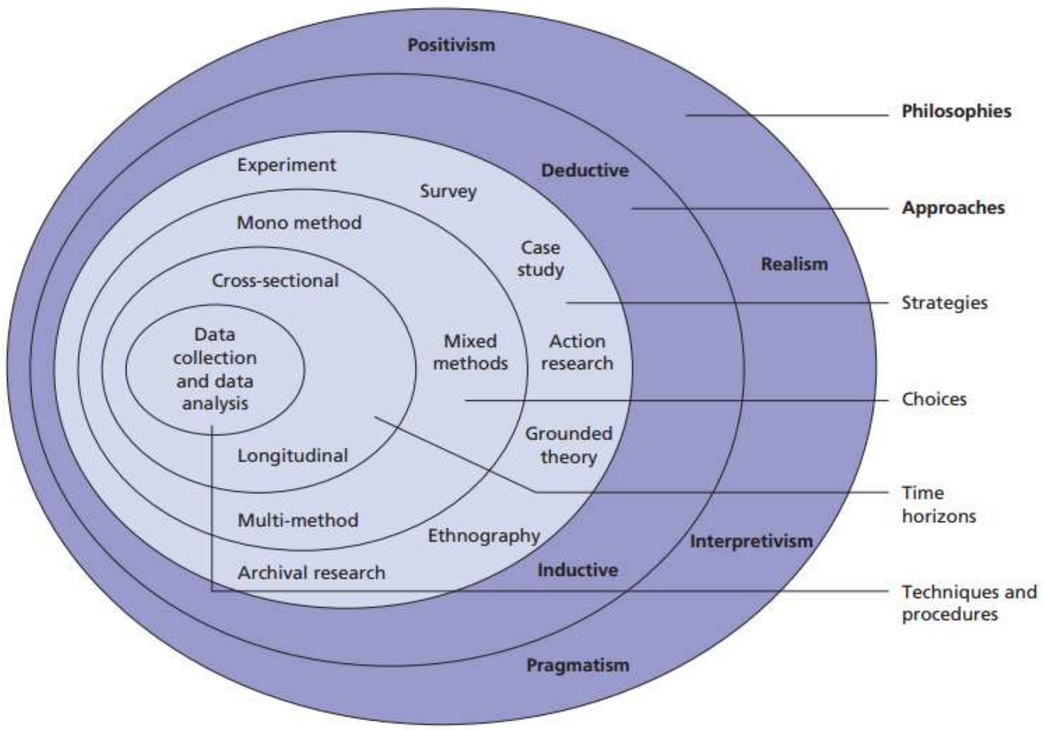


FIGURE 3.1 : The research onion (Saunders et al., 2012).

Ontology is a branch of metaphysics concerned with the study of being. Aristotle's writings about "being" were the foundation of the metaphysics field (Mitchell, 2014). The primary aspects of ontology are described as objectivism and subjectivism. Objectivism portrays "the position that social entities exist in reality external to and independent of social actors" (Saunders et al., 2012). A single reality exists independent of the researcher and there is a separation between the subject and the object. Researchers can interact with the world in an objective and value-neutral manner and knowledge is built based on facts.

Subjectivism states that “social phenomena are created from the perceptions and consequent actions of social actors” (Saunders et al., 2012). Researchers interact with their study area in an interdependent manner with multiple realities. Knowledge is based on observation and accepting that personal interpretation is valid. The details of an occurrence must be investigated to gain insight into actions and realities of a particular event. Social constructionism is the term used to describe the scenario where reality is socially constructed (Saunders et al., 2012).

Axiology is the study of values and ethics (Mitchell, 2014). Researchers need to understand how their values impact upon their research as their values have a major influence on research outcomes. The decision to select particular research topics and the philosophical research approach is determined by the researcher’s values. A statement of values can be added to research to inform readers of the researcher’s values and raise awareness of value judgements that were made during the research process (Saunders et al., 2012).

Epistemology is the study of knowledge and the methods used to acquire knowledge (Mitchell, 2014). The meaning of knowledge, deciding what knowledge is valid and the limits of understanding are all explored in epistemology. Sources of knowledge associated with epistemology include intuitive knowledge, authoritarian knowledge, logical knowledge and empirical knowledge. The important philosophical positions in epistemology are positivism, realism and interpretivism (Saunders et al., 2012).

Realism is a scientific approach where objects are independent of the mind and the researcher’s perception of events is the reality. Objective research methods are used to uncover existing realities. Realism is the opposite of idealism (Saunders et al., 2012). Direct realism and critical realism are the two types of realism. With direct realism, our senses can be trusted to provide an authentic picture of the world around us. Critical realism argues that we experience the sensory interpretations of the surrounding environment and the sensory experience is not to be trusted. Critical realism states that there are two steps involved when experiencing the world. The first step is the object and the sensation associated with the object. The second step is the processing that our minds undertake after our senses perceive the object’s sensations. The difference between direct and critical realism is that direct realism is only concerned with the first step.

Positivism is concerned with the observable social reality. A scientific and deductive approach is taken to positivism research. Data is collected from observable events, rules and relationships are identified in the data and theories are developed in a scientific manner. Existing theories can be used to develop a hypothesis for the collection of data. An ongoing process of testing and validation can lead to further development of the hypothesis. The researcher aims to be independent and value neutral in the research process and is focused on data collection and the objective interpretation of facts. A structured methodology is likely to be used for replication purposes (Gill and Johnson, 2010). The emphasis of the positivism approach is on quantitative observations that can be statistically analysed.

Interpretivism is an inductive approach where the researcher needs to understand the differences between humans in our roles as social actors. The emphasis of the interpretivism philosophy is on people rather than objects. Interpretivism is different to positivism as the researcher uses an empathic approach rather an objective approach. The aim of interpretivist researchers is to see the world from the point of view of their subjects (Saunders et al., 2012). Interpretivism is derived from the phenomenology and symbolic interactionism philosophies. Phenomenology is the study of experience and consciousness. Efforts to understand social reality must be based on experiences. Researchers need to adopt an open mind-set when experiencing phenomena to attain new meanings. Symbolic interactionism is concerned with the ongoing interpretation and interactions with the social world. People interpret the meaning of objects and actions from ongoing interactions in the world and act upon these meanings.

Pragmatism is a multiple methods approach which utilises quantitative and qualitative methodologies. Pragmatist researchers are not committed to one particular research philosophy. Interpretivist and positivism philosophies are viewed as opposite ends of the spectrum and pragmatists select appropriate methods to meet research objectives. The research approach can be both inductive and deductive. Pragmatist research can be divided into multimethod and mixed methods research. Multimethods research uses multiple data collection methods and analyses the data using the same research design. Multimethods research does not mix quantitative and qualitative research methodology. Mixed methods research combines quantitative and qualitative research methodologies. The mixing of methods at only one stage is known as partially integrated mixed methods research. Fully integrated mixed methods research describes the scenario where mixed methods are used at all stages of the research process (Saunders et al., 2012).

3.2 Research Question and Objectives

Kothari describes research as “a scientific and systematic search for pertinent information on a specific topic” and research methodology as “a way to systematically solve the research problem” (Kothari, 2004). The aim of this research is to review the adoption of PA, the barriers to widespread adoption, the drivers for adoption, the benefits of PA, enabling technologies, the outlook for PA and to determine if an intuitive decision support system incorporating remote sensing data, mapping interfaces, crowdsourced data and external data sources would address adoption challenges.

3.3 Research Approach

The research approaches considered during research design were deductive and inductive research. Deductive research is a “top-down” approach that tests a theory over a number of stages. The first stage is the development of a theory. At stage two, the researcher narrows the focus of the theory into a specific hypothesis. At stage three, the logic and basis of the argument is evaluated. Data is collected to address the hypothesis at stage four. The fifth stage analyses the data collected. The final stage of deductive research occurs if the analysis results match the hypothesis and the theory is confirmed. Deductive research places importance on a researcher’s independence, scientific principles, a structured approach and collection of quantitative data (Saunders et al., 2012).

Inductive research takes the opposite approach to deductive research and works towards building a theory. Data is initially collected to gain an understanding of the issues. The collected data is analysed and a theory is developed. Inductive research collects qualitative data, tries to understand the meanings that humans associate with events, uses a flexible approach and researchers are not independent of the research process. Deductive research can be a less risky strategy and take less time than inductive research. The data collection process with deductive research is often a single effort in contrast to the prolonged effort required with inductive research. The risk with inductive research is that no useful patterns and theories will develop (Saunders et al., 2012). This study takes the deductive approach to research and seeks to confirm the validity of the research question through data collection and analysis.

3.4 Research Methodologies

The quantitative research methodology was reviewed to determine suitability for meeting the research objectives. The quantitative research methodology uses objective numerical data generation and mathematically based analysis techniques to explain phenomena. Data is collected through surveys, experiments and observing well defined events. The data is analysed in statistical packages such as SPSS to produce results. The quantitative research methodology is usually associated with positivism and realism (Saunders et al., 2012). The quantitative research methodology enables the efficient administration and evaluation of responses, the ability to analyse the numerical data captured and the reliable capture of rigorously collected data. Weaknesses associated with quantitative research are the lack of human beliefs and views, the requirement for large sample sizes and the lack of in-depth descriptive information (Johnson and Onwuegbuzie, 2004).

The qualitative research methodology is associated with the interpretivist philosophy. Qualitative research concentrates on participant's opinions, feelings and reasons for particular outcomes. Non-numerical data is collected through interviews, case studies, action research and focus groups. The data collection process is not standardised which enables a natural interaction between the researcher and the subject. Researchers need to be empathic and perceptive during the data collection process to gain insights and understanding (Saunders et al., 2012). Qualitative research is useful for explaining complex events, when studying a limited number of scenarios in depth and when researchers are describing and understanding an individual's experience. Weaknesses associated with qualitative research are the length of time required to collect and analyse data, the researcher's bias may influence results, the data generated may be too narrow in focus due to the limited number of sources and difficulties making predictions and testing hypothesis (Johnson and Onwuegbuzie, 2004).

A mixed methods methodology leverages the strengths of qualitative and quantitative research methodologies. Key benefits of mixed methods are complementarity, triangulation, generality and facilitation. Mixing research methodologies in a complementary manner enables a deeper and broader understanding of the collected data and the relationships present. Explanations and text collected from qualitative research can add greater meaning to the quantitative research numerical data. Mixed methods methodology also enables the triangulation of multiple independent data sources to substantiate research findings and facilities one research methodology assisting the other research methodology (Saunders et al., 2012).

A pragmatism philosophy with a deductive approach and a mixed methods methodology with interviews and a survey was chosen as the appropriate research design for this study.

3.5 Limitations of mixed methods research

The complexity of mixed methods research can be a steep learning curve for researchers and it can be difficult to integrate qualitative and quantitative research methodologies successfully. Additional resources are required for mixed methods research as more time and money is spent collecting data and integrating qualitative and quantitative research methodologies (Johnson and Onwuegbuzie, 2004). As mixed methods research is a relatively new methodology, researchers may experience difficulties understanding the research and it may be difficult to convince other researchers that the research produced is valid (Creswell and Clark, 2007).

3.6 Research Description

This research uses an explanatory sequential design to collect, analyse and interpret the quantitative and qualitative data. Quantitative data is collected and analysed to produce results which are used as part of the qualitative data collection and analysis process (Creswell, 2013). Figure 3.2 illustrates the explanatory sequential research design.

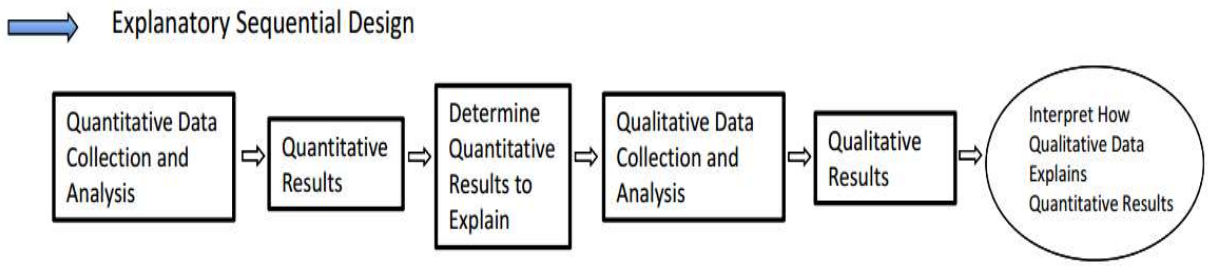


FIGURE 3.2 : Explanatory Sequential Design (Creswell, 2013)

Phase one of research was concerned with the development, dissemination and analysis of a survey and a slideshow to demonstrate key features of the PFA to stakeholders. Qualtrics surveying and analytics software was used to develop and host the survey in order to utilise the product's accessible interface and reporting functionality available. Appendix I displays the slideshow of key system features that was circulated to participants. The survey was circulated to PA stakeholders such as farmers, farming organisations, employees of DAFM and companies working with geospatial and agri-tech technologies. The survey asked participants to evaluate key features of the PFA, provide feedback and suggestions and indicate whether the developed application would be useful for addressing challenges regarding the adoption of PA technology. The ten evaluation questions presented participants with dropdown menus containing numbers in the range of one to ten. The feedback and suggestions question offered respondents the opportunity to enter constructive comments. The system usefulness question gave users a choice of a "Yes" or "No" response. Appendix II below displays the survey questions.

In phase two of research, semi-structured interviews were carried out with key stakeholders to gain a greater insight into important issues impacting the adoption of PA applications. The interviews were recorded using handwritten notes to facilitate a comprehensive discussion of the topics with the interviewees. Sim and Wright found that handwritten notes can be useful for gaining insights where participants are wary of their words being recorded. Participants may find interviews recorded with handwritten notes to be "more natural and acceptable" (Sim and Wright, 2000). Topics covered included the barriers to PA adoption, drivers for adoption, requirements for successful implementation, advantages of PA, the role of government and the media, technologies driving PA and the outlook for PA. The recorded interview data was coded using MAXQDA qualitative data analysis software. Data coding is an analytical process that categorises, labels and identifies patterns in the data. Word clouds were used to demonstrate the coded data in an understandable and graphic manner. Word clouds are useful for academic research as patterns in qualitative data can be visualised to assist researchers in identifying common themes present (McNaught and Lam, 2010).

Figure 3.3 below shows the MAXQDA qualitative data analysis software with the coded interview data.

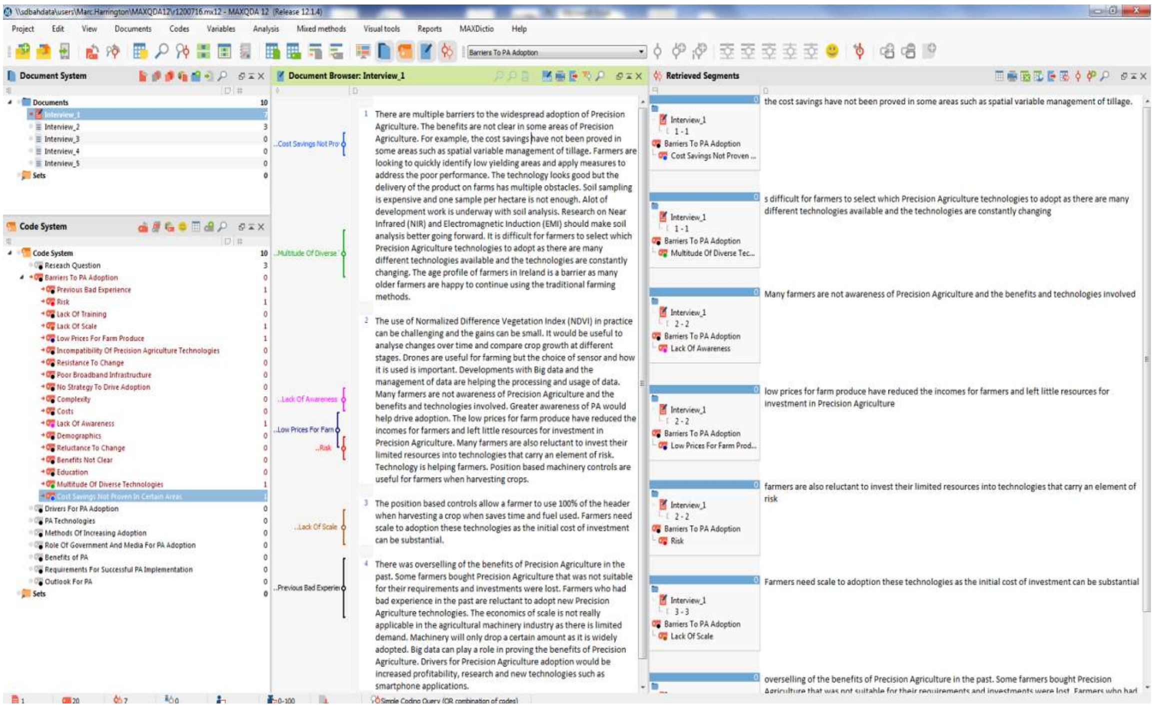


FIGURE 3.3 : MAXQDA qualitative data analysis software with coded interview data

3.7 Research Population

Resource and time constraints often make it impossible to survey an entire research population. Sampling allows researchers to survey a subset of a research population in an efficient manner (Saunders et al., 2012). The population of the first research phase were the stakeholders in PA within Ireland such as members of farming organisations, employees of DAFM and companies working with geospatial and agri-tech technologies. There are 140,000 farmers in Ireland, DAFM employs 3,027 employees (DAFM, 2016) and 1,677 people are employed in the geospatial and agri-tech industries (Indecon, 2014). The sampling frame was the subset of stakeholders that were contactable via email. The sample size was 95 and represented a cross section of stakeholders. 22 complete survey responses were received. The population of the second research phase were influential stakeholders in agribusiness. 15 professionals were contacted and interviews were held with 5 participants.

3.8 Research Ethics

Ethics are the standards of behaviour that guide the researcher's interaction with participants and the respect for the rights of the participant and those impacted by the research (Saunders et al., 2014). The research ethics application was submitted to the Ethics Approval Committee on 8th April 2016. Key ethical principles that the application included were the integrity and objectivity of the researcher, the informed consent of participants, the voluntary nature of participation and the right to withdraw, protection of the privacy of participants and data management compliance.

The research ethics application was approved by the Ethics Approval Committee on 30th May 2016. Participants were asked to sign the Participant's Consent Form, advised that data collected was subject to the Data Protection Act and data would be confidential.

3.9 Lessons Learned

The survey was circulated to PA stakeholders in June. Certain PA stakeholders were unable to complete the survey due to time pressures and farming commitments. Other PA stakeholders were traveling overseas for work or holidays and did not have an opportunity to complete the survey. A higher response rate would have been achieved if the survey was circulated at an earlier and quieter time of the year for farmers.

The survey was initially developed using Google Forms. Following feedback from the Ethics committee, the survey was switched to the Qualtrics platform. The Google Forms survey was missing workflow features for managing user navigation. Time savings would have been achieved if the survey had been initially developed in Qualtrics.

3.10 Overview of the Precision Farming Application

The PFA was developed as a mobile and desktop application using a Google Maps interface, Sentinel 2 satellite data from the European Space Agency (ESA), soils data from the Environmental Protection Agency, agricultural news from the Farmers Journal, weather forecasts from Met Eireann, Microsoft Asp.Net technologies, ESA Sentinel Application Platform (SNAP) software and Microsoft Azure Cloud hosting. Every 5 days, Sentinel 2 satellites image the earth in multiple spectrums at 10 meter resolution. The Sentinel 2 imagery is freely available to the public and can be used to monitor vegetation growth. The application supports the usage of drone data and has been developed to be low cost and accessible to farmers. Open and free data from the Sentinel 2 satellites, crowdsourced data and an intuitive Google Maps interface are used to explore how PA adoption barriers can be addressed.

Figure 3.4 below displays the Map Interface of the PFA which integrates multiple spatial data layers, crowdsourced data, geolocation data, agricultural news and weather data in one location to enable farmers to make better decisions regarding the management of their land, crops and livestock. Farmers can use the Map Interface to highlight areas of their fields that are productive and identify areas requiring attention.

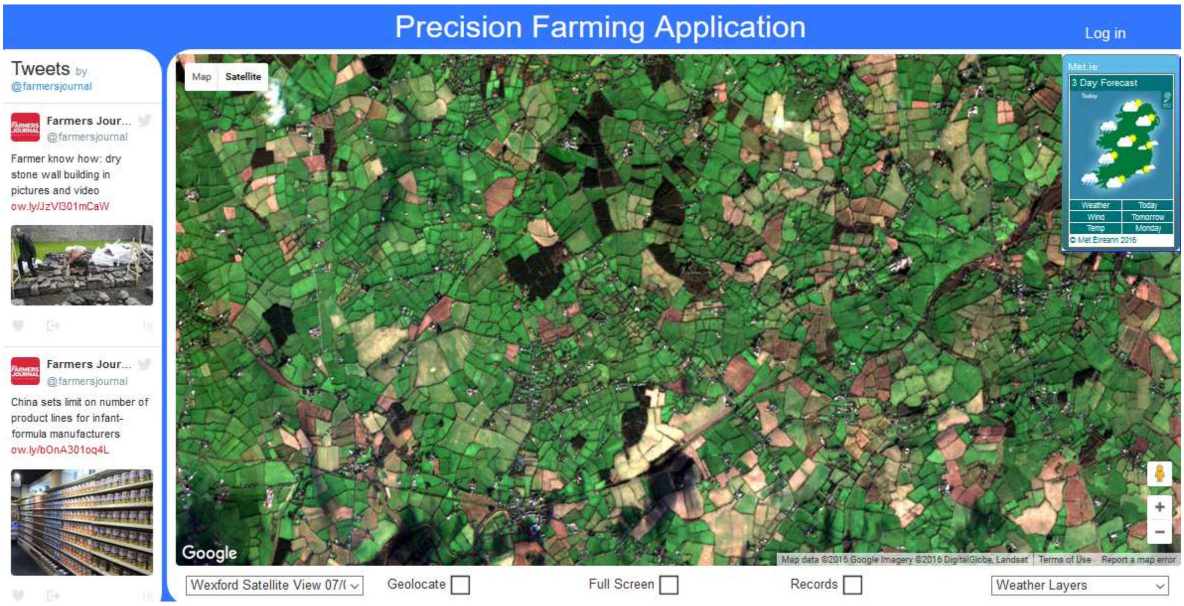


FIGURE 3.4 : Map Interface of the PFA displaying a Satellite View Layer

Layers that can be selected by users on the Map Interface include Satellite View Layers, NDVI Layers, Infrared Layers and Change Detection Layers. The Satellite View Layers display colour imagery derived from the European Space Agency's Sentinel 2 program. The imagery is freely available and is provided at 10 meter resolution. The NDVI Layers display plant greenness/photosynthetic activity on imagery derived from the European Space Agency's Sentinel 2 program. Figure 3.5 below displays an NDVI Layer on the Map Interface. Dark green areas of the NDVI image indicate healthy vegetation. The scale bar on the left of the NDVI image displays the range of values present.

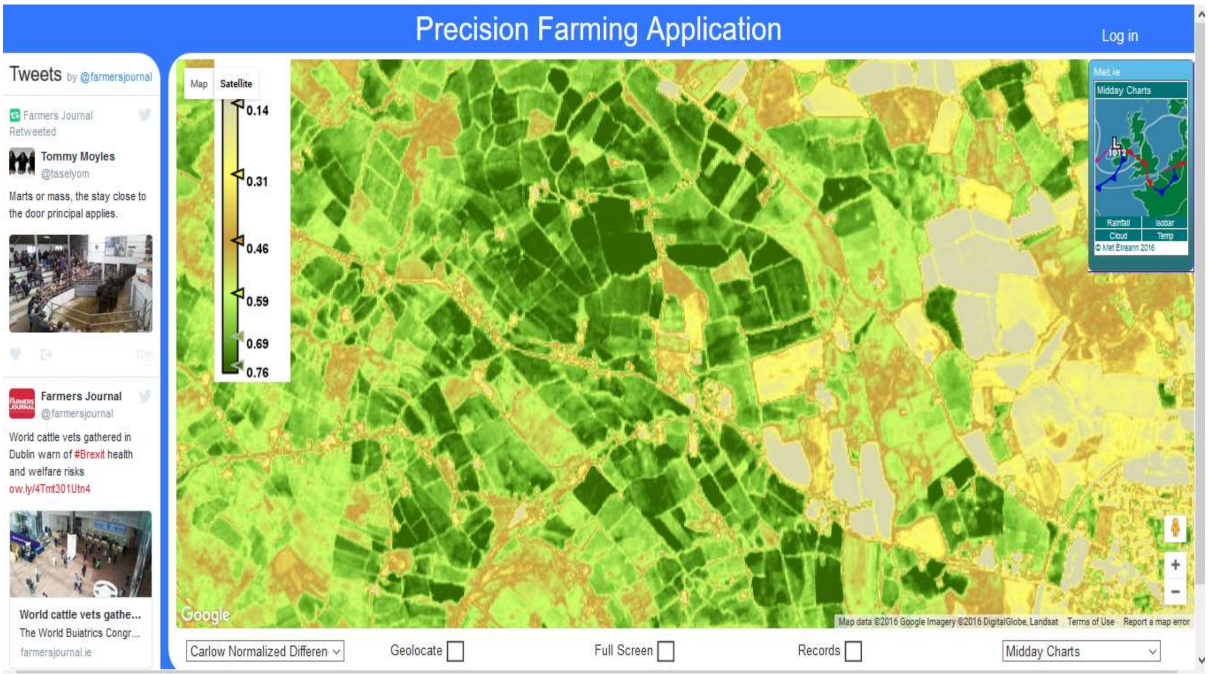


FIGURE 3.5 : Map Interface of the PFA displaying an NDVI Layer

The Infrared Layers display plant health information on imagery derived from the European Space Agency's Sentinel 2 program. Dark red areas on the Infrared Layer imagery indicate dense and healthy vegetation. White areas on the Infrared Layer imagery indicate harvested crops or ploughed fields.

Figure 3.6 below displays the Infrared Layer on the Map Interface.

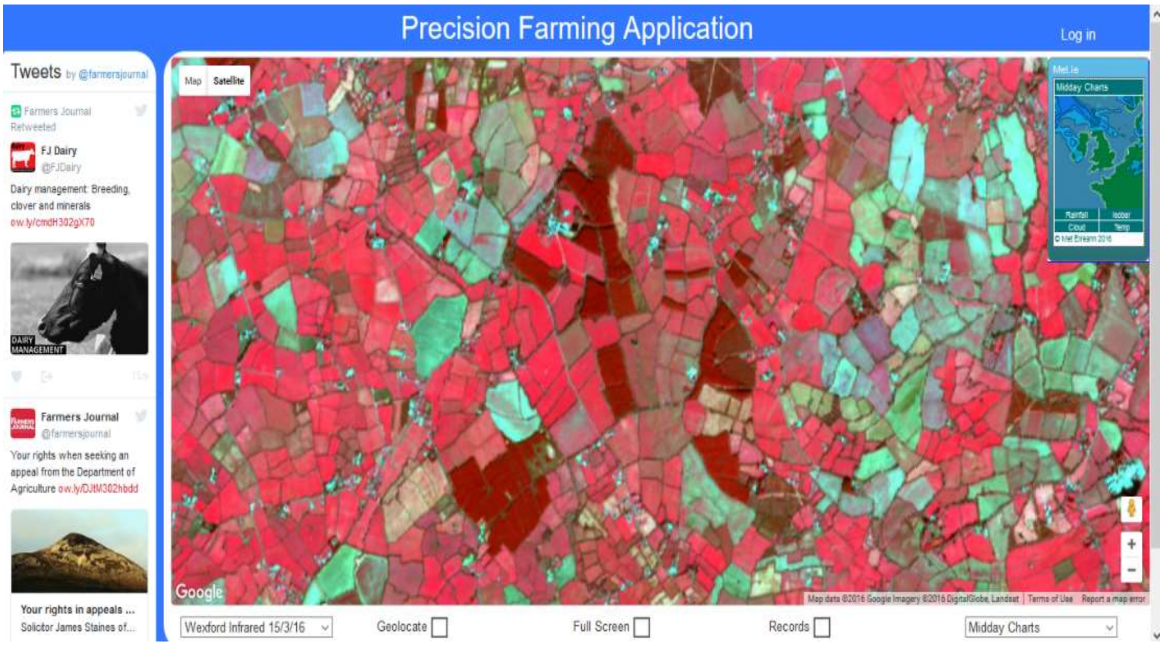


FIGURE 3.6 : Map Interface of the PFA displaying an Infrared Layer

The Records facility allows users to save location based data and enables crowdsourcing and data analysis. Figure 3.7 below displays the Records facility on the Map Interface. Users click a location on the map, add details and specify if they wish to share the record with the public or keep it private.

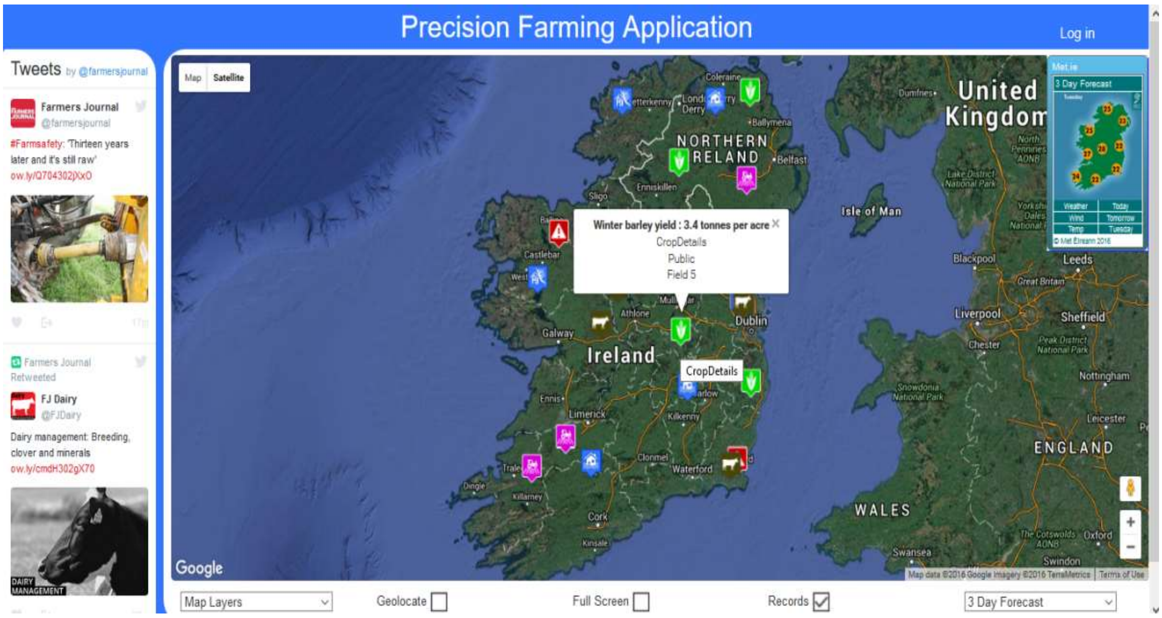
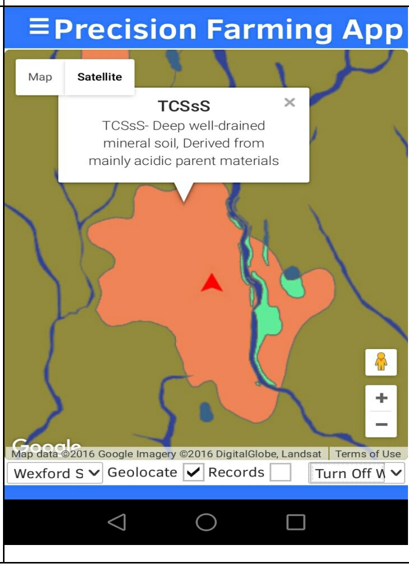


FIGURE 3.7 : Map Interface of the PFA displaying the Records facility

The PFA was developed with responsive design for mobile and desktop devices. The Geolocation facility uses the GPS functionality on the user's mobile device to zoom to their current location and carry out onsite analysis with the Map Interface. The red triangle indicates the user location on the map. The Change Detection layers display differences between sets of NDVI or Infrared images. Areas with good vegetation growth are displayed in green. Areas with poor growth are displayed in red and can be targeted for additional fertilizer or irrigation. Figure 3.8 below displays the Geolocation layer, the Map Interface and the Change Detection layer of the PFA on a mobile device.

Map Interface

Geolocation



Change Detection

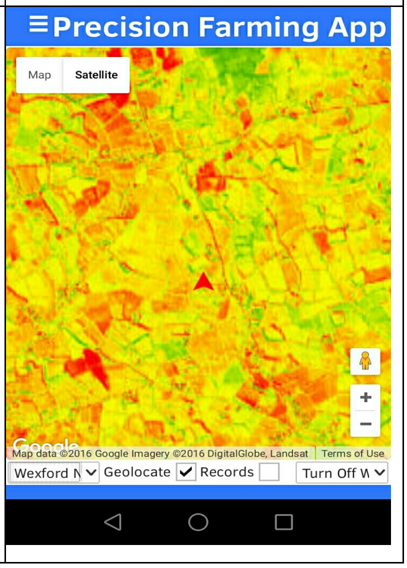


FIGURE 3.8 : Mobile view of the Map Interface, Geolocation and Change Detection layers

4 Findings and Analysis

4.1 Evaluation Results

Twenty two complete responses were received from PA stakeholders for the evaluation survey. The results contain responses from a diverse array of PA stakeholders including farmers, farming organisations and employees of companies working with drone and geospatial technologies. The respondents' roles are listed in Appendix III. Respondents were asked to evaluate the key features of the developed PFA, provide feedback or suggestions and indicate if the application would be a useful tool for addressing challenges regarding the adoption of PA technology.

The first question on the survey asked participants if the PFA would be a useful tool for addressing challenges regarding the adoption of PA technology. Participant responses are shown on the pie chart in Figure 4.1 below:

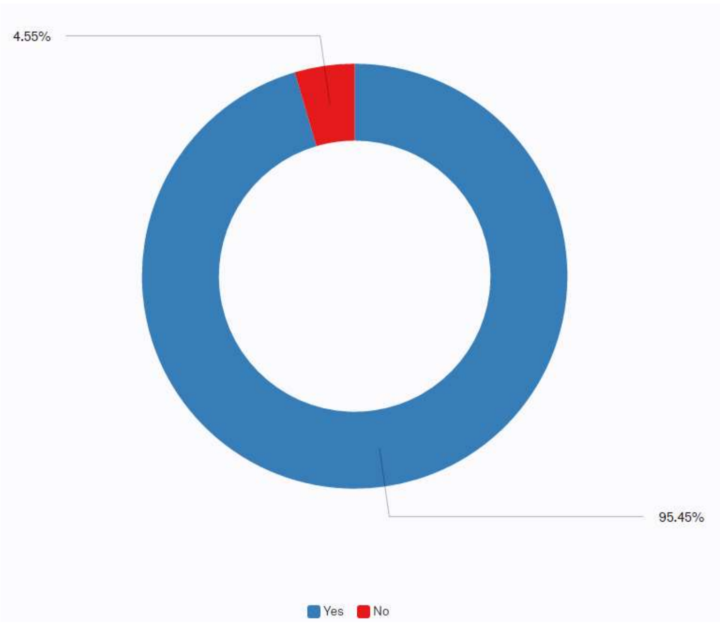


FIGURE 4.1 : Ratings for the PFA

21 of the 22 respondents (95.45%) indicated that the PFA would be a useful tool for addressing challenges regarding the adoption of PA technology.

Respondents were asked to rate the Map Interface functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The Map Interface uses Google Maps to enable enhanced decision making by displaying spatial, crowdsourced, news and weather data in one location. The ratings are shown in the bar chart on Figure 4.2 below. The vertical axis displays ratings and the horizontal axis displays the number of selections.

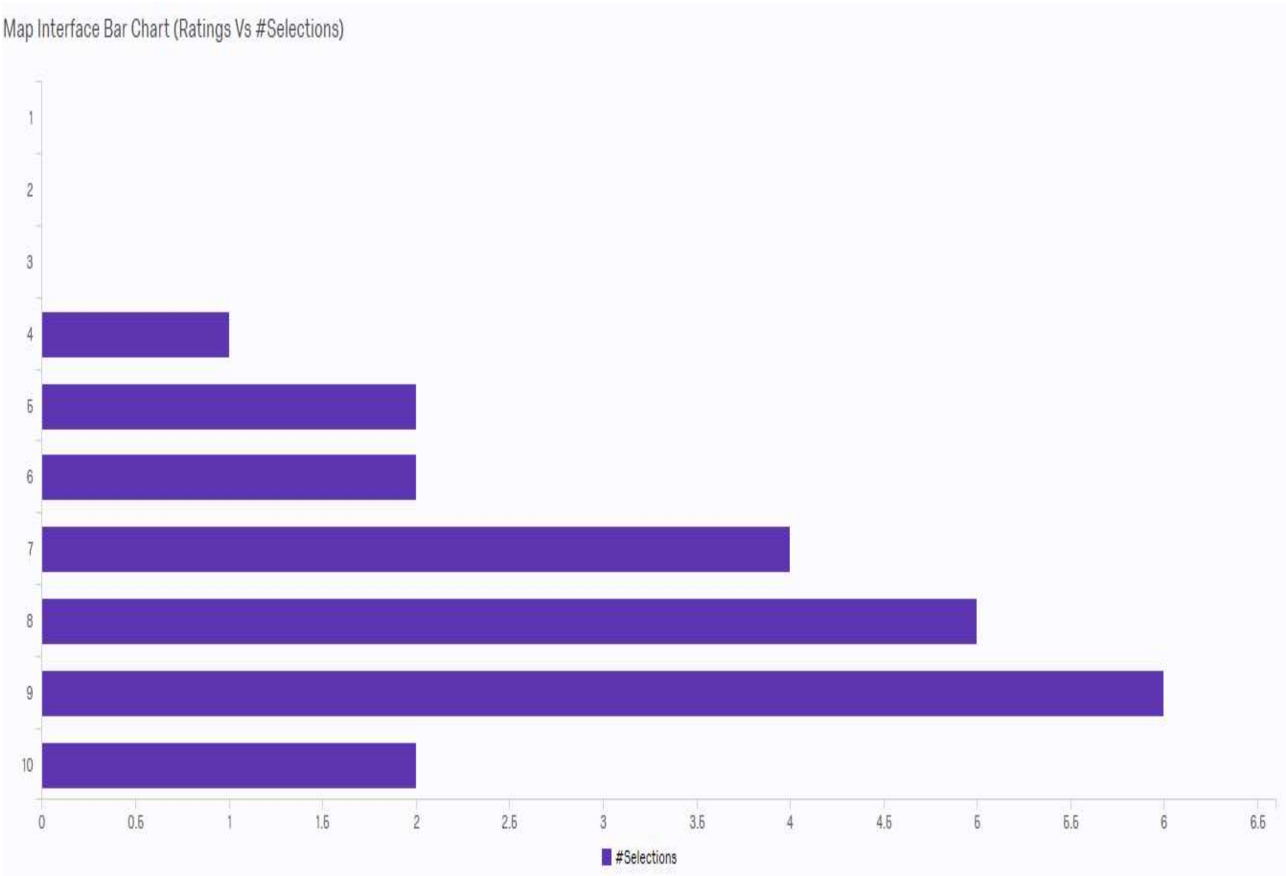


FIGURE 4.2 : Ratings for the Map Interface functionality

22 responses were received for this question and the mean rating of 7.64 received for the Map Interface indicates a positive response from the reviewers. The standard deviation of the responses is 1.61. The standard deviation measures the dispersion of the survey responses.

Respondents were asked to rate the Satellite View Layers functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The Satellite View Layers functionality displays colour imagery derived from the European Space Agency's Sentinel 2 program. The vertical axis displays ratings and the horizontal axis displays the number of selections. Responses are shown in Figure 4.3 below.

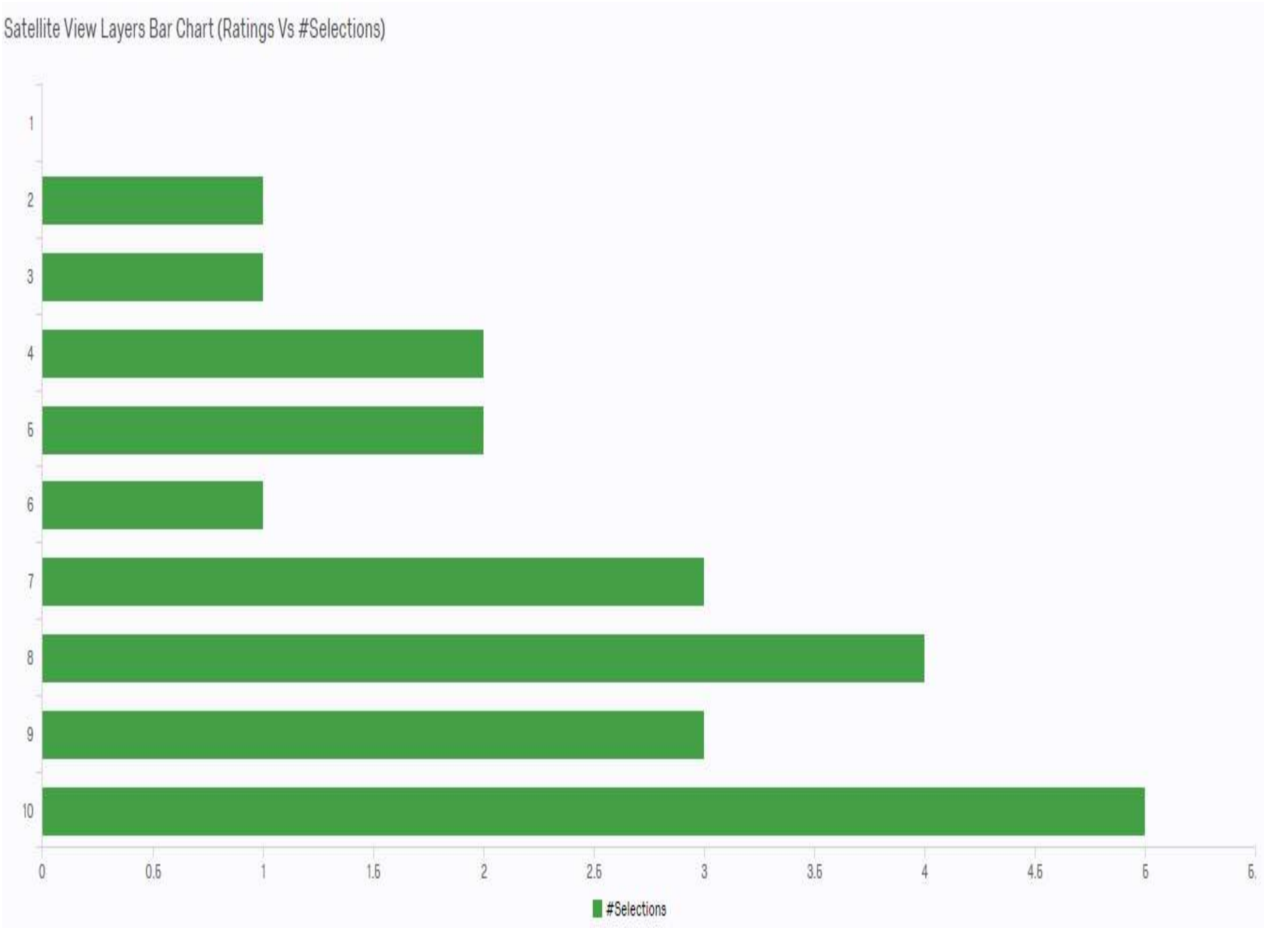


FIGURE 4.3 : Ratings for the Satellite View Layers functionality

22 responses were received for this question and the mean rating of 7.23 received for the Satellite View Layers functionality indicates a positive response from the reviewers. The standard deviation of the responses is 2.41.

Respondents were asked to rate the NDVI Layers functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The NDVI Layers functionality displays plant greenness/photosynthetic activity on imagery derived from the European Space Agency's Sentinel 2 program. Responses are shown in Figure 4.4 below. The vertical axis displays ratings and the horizontal axis displays the number of selections.

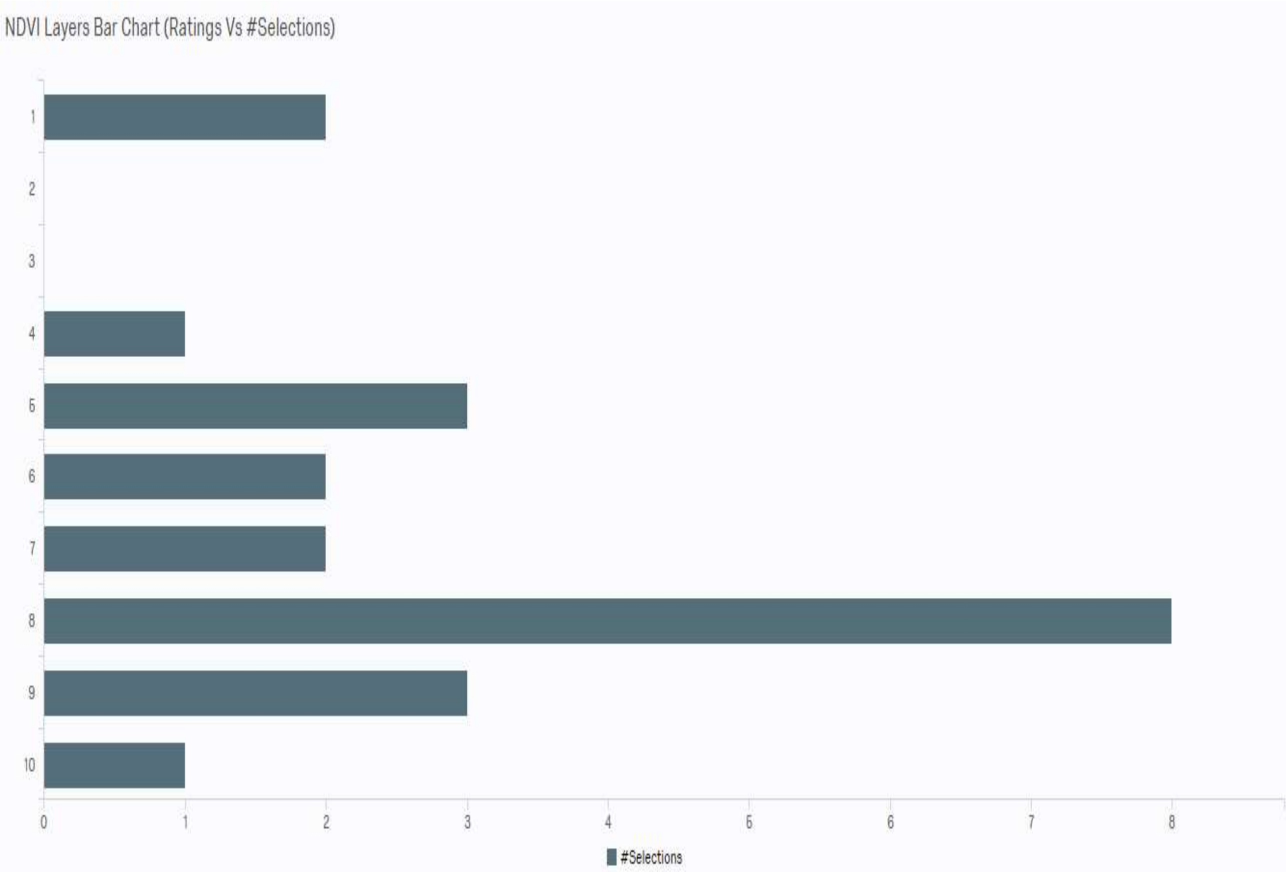


FIGURE 4.4 : Ratings for the Normalized Difference Vegetation Index Layers functionality

22 responses were received for this question and the mean rating of 6.73 received for the NDVI Layers functionality indicates a positive response from the reviewers. The standard deviation of the responses is 2.36.

Respondents were asked to rate the Infrared Layers functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The Infrared Layers functionality displays plant health information on imagery derived from the European Space Agency's Sentinel 2 program. Responses are shown in Figure 4.5 below. The vertical axis displays ratings and the horizontal axis displays the number of selections.

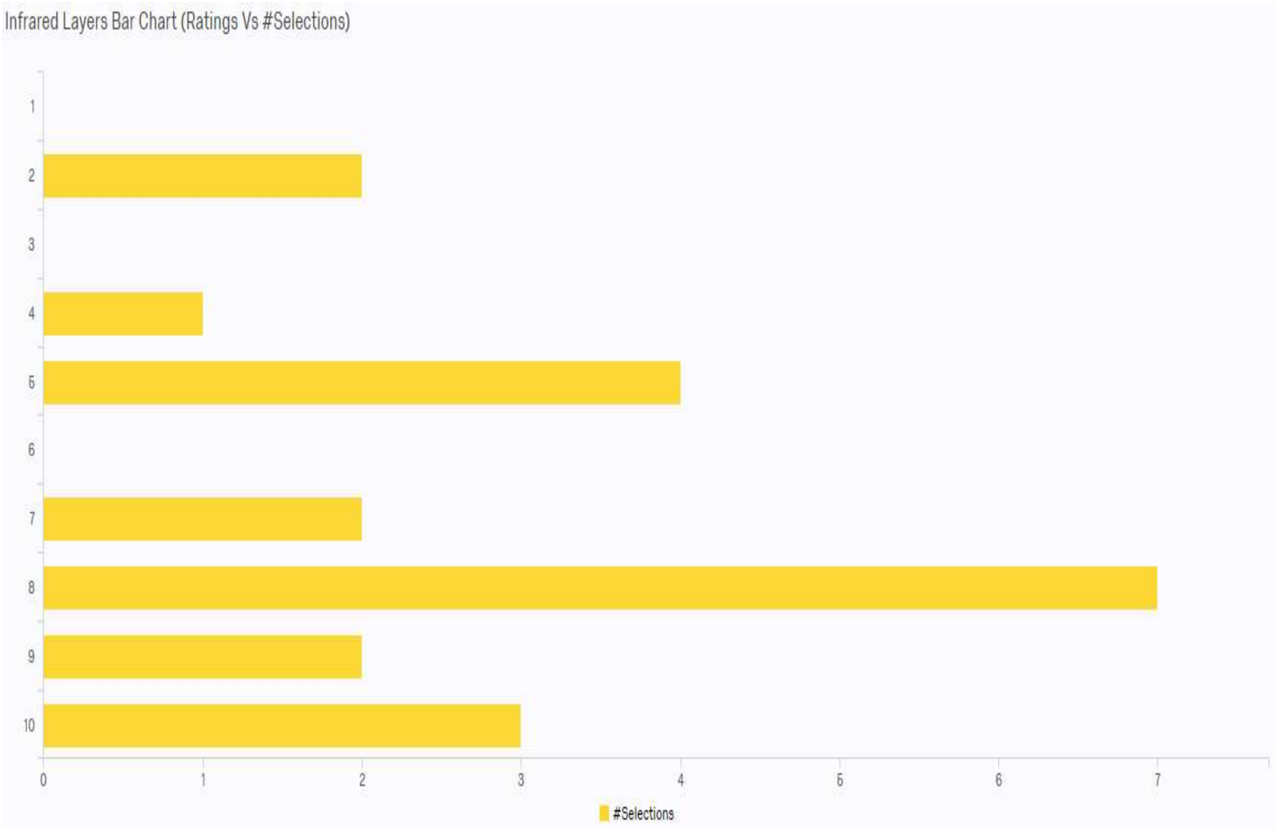


FIGURE 4.5 : Ratings for the Infrared Layers functionality

21 responses were received for this question and the mean rating of 6.95 received for the Infrared Layers functionality indicates a positive response from the reviewers. The standard deviation of the responses is 2.36.

Respondents were asked to rate the Change Detection Layers functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The Change Detection Layers display differences between sets of NDVI or Infrared images. Areas with poor growth can be identified and targeted for additional fertilizer. Responses are shown in Figure 4.6 below. The vertical axis displays ratings and the horizontal axis displays the number of selections.

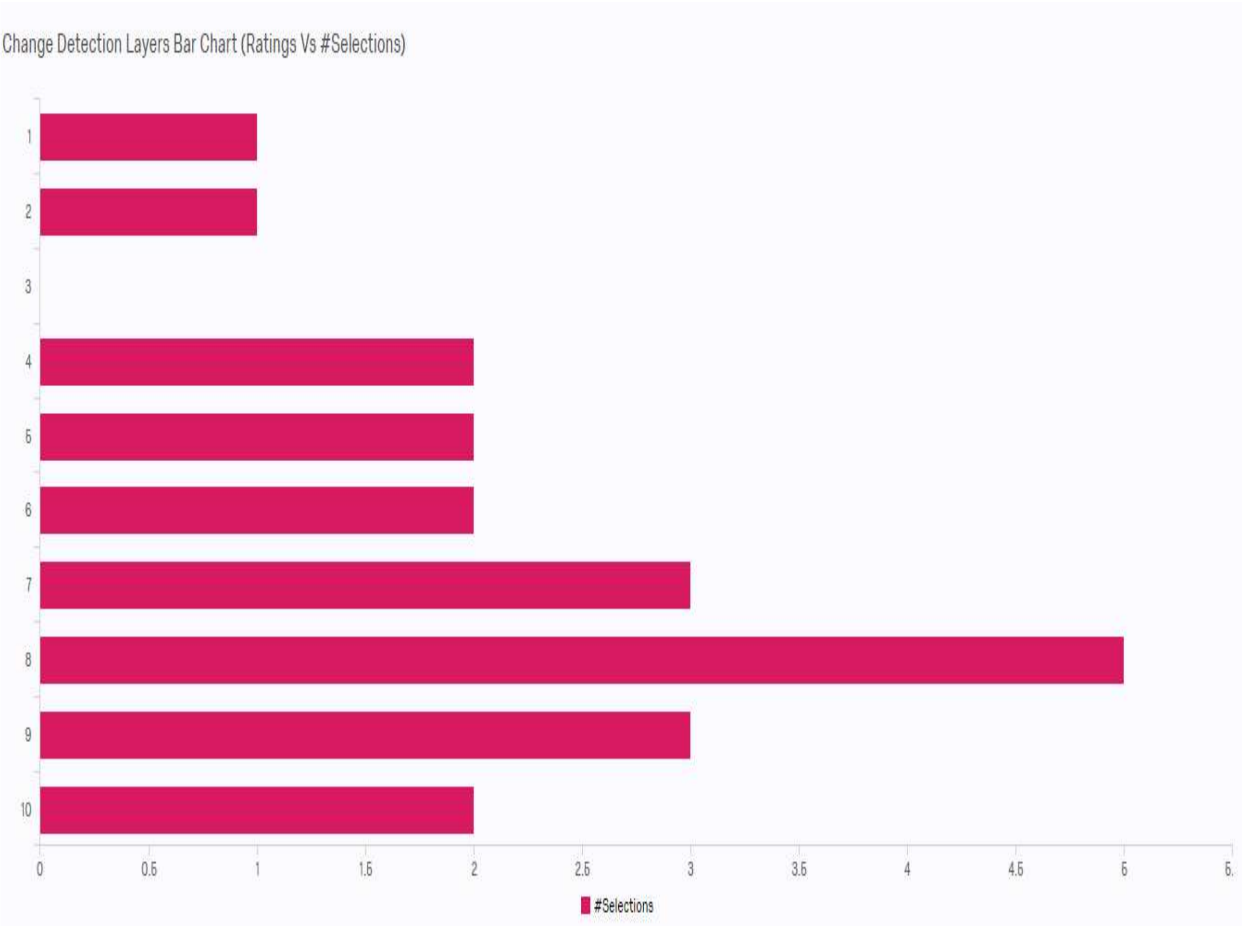


FIGURE 4.6 : Ratings for the Change Detection Layers functionality

21 responses were received for this question and the mean rating of 6.71 received for the Change Detection Layers functionality indicates a positive response from the reviewers. The standard deviation of the responses is 2.41.

Respondents were asked to rate the Geolocation functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The Geolocation facility allows users to carry out onsite analysis with the Map Interface. Responses are shown in Figure 4.7 below. The vertical axis displays ratings and the horizontal axis displays the number of selections.

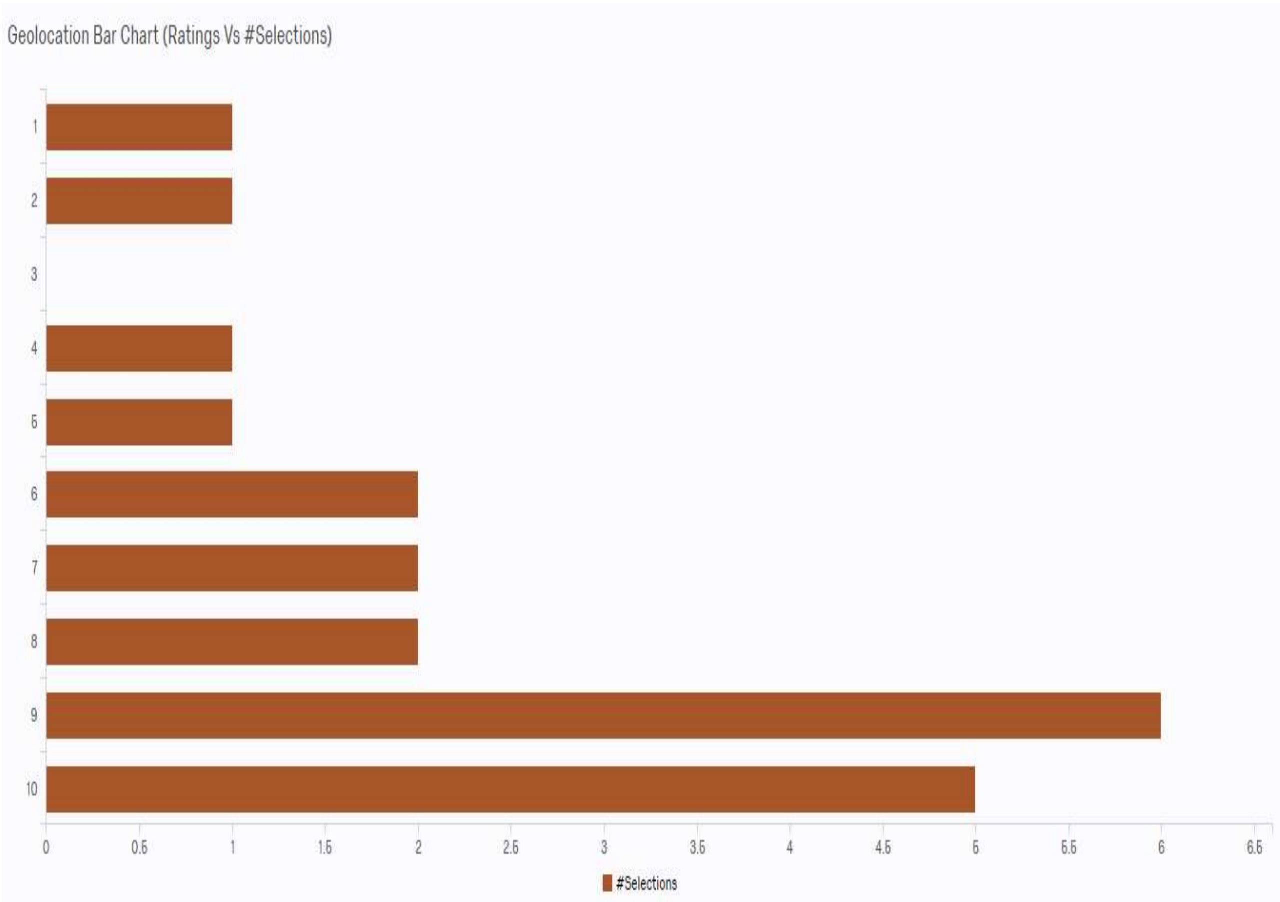


FIGURE 4.7 : Ratings for the Geolocation functionality

21 responses were received for this question and the mean rating of 7.52 received for the Geolocation functionality indicates a positive response from the reviewers. The standard deviation of the responses is 2.59.

Respondents were asked to rate the Records functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The Records facility allows users to save location based data and enables crowdsourcing and data analysis. Responses are shown in Figure 4.8 below. The vertical axis displays ratings and the horizontal axis displays the number of selections.

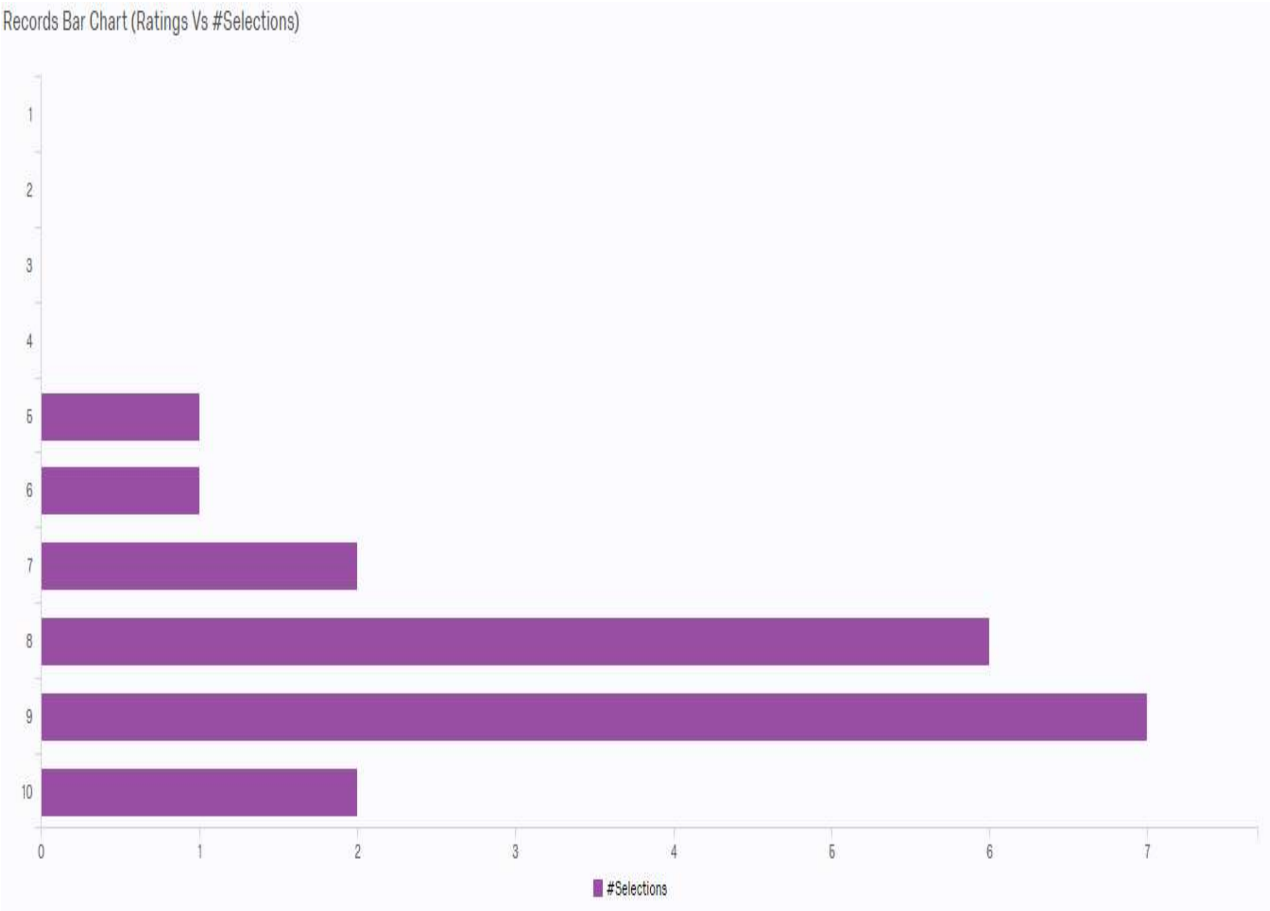


FIGURE 4.8 : Ratings for the Records functionality

19 responses were received for this question and the mean rating of 8.21 received for the Records functionality indicates a positive response from the reviewers. The standard deviation of the responses is 1.24.

Respondents were asked to rate the Responsive Design functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The application has been designed with responsive design to deliver content on mobile and desktop devices. Responses are shown in Figure 4.9 below. The vertical axis displays ratings and the horizontal axis displays the number of selections.

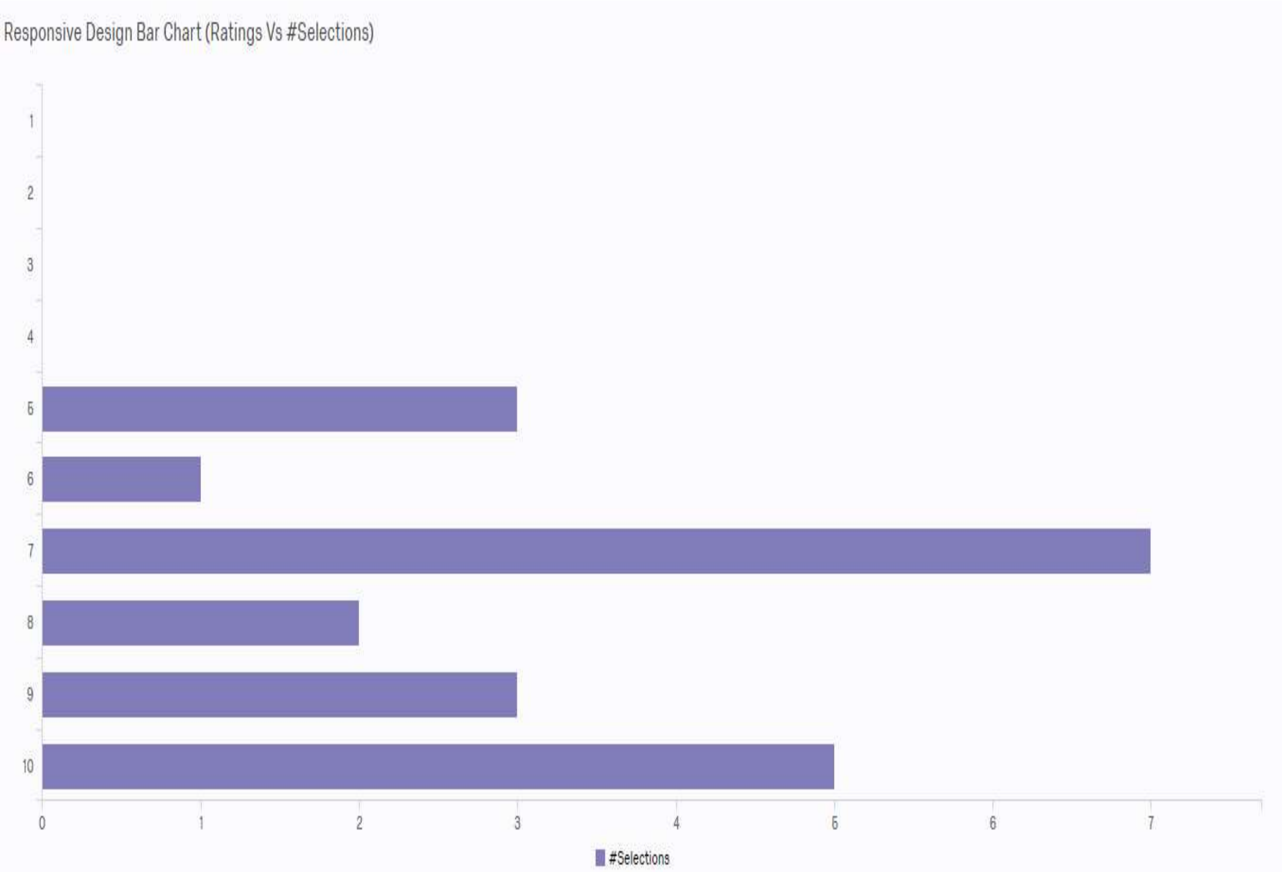


FIGURE 4.9 : Ratings for the Responsive design functionality

21 responses were received for this question and the mean rating of 7.76 received for the Responsive Design functionality indicates a positive response from the reviewers. The standard deviation of the responses is 1.69.

Respondents were asked to rate the Layer Management Interface functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The Layer Management Interface functionality allows users to add their own spatial data (drone/satellite/surveyed) to the application. Responses are shown in Figure 4.10 below.

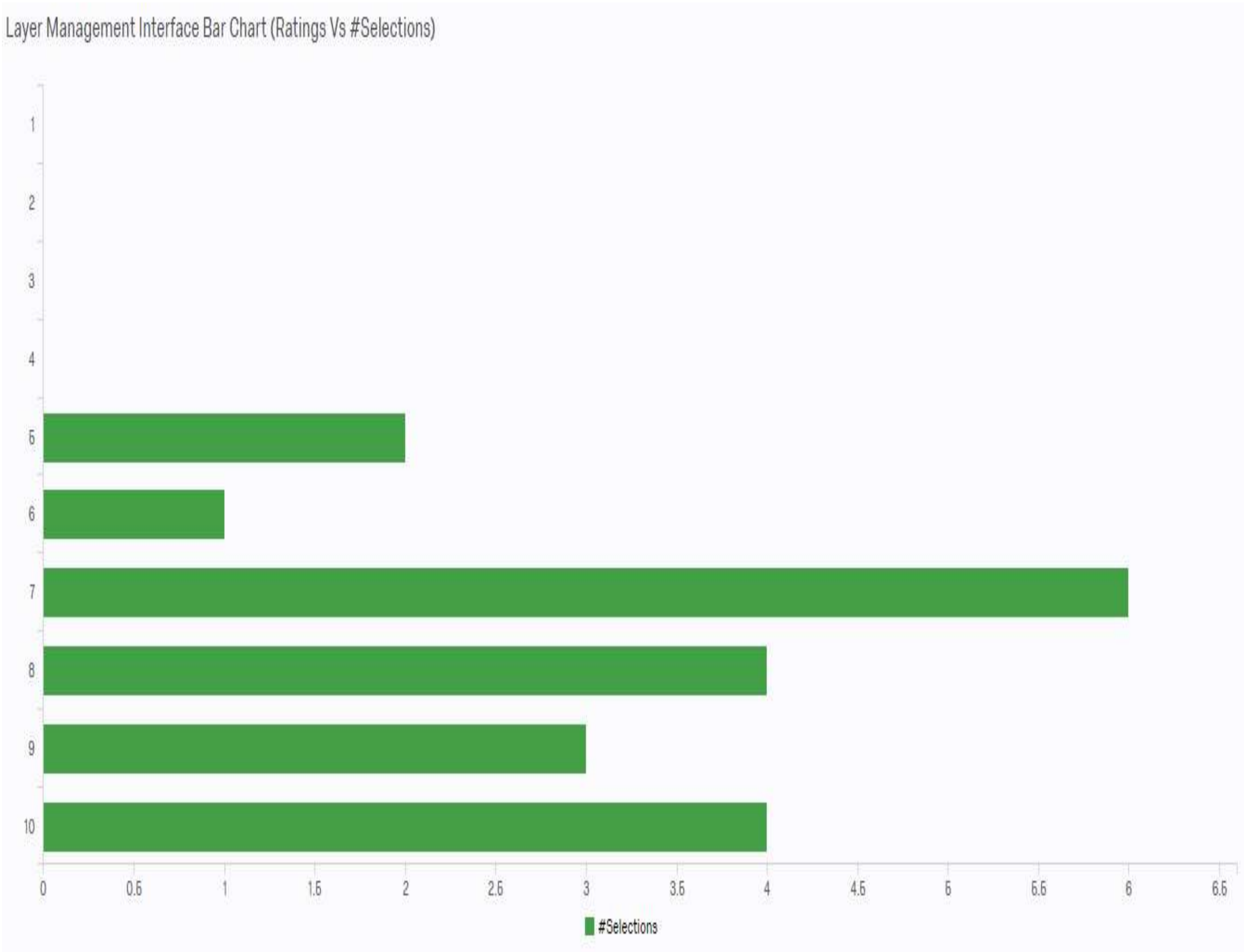


FIGURE 4.10 : Ratings for the Layer Management Interface functionality

20 responses were received for this question and the mean rating of 7.85 received for the Layer Management Interface functionality indicates a positive response from the reviewers. The standard deviation of the responses is 1.53.

Respondents were asked to rate the Reporting Interface functionality on a scale of 1 to 10, where 1 indicates weak and 10 is excellent. The Reporting Interface displays change detection imagery and reports on the usage of the Records and Layers Interfaces. Responses are shown in Figure 4.11 below.

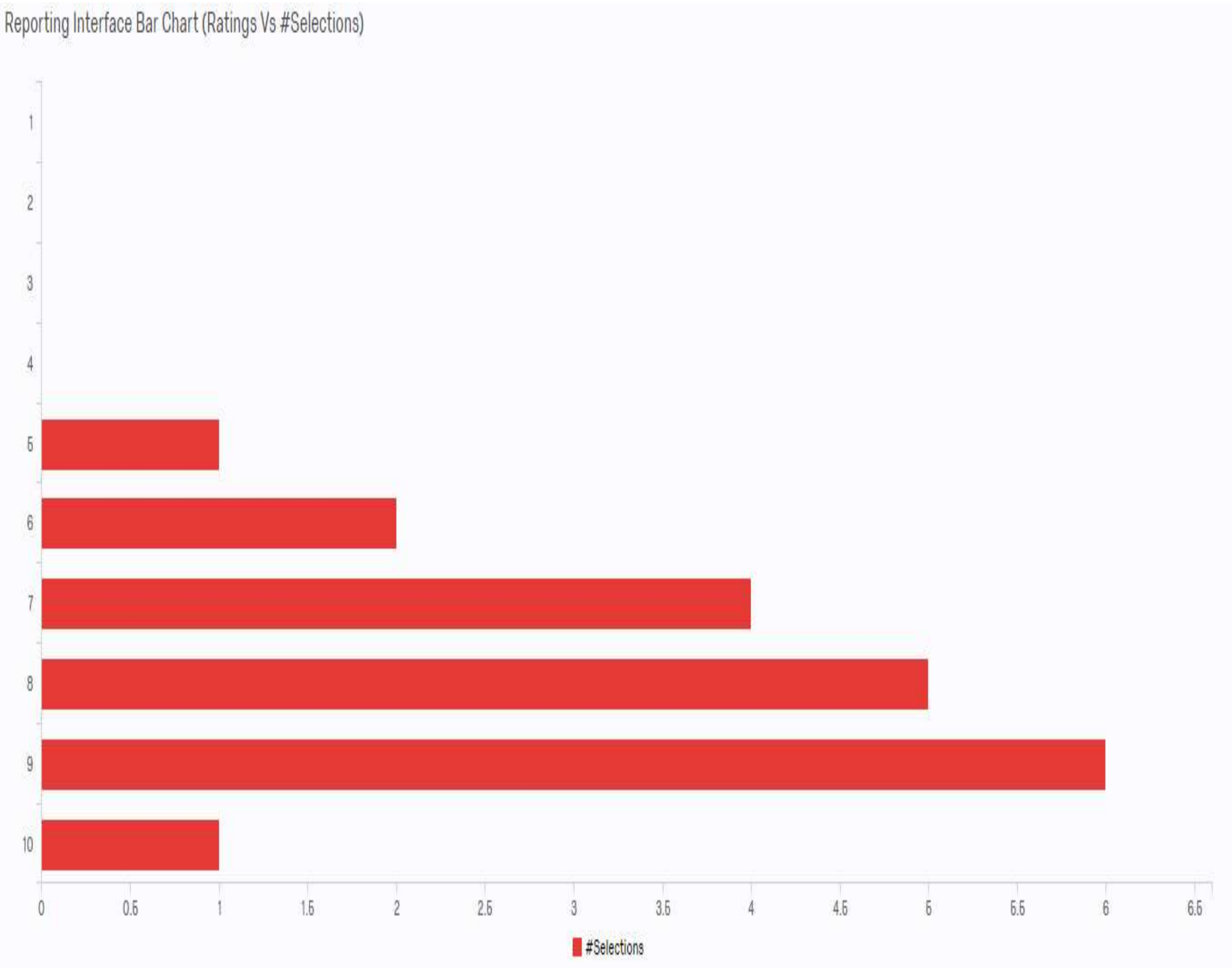


FIGURE 4.11 : Ratings for the Reporting Interface functionality

19 responses were received for this question and the mean rating of 7.84 received for the Reporting Interface functionality indicates a positive response from the reviewers. The standard deviation of the responses is 1.27.

The final question on the survey asked respondents for feedback and suggestions on the PFA. Appendix IV lists the twelve responses received. The majority of the feedback was positive towards the PFA. Respondents provided valuable feedback on the system such as the necessity for testing and validating the system in the field. Suggestions for further development of the system included the use of higher resolution imagery, focusing on grassland monitoring, data output functionality, using the GeoLocation functionality for farmer safety, using the Reports feature to report farm machinery theft, the development of a national crop database and the need for guidelines on the best use of the system.

Participant 11 commented that Ireland has a relatively low level of arable farming and the soils in Ireland are highly variable within fields. Farmers using the PFA software should not always interpret low yield as being a sign of a shortage of inputs as certain areas are not capable of producing at the same rate of surrounding parts of the field. The ability for farmers to upload their own spatial layers on the PFA was mentioned to be useful for identifying areas with known yield issues. Areas for further research were identified with participant 4 highlighting the need for a national crop database and participant 11 commenting that it would be beneficial to research the capabilities of PA for monitoring grassland.

4.2 Interviews

Interviews were carried out with five key stakeholders in the PA area. These experts have extensive experience of PA technologies and work for a number of farming, agricultural manufacturing, agricultural services and agricultural research organisations. Selected quotes and word clouds are used below to illustrate the common themes and protect participants' privacy. Figure 4.12 below lists the interviewees' location, role and experience:

Location	**Role**	**Years Of Experience**	**Participant Name**
Ireland	Researcher	17	Participant A
Ireland	Company Director	18	Participant B
Ireland	IT Manager	10	Participant C
Ireland	Services	5	Participant D
Ireland	Farm Manager	20	Participant E

FIGURE 4.12 : Interviewees' location, role and experience

Interview Question 1: What are the barriers to the adoption of PA technologies and practices?

The feedback from the interviewees was that the initial cost of investment, a lack of awareness of PA and the complexity of the PA technologies are major barriers to PA adoption.

”Farmers are receiving low prices for their produce and do not have the resources to invest in new PA technologies”.

“Many farmers are unaware of the economic, labour saving and environmental benefits of PA technologies”.

“Some PA technologies can be difficult to setup and use. Farming equipment using PA technologies require calibration in the field to ensure that data is captured correctly”

Figure 4.13 below displays the barriers to PA adoption provided by interviewees:

FIGURE 4.13 : The barriers to PA adoption

Interview Question 2: What are the drivers for the adoption of PA technologies?

The primary factors cited by interviewees for adopting PA were increased profitability, labour savings and environmental sustainability.

“Increased profitability is a key driver of PA adoption. Farmers are looking for easy to use PA products that provide a rapid return on investment and enhanced farm profits”.

“Many farmers today have off farm jobs and the labour savings that PA technologies can deliver are attractive to farmers with busy schedules”

“PA technologies that protect the environment are interesting for farmers as they are looking to protect and improve the quality of their land and water sources”

Figure 4.14 below displays the drivers for PA adoption provided by interviewees:

FIGURE 4.14 : The drivers for adoption of PA technologies

Interview Question 3: What are the technologies that are driving PA adoption?

The interviewees described high precision positioning systems, mobile applications and geospatial systems as playing an important role in driving PA adoption.

“Many farmers have smartphones and can download free PA applications for analysing crops or animals. Mobile applications are raising awareness of PA and suit the active and outdoors nature of farm work”

“Farmers are using high precision positioning systems for precise planting, spraying and harvesting of crops.”

“Geospatial systems are allowing farmers to electronically map information and combine multiple sources of data to track the performance of their land”

Figure 4.15 below displays the technologies driving PA:

FIGURE 4.15 : The technologies driving PA

Interview Question 4: What are the requirements for the successful implementation of PA technologies?

The feedback from the interviewees was that training and education, clear requirements from the farmers and financing were important requirements for the successful implementation of PA technologies.

“Training and education is fundamental to the success of a PA implementation”

“Farmers need to be clear on what they want when investing in PA”

“Funding needs to be available to support the initial investment in PA technologies and to support the ongoing costs”

Figure 4.16 below displays the requirements for successful PA implementations:

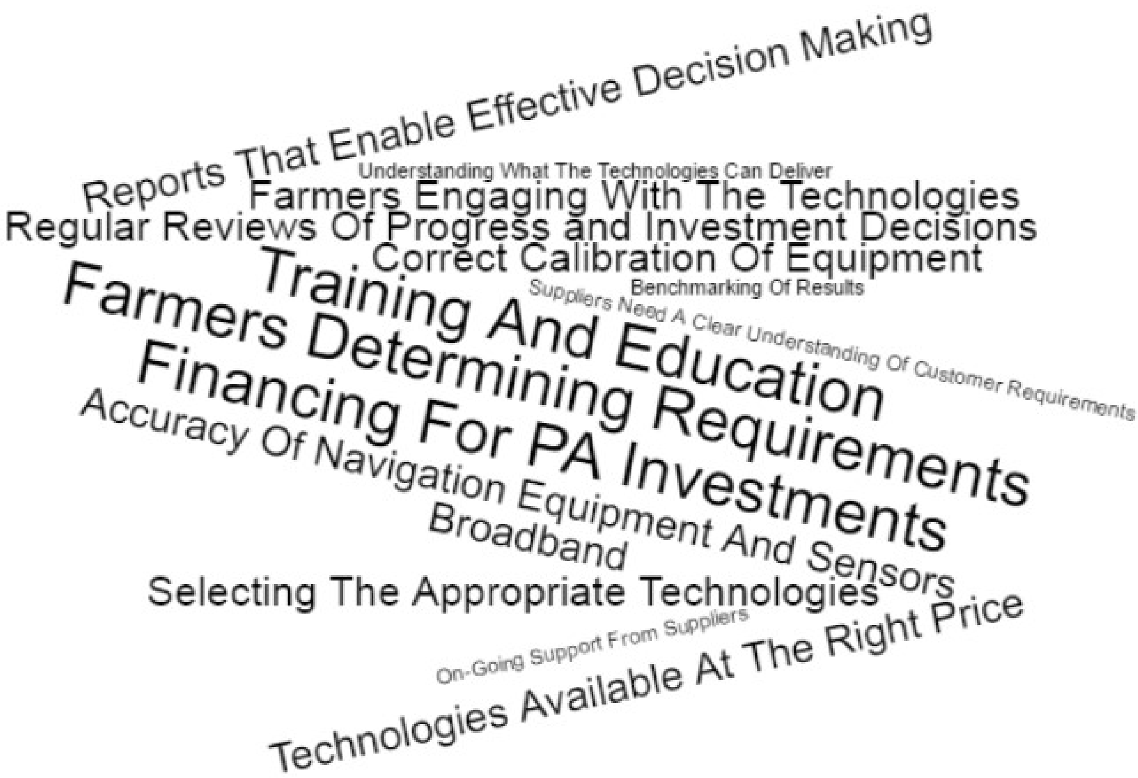


FIGURE 4.16 : The requirements for successful PA implementations

Interview Question 5: What are the benefits of PA?

The interviewees provided labour savings, increased profits and environmental protection as the primary benefits of PA.

“A key benefit of adopting PA technologies is increased farm profitability”.

“PA technologies can monitor important aspects of a farm’s environment and alert the farmer when there are issues to be addressed. Farmers can also use PA to achieve environmental compliance”

“Farmers can take the drudgery out of repetitive tasks and save money by reducing the numbers of farm employees with the adoption of labour saving PA technologies”

“Farmers can use PA technologies to achieve better reproduction rates for their herds and get cows milking earlier”

Figure 4.17 below displays the benefits of PA technologies and practices:

FIGURE 4.17 : The benefits of PA technologies and practices

Interview Question 6: What role can the media and government play regarding PA adoption?

The responses from the interviewees highlighted the media's role in raising awareness of PA, the role of government in developing a national PA strategy and the role of government in designing agricultural schemes that encourage the adoption of proven PA technologies.

"The media can raise awareness of PA technologies and keep farmers informed on the latest PA developments"

"Agricultural schemes can drive PA adoption by incentivising investment by farmers in PA technologies that have been shown to be beneficial"

"A clear national PA strategy is needed to drive the adoption of PA in Ireland."

Figure 4.18 below displays the role of government and the media in PA adoption

FIGURE 4.18 : The role of government and the media in PA adoption

Interview Question 7: What methods can be used to increase PA adoption?

The interview participants suggested a number of ways of increasing PA adoption including increased collaborative research, government agricultural schemes that assist PA adoption and the sharing of PA knowledge

"Agricultural schemes with incentives for investing in PA technologies could be used by the government to drive PA adoption".

"Collaborative research with farmers and state agencies can prove the benefits of PA".

"Expanding the number of farmers using knowledge transfer groups would increase awareness of PA"

"The availability of cheaper PA products would drive adoption."

Figure 4.19 below displays the methods which can be used to increase PA adoption

FIGURE 4.19: Methods which can be used to increase PA adoption

Interview Question 8: What is the outlook for PA?

The feedback from the five interview participants was a positive future for PA with increased adoption by farmers once barriers are addressed.

“There will be rapid development and adoption of mechanical and position based PA products and slower development with the more complex crop growth and animal disease control PA products“

“PA is on a development path and state agencies need to focus research on areas that are important for Irish agriculture”

“The rate of adoption will depend on the PA product. Farmers will only invest in intuitive PA products where the benefits are clear and there is a good return on investment.”

“Farmers will need to adopt PA to remain competitive”

“Independent PA companies, government agencies and government agricultural schemes will play an important role in increasing PA adoption”.

Figure 4.20 below displays the outlook for PA technologies and practices:

FIGURE 4.20 : The outlook for PA technologies and practices

Research Question

The PFA was demonstrated to the five interviewees and they were asked about their opinions regarding the research question. Four of five interviewees stated that the PFA would be a useful tool for overcoming PA adoption barriers and increasing PA adoption. The availability of the mobile interface was cited by many participants as an important feature that would aid adoption.

“The use of open and free data, the accessible interface and the ability to observe changes over time are useful”

“The crowdsourcing element of the application would be useful for farmers sharing information and validating PA products”.

“The application would overcome the cost and complexity barriers that have hampered PA adoption”.

Figure 4.21 below displays the feedback from the interviewees on the research question:

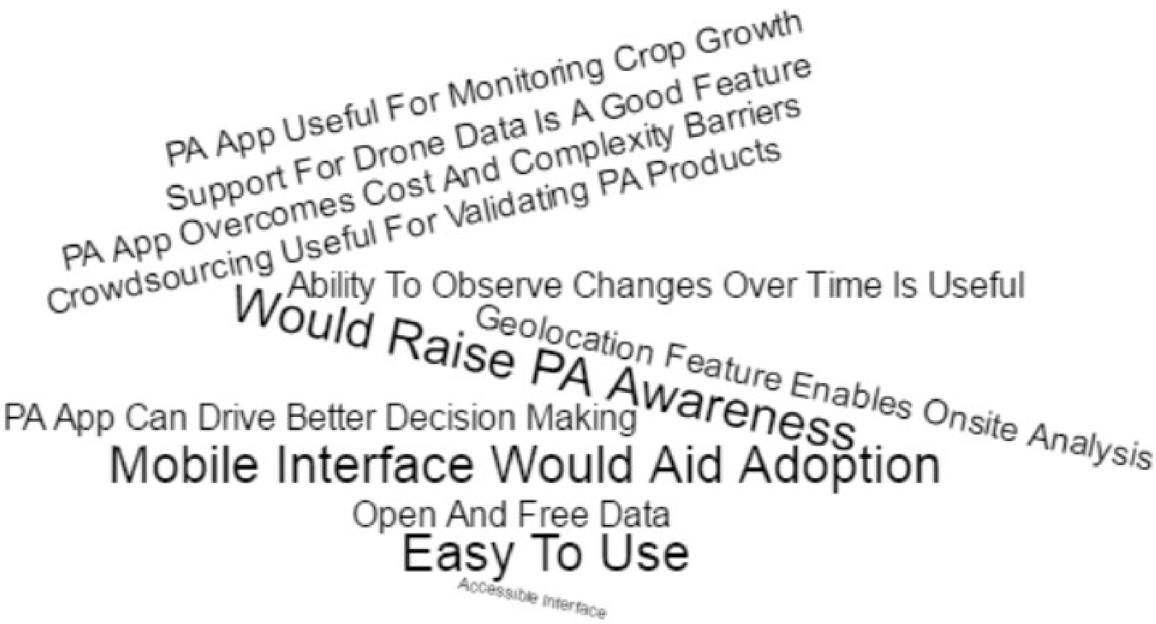


FIGURE 4.21: The feedback from interviewees on the research question

5 Conclusions and Future Work

5.1 Conclusions

The majority of survey respondents and interview participants indicated that the PFA would be a useful tool for addressing the challenges facing the adoption of PA. The highest rated features from the survey were the crowdsourcing feature, the responsive design functionality, the Reports facility and the Layer Management Interface. The crowdsourcing feature was deemed to be a useful platform for farmers to share information, compare PA experiences and validate results. The sharing of geo-located PA data can help farmers make decisions on effective PA farming practices and purchases of PA equipment. Feedback was positive on the responsive design functionality as respondents appreciated the mobile interface and the full screen capabilities of the responsive design. Many farmers have smartphone access and the mobile interface supports their work in the field. The reports generated from multiple sources of open data were found to be useful features. The reports enable effective decision making for farmers by presenting analytics on crop health and system activity. Feedback on the Layer Management Interface was also positive as users could see the benefit of adding their own spatial data to the system.

Positive responses were also received for the Map Interface, the NDVI layers, the Infrared layers, the Change Detection layers and the Geolocation facility. The Map Interface brought multiple sources of free and open data together in an accessible map interface to display data for effective decision making by farmers. The NDVI and the Infrared layers displayed plant health data from the Sentinel 2 satellites in an intuitive manner that would benefit farmers monitoring the performance of their land. The Change Detection layers displayed the results of analysis on different sets of NDVI or Infrared layers. Farmers can use the Change Detection layers to determine areas on their farm that are performing poorly and require attention. The Geolocation facility uses the user’s smartphone GPS sensor to zoom to their location on the map interface and displays their location in the field. A farmer can use the Geolocation facility in tandem with the NDVI, Infrared and Change Detection layers to apply fertiliser or pesticides in areas of poor crop performance.

A greater understanding of the factors that influence PA adoption has been developed with this study. The interview participants provided valuable feedback on the barriers to PA adoption, the drivers for PA adoption, the technologies driving PA, the benefits of PA, the requirements for successful PA implementations, the role of government and the media in the adoption of PA and the outlook for PA adoption going forward.

Cost, complexity and lack of awareness were described by interview participants to be key barriers to PA adoption. Poor broadband infrastructure, demographics, the uncertainty about the economic benefits of certain PA technologies, the lack of an implementation strategy and the lack of scale were also raised as barriers to PA adoption. There are many barriers to the wider adoption of PA which explains why the adoption has been low until now.

Key drivers for PA adoption were found to be increased profitability, labour savings and environmental sustainability. Interview participants cited additional drivers for PA adoption to be easy to use PA products, increased production, mobile applications and reduced risk. It is clear that farmers have different motivations when adopting PA technologies. Farmers with off farm employment may be interested in the labour savings capabilities of PA while others farmers may be interested in the environmental benefits of PA.

Important PA technologies were found to be high precision positioning systems, mobile applications and geospatial systems. Other technologies cited by interview participants were machine controls, sensors, broadband, data analytics, remote sensing, IOT, voice applications, cloud computing, M2M and drones. PA applications use a multitude of diverse technologies to deliver benefits to farmers and the PA products that will succeed will package these technologies into easy to use devices.

The primary requirements for successful PA implementations were found to be training and education, financing for PA investments and clear requirements defined by the farmer. Additional requirements cited by interview participants were the correct calibration of equipment, the accuracy of navigation equipment and sensors, reports that enable effective decision making, technologies available at affordable prices, broadband, farmers engaging with the PA technologies and regular progress and investment reviews. The adoption of PA within Ireland will be influenced by the successful implementations of PA by early adopting farmers. A good understanding of the requirements for success can assist farmers when planning their own PA adoption strategy.

Environmental protection, increased profitability and labour savings were identified as the key benefits of PA by the interviewees. Additional benefits cited were better fertility management for livestock, cost savings, disease control, enhanced production, pro-active alerts, reduced inputs, time savings, better farming methods and new business practices. A greater awareness of the diverse benefits of PA technologies in the farming community should drive the greater adoption of PA within Irish agriculture.

Areas of importance for the government and the media in the adoption of PA were identified by the interviewees to be the development of a national PA strategy to drive adoption, the role of government agricultural schemes in encouraging PA adoption and the raising of PA awareness within the farming community by the media. Additional areas of relevance for the media and government were the need to prioritise PA Investments for specific areas in alignment with the national agricultural strategy, the need for an integrated and inclusive approach, a clear direction to focus on PA that delivers a return on investment, the need to explore the capabilities of PA technologies for reducing the national carbon footprint and the need for government agencies to support collaborative research with PA stakeholders. The interviewees were clear that the government and the media have an important role to play in the development and adoption of PA technologies.

A number of proposals on increasing PA adoption were put forward by the interviewees including increased collaborative research proving the benefits of PA technologies, the expansion of knowledge transfer groups, a drive to develop cheaper PA products and the development of agricultural schemes by the government that incentivise PA adoption. Interviewees also proposed increased demonstrations of PA to farmers, informing farmers on the economic benefits of PA, greater access to finance for PA investment, identifying the PA products that deliver a good return on investment, increased development of PA mobile apps and timely decision support tools.

The interview participants had a positive outlook for the adoption of PA technologies in Ireland once measures have been put into place to address the current adoption barriers. Interview participants see a greater awareness of the economic benefits of PA products developing among farmers. Mechanical and position based PA products may drive PA adoption in many areas. The interviewees commented that PA is on a development path with research underway to develop new products and prove the benefits of PA. Rural broadband should improve and assist the greater adoption of PA technologies. There will be slower development of complex animal disease control and crop growth PA products due to the multiplicity of interactions that occur. Interviewees predicted that many farmers will need to adopt PA to remain competitive going forward and there will be increased usage of drones and vehicle guidance aids by Irish farmers. Smartphone adoption by farmers was anticipated to rise and more farmers will be using PA applications on their smartphones. Smart data alerts and reports generated with data analytics and the IOT will enable better decision making by farmers.

Generalisability

The findings of this study can be applied to the other countries in the EU that are experiencing low levels of PA adoption. Many European countries have small farms and similar challenges with PA adoption as Irish farmers. The PFA uses software and data sources that are freely available to other member states.

Limitations

A limitation of this research is that the survey participants were selected from the population of PA stakeholders that were contactable via publicly available email addresses. A larger cross section of the agribusiness sector would have been encountered if the PFA was presented at a public farming event where farmers of all ages and backgrounds could contribute their opinions and insights on PA.

Advancing the current state of knowledge

This study has answered Commissioner Hogan's call for research on the adoption of PA and the positive feedback to the PFA validates the recommendations of the EIP-AGRI and JRC reports regarding the usage of open data, GNSS and Copernicus remote sensing programme data, crowdsourcing, integrated data sets and intuitive map interfaces in increasing PA adoption. The potential for PA to deliver competitive advantage for Irish farmers is substantial. Feedback from survey and interview participants points towards the need for ongoing PA research, PA training programs, enhanced product development, a national implementation strategy and support for PA investments. PA research can identify PA technologies and practices that yield high returns on affordable investments for farmers. Packaging suitable PA technologies together into single products can drive adoption by enabling simpler purchasing by farmers.

New and interesting findings

An interesting finding of this research was the diversity of benefits that farmers realise with PA technologies. Participants described benefits such as time and labour savings, environmental protection, better animal welfare and enhanced profits. Participants also stated that some areas of PA do not provide a return on investment while other PA areas are profitable. Identifying the PA technologies that are affordable for the farmer and deliver a good return on investment will drive adoption. A national PA implementation strategy was identified as an important driver of PA adoption. A PA implementation strategy could target areas of agriculture where PA can deliver competitive advantage to meet the national 2025 Food Wise targets. The most important factor in the adoption of PA technology is the farmer. With the appropriate supports and training, an increasing number of farmers will leverage PA applications to enhance output, drive efficiencies, protect the environment and increase profits.

5.2 Future Work

An area for future research would be monitoring grassland in Ireland using the Sentinel 2 satellite data. The sustainable growth of grass is a major benefit to the Irish agricultural sector and any improvements that can be made in this area would be useful to Irish farmers. The five day revisit intervals of the Sentinel 2 satellites could be used to build up a repository of data on the performance of the grass in farmers' fields and to identify areas of poor performance in fields for further attention by farmers.

A participant suggested that the PFA could be beneficial for health and safety purposes as a farmer could issue a location based alert that could help emergency services identify their location. Further research on smartphone applications that use location information to assist farmers with health and safety would be useful.

A number of participants commented that higher resolution data would be more useful for their farming practices. Higher resolution data could be obtained from drones or vendors of high resolution satellite data. It would be beneficial to research the use of high resolution satellite data for agricultural monitoring and to determine the benefits of the higher resolution imagery versus the cost of purchasing the imagery.

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7 Appendices

7.1 Appendix I: Key Features Slideshow

Precision Farming Application - Key Features Slideshow

This Precision Farming Application has been developed as part of the research element of a masters in the Management of Information Systems with Trinity College.

Precision Farming uses a combination of technologies to deliver benefits for farmers such as cost savings, increased production, decision making tools and environmental compliance. The adoption of Precision Farming in Ireland has traditionally been low due to barriers such as cost and complexity. The aim of this dissertation is to research methods of increasing the adoption of Precision Agriculture in Ireland.

This mobile and desktop application has been developed using a Google Maps interface, Sentinel 2 satellite data and SNAP software from the European Space Agency, weather data, agricultural news, Microsoft Asp.Net technologies and Azure Cloud hosting.

Every 5 days, Sentinel 2 satellites image the earth at 10 meters resolution, which allows farmers to monitor their crops progress. Farmers can also add their own spatial and agricultural data to the application. The software has been developed to be low cost and accessible to farmers. Open and free data and software from the Sentinel 2 satellite, crowd-sourced data and a Google Maps interface are used to explore how adoption barriers can be addressed.

The research question is 'would an intuitive decision support system incorporating remote sensing data, mapping interfaces, crowd-sourced data and external data sources address challenges facing the adoption of precision farming?'.

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Precision Farming Application - Key Features Slideshow

Key features include :

- A Map Interface that displays spatial data, crowdsourced data, agricultural news and weather data in one location.
- Satellite View Layers that display colour imagery from the European Space agency's Sentinel 2 program.
- Normalised Difference Vegetation Index (NDVI) Layers that display plant greenness/photosynthetic activity
- Infrared Layers that display plant health information.
- Change Detection Layers display differences between sets of NDVI or Infrared images. Areas with poor or good growth can be identified.

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Precision Farming Application - Key Features Slideshow

Key features (continued) :

- A Geolocation facility allows users to carry out onsite analysis with the Map Interface
- A Records facility allows users to save location based data and enables crowdsourcing and data analysis
- Responsive design is used to delivery content on mobile and desktop devices
- A Layer Management interface allows users to add their own spatial data (drone/satellite/surveyed) to the application
- A Reporting Interface displays change detection imagery and reports on the usage of the Records and Layers Interfaces.

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Precision Farming Application - Key Features Slideshow

This is the homepage of the application. The Map Interface displays spatial data layers, crowdsourced data, geolocated data, agricultural news and weather data in one location to enable effective decision making. Farmers can use the Map Interface to identify areas of their fields that are productive and to determine which areas require further attention

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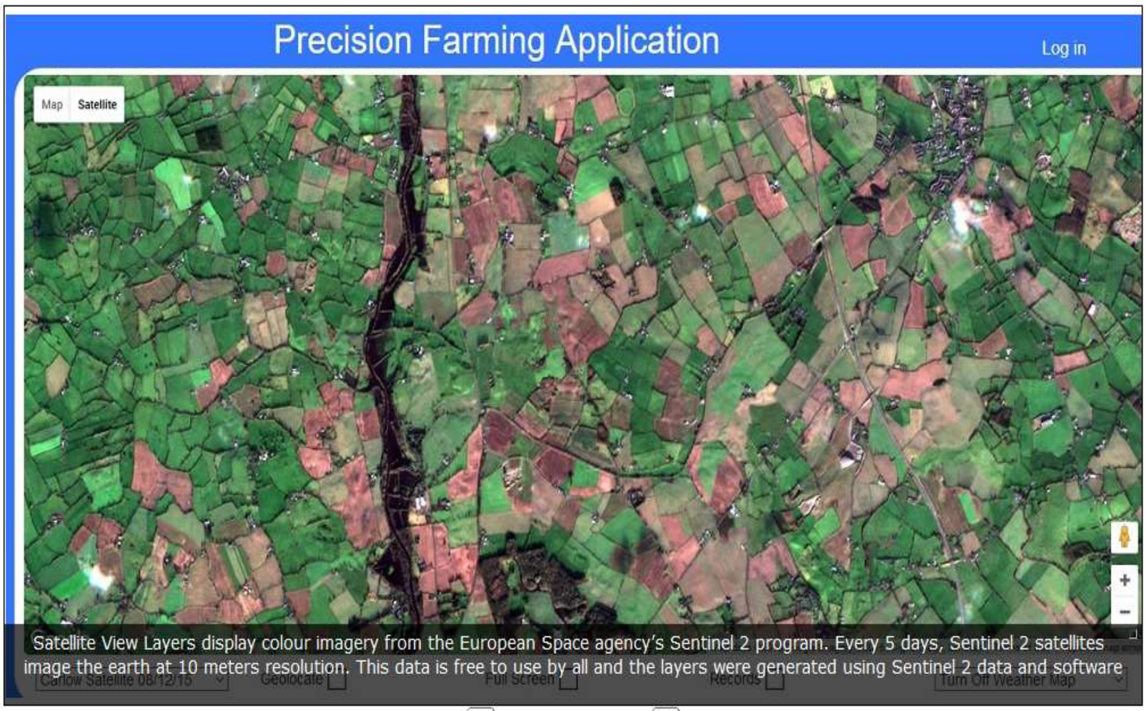
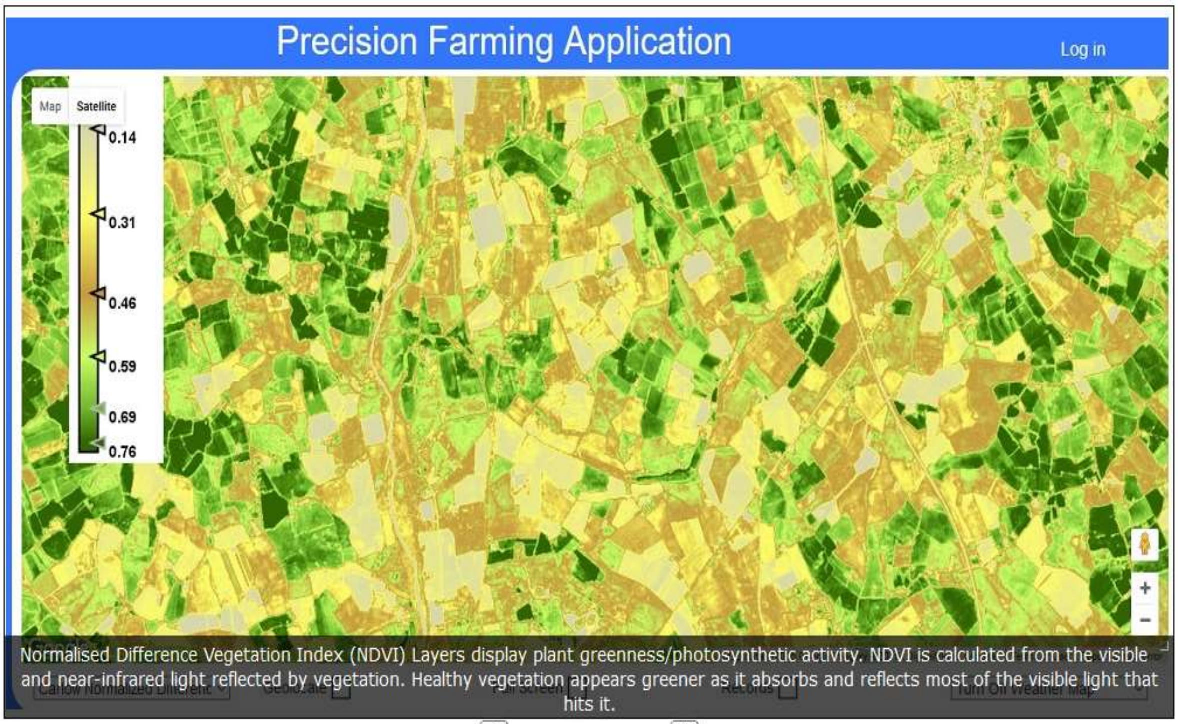
Precision Farming Application - Key Features Slideshow



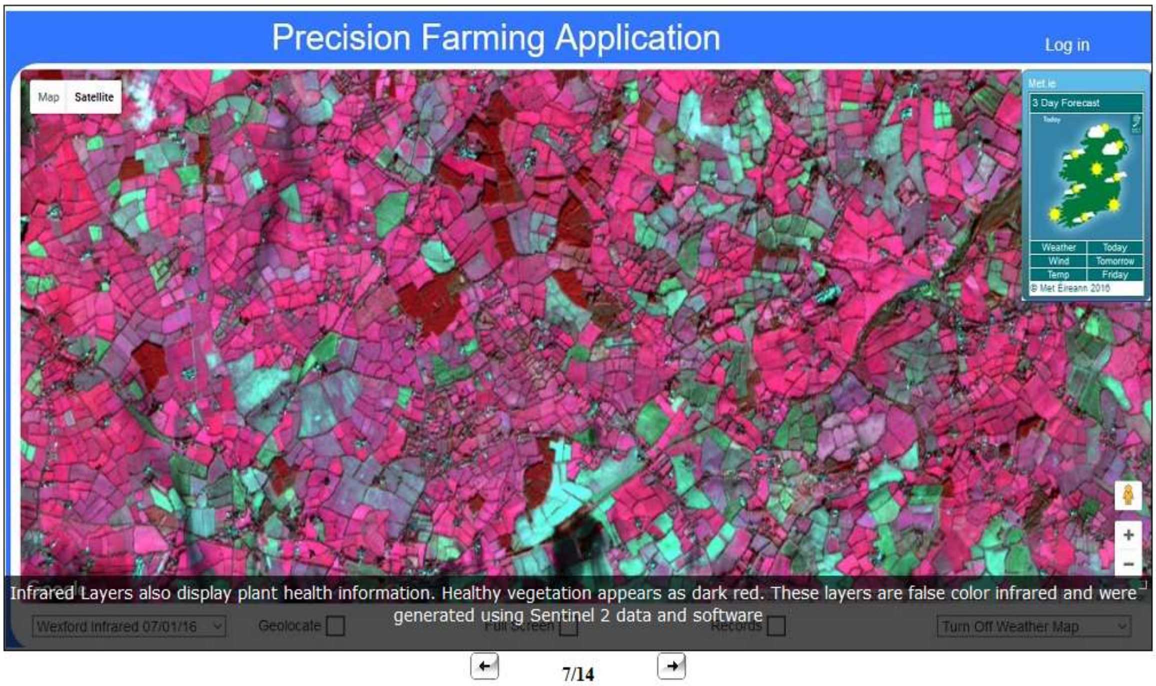
5/14

Precision Farming Application - Key Features Slideshow



6/14

Precision Farming Application - Key Features Slideshow



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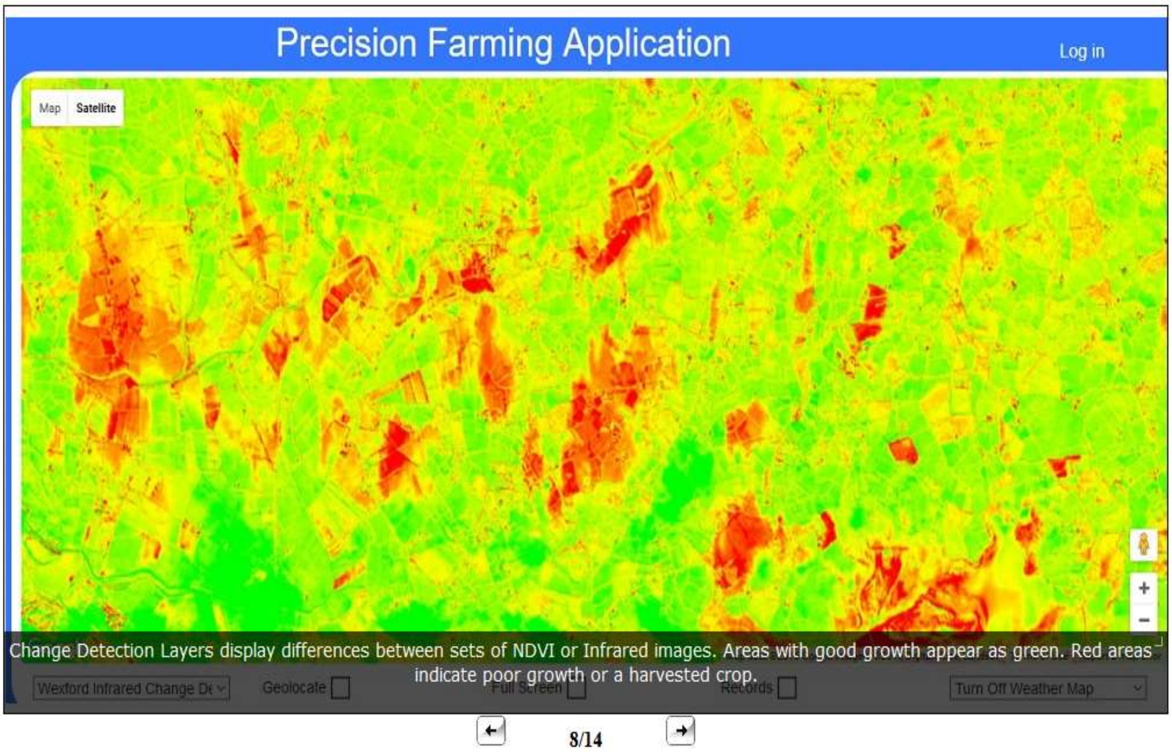
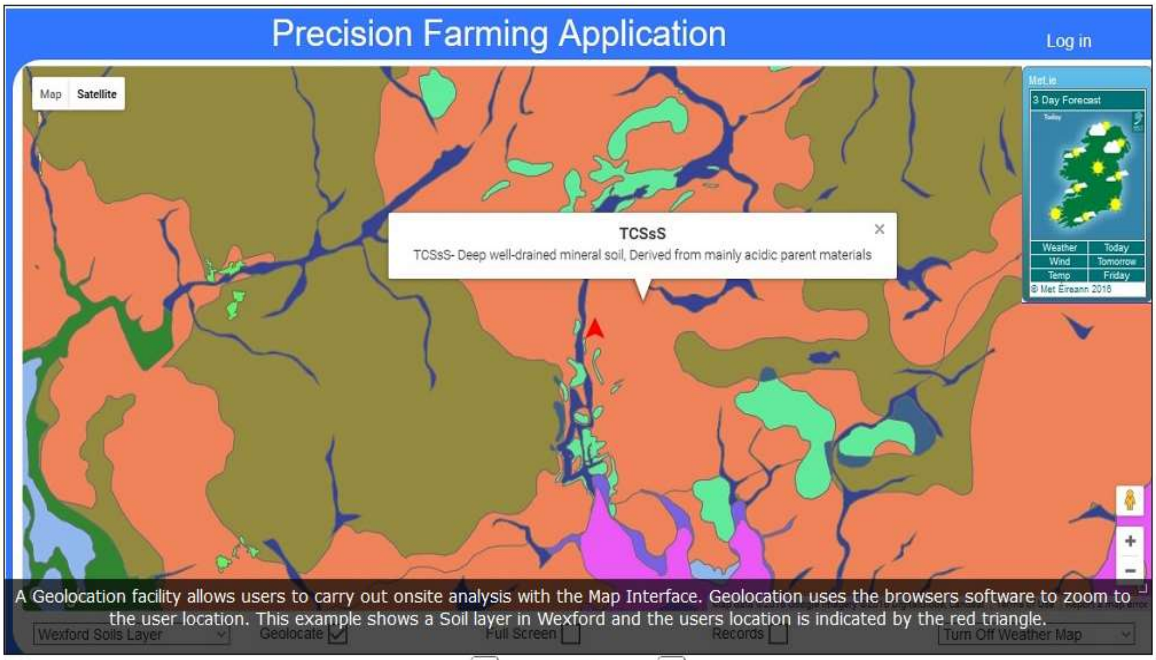
Precision Farming Application - Key Features Slideshow



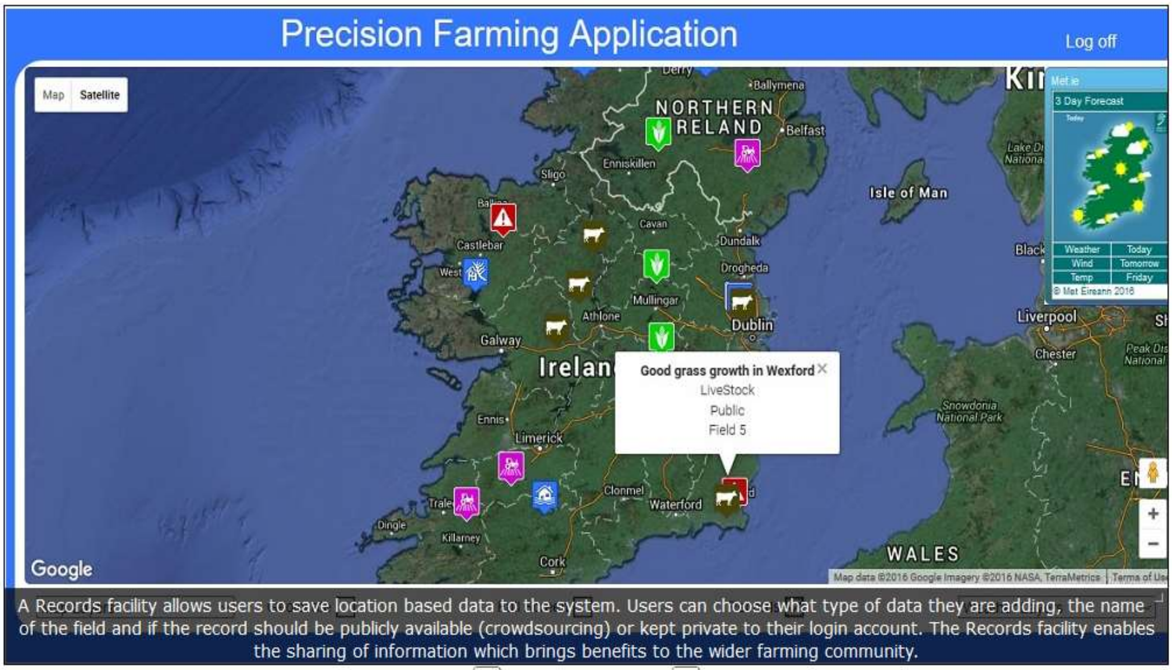
8/14

Precision Farming Application - Key Features Slideshow



9/14

Precision Farming Application - Key Features Slideshow



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Precision Farming Application - Key Features Slideshow

Responsive design is used to delivery content on mobile and desktop devices. The same information is available regardless of the device used to access the application. Users can also view the Map Interface on a full screen interface if required

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Precision Farming Application - Key Features Slideshow

Precision Farming Application — Log off

Layers

	Id	Name	FileLocation	Description	Date_Inserted	Username	Source	Privacy	DateCaptured	Lat	Lng
Edit Delete	1	Dublin/Meath Soils testing	http://dl.dropboxusercontent.com/s/4luq28aomu5mfjs/Soils1.kmz	Dublin/Meath Soils	3/21/2016 12:00:00 AM	Admin1@gmail.com	Drone	Private	3/15/2016 12:00:00 AM	53.459191	-6.355505
Edit Delete	2	layer_01_1	http://dl.dropboxusercontent.com/s/pb7pdaqin2ehgrm/overlay.kml	testing	3/21/2016 12:00:00 AM	Admin1@gmail.com	Drone	Private	3/15/2016 12:00:00 AM	53.390325	-6.298401
Edit Delete	3	layer_01_2	http://dl.dropboxusercontent.com/s/0ltyib45xy77asa/overlays.kml	testing	3/21/2016 12:00:00 AM	Admin1@gmail.com	Drone	Private	3/15/2016 12:00:00 AM	53.459191	-6.355505
Edit Delete	5	Wexford Normalized Difference Vegetation Index (NDVI) 07/01/16	http://dl.dropboxusercontent.com/s/zoz0y9f06lqwvno/NDVI_Overlay_Wex_7_Jan_16_kml_3.kml	Wexford 07-01-16 Normalized Difference Vegetation Index (NDVI)	3/25/2016 12:00:00 AM	Admin1@gmail.com	Satellite	Public	1/7/2016 12:00:00 AM	52.255690	-6.521759
Edit Delete	6	Wexford Soils Layer	http://dl.dropboxusercontent.com/s/xczp63p1ymonj0d/wexfordsoils3.kml	Wexford Soils Layer 2016	3/25/2016 12:00:00 AM	Admin1@gmail.com	Other	Public	1/1/2016 12:00:00 AM	52.255690	-6.521759
Edit Delete	7	Wexford Infrared 07/01/16	http://dl.dropboxusercontent.com/s/n0kywwiy2q4zyhx/RGB-INFARED-WEX-7-JAN_1.kml	Wexford 07-01-16 Infrared	3/25/2016 12:00:00 AM	Admin1@gmail.com	Satellite	Public	1/7/2016 12:00:00 AM	52.255690	-6.521759
Edit Delete	9	Wexford Satellite View 07/01/16	http://dl.dropboxusercontent.com/s/4eo67yy33ewq1pa/wex_rgb_jan_7_2_2.kml	Wexford2 7-Jan-16 Satalite View	3/26/2016 12:00:00 AM	Admin1@gmail.com	Satellite	Public	1/7/2016 12:00:00 AM	52.255690	-6.521759
Edit Delete	10	Wexford Normalized Difference Vegetation Index (NDVI) 15/3/16	http://dl.dropboxusercontent.com/s/gflxelbrgpiweml/NDVI_wex_march_15_1_2.kml	Wexford NDVI 15 March 2016	3/26/2016 12:00:00 AM	Admin1@gmail.com	Satellite	Public	3/15/2016 12:00:00 AM	52.255690	-6.521759
Edit Delete	11	Wexford Infrared 15/3/16	http://dl.dropboxusercontent.com/s/1dszmu2o7okullx/Infrar_wex_march_15_1_2.kml	Wexford Infrared 15-March-2016	3/26/2016 12:00:00 AM	Admin1@gmail.com	Satellite	Public	3/15/2016 12:00:00 AM	52.255690	-6.521759
Edit Delete	12	Wexford Satellite View 15/03/16	http://dl.dropboxusercontent.com/s/fh6mse5y84mpl7/RGB_wex_march_15_1_2.kml	Wexford 15-Mar-16 Satalite View	3/26/2016 12:00:00 AM	Admin1@gmail.com	Satellite	Public	3/15/2016 12:00:00 AM	52.255690	-6.521759

A Layer Management interface allows users to add and edit their own spatial data (drone/satellite/surveyed) to the application.

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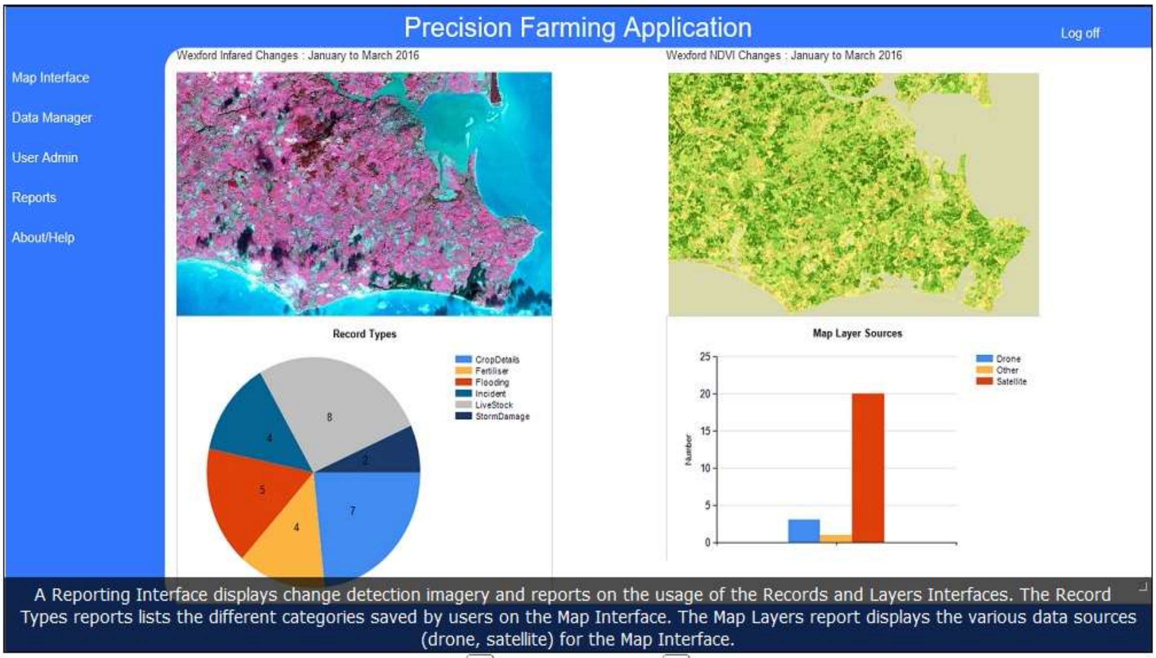
Precision Farming Application - Key Features Slideshow



13/14

Precision Farming Application - Key Features Slideshow

Thank you for reviewing the features of the Precision Farming Application.

Please click here or on the "Complete the evaluation form" link below to rate the system features.

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View the Precision Farming Application | Complete the evaluation form

7.2 Appendix II: Survey Questions

Precision Farming Application Evaluation (Page 1 of 3)

TRINITY COLLEGE DUBLIN INFORMATION SHEET FOR PROSPECTIVE PARTICIPANTS

Researcher: Marc Harrington

Title of project: Precision Farming Application

Background/Purpose of project: The European Parliament recently published a report on precision farming in Europe and described how precision farming can deliver benefits such as the efficient application of inputs (seed, fertiliser) improved crop and field measurements and enhanced decision making. The report also highlighted the barriers to the adoption of precision agriculture to be high start-up costs, a risk of insufficient return on the investment, infrastructure and institutional constraints, knowledge and technical gaps, the lack of local technical expertise and cultural perception. The Precision Mapping Application has been to explore how information technology can address the challenges regarding the adoption of precision farming technology. The research question is 'would an intuitive decision support system incorporating remote sensing data, mapping interfaces, crowdsourced data and external data sources address challenges facing the adoption of precision farming?'.

Conflict Of Interest: I do not see any conflict of interest regarding the research process

Description of methods: A survey has been developed to evaluate key features of the system and determine if participants think the system can address the challenges regarding the adoption of precision farming technology. Semi-structured interviews will also be carried out with certain stakeholders. Interview questions will address the adoption of precision agriculture, barriers to adoption, enablers for adoption, requirements for successful implementation, advantages and disadvantages of precision agriculture, technologies driving precision farming, the role of government and the media and the outlook for precision agriculture.

The survey can be accessed here:

https://scsstcd.qualtrics.com/SE/?SID=SV_ema40oNKzLoelhj

Participants: Project participants will be stakeholders in the agri-tech sector.

Stage	Description	Anticipated Timeline
1	Email invite sent to Participants	25th May 2016
2	Close of survey	23th June 2016
3	Interviews	24th June 2016
4	Analysis of Survey	July 2016
5	Report on Findings	July 2016

I do not anticipate any risks to the participants as it will be a self-selecting questionnaire outlining details of the study and allowing for participants to opt in or out of participation. Also, participants can opt out of the study at any stage of the questionnaire.

Publication: The results when analysed, will be presented in a dissertation. Individual results will be aggregated anonymously and research reported on aggregate results.

Statement of Ethical consideration raised by the project and how you intend to deal with it: This project does not raise any ethical issues.

Relevant legislation relevant to the project with the method of compliance:

The data will be stored on a password protected Google form. Access to the data will be confined to the researcher who will be responsible for the subsequent analysis.

Data collection, analysis and retention will be undertaken in full compliance with the Data Protection Acts 1988 and 2003.Third parties: Please do not name third parties in any open text field of the questionnaire. Any such replies will be anonymised. Illicit activity: In the extremely unlikely event that illicit activity is reported I will be obliged to report it to appropriate authorities.

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Precision Farming Application Evaluation (Page 2 of 3)

TRINITY COLLEGE DUBLIN INFORMED CONSENT FORM
LEAD RESEARCHER: Marc Harrington
BACKGROUND OF RESEARCH: The European Parliament recently published a report on precision farming in Europe and described how precision farming can deliver benefits such as the efficient application of inputs (seed, fertiliser) improved crop and field measurements and enhanced decision making. The report also highlighted the barriers to the adoption of precision agriculture to be high start-up costs, a risk of insufficient return on the investment, infrastructure and institutional constraints, knowledge and technical gaps, the lack of local technical expertise and cultural perception.

The Precision Mapping Application has been to explore how information technology can address the challenges regarding the adoption of precision farming technology. The research question is 'would an intuitive decision support system incorporating remote sensing data, mapping interfaces, crowdsourced data and external data sources address challenges facing the adoption of precision farming?'.

PROCEDURES OF THIS STUDY: On behalf of Trinity College, you are asked to devote 10-15 minutes to complete an online survey that will evaluate key features of the Precision Farming Application system and if the system can address the challenges regarding the adoption of precision farming technology. The results will be analysed and presented in my dissertation. Your co-operation is much appreciated

PUBLICATION: Individual results may be aggregated anonymously and research reported on aggregate results. The survey results will form part of a report for dissertation throughout College. Only anonymous data will be used, no individual will be identifiable in any report (or journal article). In keeping with standard professional practice, your data may be retained for 10 years, during which time only the investigators on this project will have access to them. The identity of you and all participants will be totally confidential.

DECLARATION:

I am 18 years or older and am competent to provide consent.

I have read, or had read to me, a document providing information about this research and this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction and understand the description of the research that is being provided to me.

I agree that my data is used for scientific purposes and I have no objection that my data is published in scientific publications in a way that does not reveal my identity.

I understand that if I make illicit activities known, these will be reported to appropriate authorities.

I understand that I may stop electronic recordings at any time, and that I may at any time, even subsequent to my participation have such recordings destroyed (except in situations such as above).

I understand that, subject to the constraints above, no recordings will be replayed in any public forum or made available to any audience other than the current researchers/research team.

I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.

I understand that I may refuse to answer any question and that I may withdraw at any time without penalty.

I understand that my participation is fully anonymous and that no personal details about me will be recorded.

I have received a copy of this agreement

CONSENT STATEMENT:
I have read the description of the procedure. I am 18 years or older and am competent to supply consent. I wish to proceed and I consent to participate in the study that has been described above.

○ Yes, I would like to proceed with the survey

○ No, I would not like to proceed [EXIT survey]

Statement of investigator's responsibility: I have explained the nature and purpose of this research study, the procedures to be undertaken and any risks that may be involved. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

RESEARCHERS CONTACT DETAILS:
Marc Harrington
Email harrinm2@tcd.ie

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Precision Farming Application Evaluation (Page 3 of 3)

Name:

Organisation:

Role:

Would the Precision Farming Application be a useful tool for addressing challenges regarding the adoption of precision farming technology?

Map Interface:

Rate from 1 to 10 (1=weak and 10=excellent) - The Map Interface uses Google Maps to enable enhanced decision making by displaying spatial, crowdsourced and weather data in one location

Satellite View Layers:

Rate from 1 to 10 (1=weak & 10=excellent) - The Satellite View Layers display colour imagery derived from the European Space agency's Sentinel 2 program.

Normalized Difference Vegetation Index (NDVI) Layers:

Rate from 1 to 10 (1=weak & 10=excellent) - The Normalised Difference Vegetation Index (NDVI) Layers display plant greenness/photosynthetic activity on imagery derived from the European Space agency's Sentinel 2 program.

Infrared Layers:

Rate from 1 to 10 (1=weak & 10=excellent) - The Infrared Layers display plant health information on imagery derived from the European Space agency's Sentinel 2 program.

Change Detection Layers:

Rate from 1 to 10 (1=weak & 10=excellent) - The Change Detection Layers display differences between sets of NDVI or Infrared images. Areas with poor growth can be identified and targeted for additional fertilizer

Geolocation:

Rate from 1 to 10 (1=weak & 10=excellent) - The Geolocation facility allows users to carry out onsite analysis with the Map Interface

Records:

Rate from 1 to 10 (1=weak & 10=excellent) - The Records facility allows users to save location based data and enables crowdsourcing and data analysis

Responsive design:

Rate from 1 to 10 (1=weak & 10=excellent) - The application has been designed with responsive design to delivery content on mobile and desktop devices

Layer Management interface:

Rate from 1 to 10 (1=weak & 10=excellent) - The Layer Management interface allows users to add their own spatial data (drone/satellite/surveyed) to the application

Reporting Interface:

Rate from 1 to 10 (1=weak & 10=excellent) - The Reporting Interface displays change detection imagery and reports on the usage of the Records and Layers Interfaces.

Please enter any further feedback or suggestions below:

Not Submit, Exit Without Submitting

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7.3 Appendix III: Survey Participant Roles

Roles	Account Manager/Operator Agricultural Journalist Agronomist Researcher Director Drone Operator Farm Manager Farmer GIS Developer IT Contractor GIS Manager Project Manager Remote sensing Analyst

7.4 Appendix IV: Survey Feedback and Suggestions

Response #	Feedback And Suggestions
1	I would avoid using Google Maps as it is very hit and miss with satellite imagery. OSI maps tend to be slightly better. We use them professionally and they seem to do the business.
2	The tool looks very useful and is fast & responsive.
3	Needs an output function to make the collected information usable. 10m NDVI not good enough, need better resolution.
4	A national database reporting crops sowed, date, location, harvest date and yield would help with research.
5	All good sources of information. Are they proposed to be pulled together and how do we set out parameters/ guidelines to use the information eg. if something is light green it needs more Nitrogen and by looking at the weather it’s not going to rain so is there any point in applying more nitrogen at the this time. Would also need to know the stocking rate on the farm.
6	The use of satellites in crop imaging is limited due to the sheer ability to get detailed enough. If this software was in use on drones or other UAV's it would be a better fit. But it is understandable to use satellites that are open to public access due to cost limitation. The use of this data to me provides no real beneficial

	information due to the fact if I could generate a map that I can upload to my tractor based GPS device and use to apply say nitrogen in a variable rate across the field. It wouldn't allow the scale that I require. Satellite based PA I feel not the way forward but say sensors mounted on a sprayer boom to give real-time information of the crop as the grower is passing through that crop.
7	Until Satellites can zoom in to 1cm/Pixel to identify weeds/disease etc they will not be suitable for this application. We are using a drone to fly crops and analysis imagery. NVDI is not a suitable method to analysis crops, light has a major bearing on the effectiveness.
8	The Geolocate could be modified in the future to generate a SOS for farmers needing the energy services in isolated areas. The report layer is great. It would be useful to display areas of Farm accidents and deaths to act as reminders of the dangers associated with farming. Reporting instances of farm theft, including descriptions/photos of equipment/livestock taken would also be useful. Have a layer that displays a map of broadband and G4 coverage maybe be help to users.
9	While you have provides a useful description of what the system does and how it works its usefulness is totally dependent on being able to ground truth

	and colours to what is happening in fields historically or even live.
10	This application assembles the core processed data that is freely made available to be used for just this purpose. The framework and agile approach to development have yielded an interface that covers all the required bases and presents the user with more than enough to visualise how the concepts could be further developed into a commercial application
11	Just a few general comments that are relevant. PA tends to be focused on arable farming. Compared to the UK or continental Europe Ireland has a relatively low level of arable farming, with approximately 15,000 herds (from 135,000) having some arable land but only 7,000 that are predominately arable. Soils in Ireland are highly variable within field. Care needs to be taken to ensure that the software does not interpret low yield as being a sign of a shortage of inputs. This lower yield could be due to the fact that the land is not capable of producing at the same level of surrounding parts of the field. Any soils data available out there is technically not suitable to be used at field level. In saying all of this as the user can add their own layer, which for example could be a layer indicating areas of know yield issues e.g. poor drainage, poor soils etc., this can be overcome. An interesting

	focus would be on how PA can work on grassland.
12	Using google maps as the basis for the app, while a good idea is dependent on the quality of the imagery available. From looking at it I found it difficult to identify individual fields, while it would be ok if the fields were large enough I feel that it would be difficult if the fields were small, especially on fragmented farms where it is difficult to identify boundaries from satellite imagery. If a higher quality image could be used then it would be very beneficial. Also the language used to describe each layer on the map needs to be very clear and self-explanatory. Overall a very good idea