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PRECISION AGRICULTURE: AN OPPORTUNITY FOR EU FARMERS - POTENTIAL SUPPORT WITH THE CAP 2014-2020

IN-DEPTH ANALYSIS

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AGRICULTURE AND RURAL DEVELOPMENT

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This document was requested by the European Parliament's Committee on Agriculture and Rural Development.

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Abstract

Precision Agriculture (PA) is a whole-farm management approach using information technology, satellite positioning (GNSS) data, remote sensing and proximal data gathering. These technologies have the goal of optimising returns on inputs whilst potentially reducing environmental impacts. The state-of-the-art of PA on arable land, permanent crops and within dairy farming are reviewed, mainly in the European context, together with some economic aspects of the adoption of PA.

Options to address PA adoption are discussed, including measures within the CAP 2014-2020 legislation and the important contribution of advisory services across Europe.

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CONTENTS

LIST OF ABBREVIATIONS

CAP	Common Agricultural Policy
CGMS	Crop Growth Monitoring System
CSA	Climate Smart Agriculture
CTF	Controlled Traffic Farming
CYFS	Crop Yield Forecast System
DGPS	Differential Global Positioning System
EC	European Commission
EIP	European Innovation Partnership
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAS	Farm Advisory Services (including Farm Advisory Systems)
FSS	EU's Farm Statistical Survey
GAEC	Good Agricultural and Environmental Conditions
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communication
HGCA	Home Grown Cereals Authority, England
hp	Horsepower
IACS	Integrated Administration and Control System
IMS	Integrated Management System
JRC	Joint Research Centre, European Commission
LPIS	Land Parcel Identification System
LUCAS	Land use - cover area frame survey
MS	Member States
PA	Precision Agriculture
PLF	Precision Livestock Farming
PRD	Partial Root Drying
PV	Precision Viticulture

RDI	Regulated Deficit Irrigation
RDP	Rural Development Programme
RPAS	Remotely Piloted Aerial Systems
RTK	Real-time Kinematic correction
RS	Remote Sensing
SARA	Sub-Acute Ruminal Acidosis
SDI	Sustained Deficit Irrigation
SSM	Site Specific crop Management
SWOT	Strengths-Weaknesses-Opportunities-Threats analysis
UAV	Unmanned Aerial Vehicle
VHR	Very High Resolution
VR	Variable Rate
VRA	Variable Rate Application
VRT	Variable Rate Technology
WUE	Water Use Efficiency

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Precision Agriculture (PA) is a farming management concept based upon observing, measuring and responding to inter and intra-field variability in crops, or to aspects of animal rearing. The benefits to be obtained are chiefly due to increased yields and/or increased profitability of production to the farmer. Other benefits come from better working conditions, increased animal welfare and the potential to improve various aspects of environmental stewardship. Thus, PA contributes to the wider goal concerning sustainability of agricultural production.

The implementation of PA has become possible thanks to the development of sensor technologies combined with procedures to link mapped variables to appropriate farming practices such as tillage, seeding, fertilization, herbicide & pesticide application, harvesting and animal husbandry. The key feature of PA comes from positioning systems, principally Global Navigation Satellite Systems (GNSS) that are a major enabler of 'precision'. PA is most advanced amongst arable farmers, particularly with large farms and field sizes in the main grain growing areas of Europe, USA and Australia, and where a business model to maximise profitability is the main driver. Controlled Traffic Farming (CTF) and auto-guiding systems are the most successful applications on arable land showing clear benefits in nearly all cases. For Variable Rate Application (VRA) methods, such as optimizing fertilizer or pesticide use to areas of need, the success varies greatly according to the specific factors of the application.

For fruit & vegetables and viticulture, machine vision methods have brought benefits to products which are typically of high value and where quality is key to obtaining a high price. Additionally, for such crops and also for arable areas, irrigation is under increased scrutiny since water shortages are more frequently occurring whilst availability on intensive agricultural areas requires precise management. Hence, PA technologies that use accurate indicators of water stress are employed to maximise the water use efficiency. Precision Livestock Farming (PLF) relying on automatic monitoring of individual animals is used for meat, milk and egg production and for monitoring animal behaviour, welfare and productivity and also their physical environment.

The present briefing, based on a detailed review, confirms that Precision Agriculture can play a substantial role in the European Union in meeting the increasing demand for food, feed, and raw materials while ensuring sustainable use of natural resources and the environment. Nevertheless, the adoption of PA in Europe encounters specific challenges due to the sizes and diversity of farm structures. An assessment of the potential actions to support the adoption of PA by medium and smaller sized farmers is identified as an important enabling step. In particular, the new EU Common Agriculture Policy provides a key opportunity with a number of instruments and measures, identified in the current briefing, which are available to be used by the EU Member States competent authorities. A number of recommendations are proposed:

1. There is a need of **appropriate guidelines and implementation assistance** to EU Member States. A study is needed to identify regions and typology of farms most appropriate for PA and to potential support measures. Also, the development of an EU **'precision farming calculator'** tool, made available for differing farming systems and including environmental benefits, would bring decision-support value to farmers and advisers.

2. This should be accompanied by **research and development studies**. Pilot studies are required to define, monitor and evaluate specific programmes and measures. An example is to improve the assessment of environmental impact, including the wider environmental footprint beyond farm-level. The benefits of PA for more efficient water productivity management is an additional area of high importance for study.

3. The **roles of the Farm Advisory Services (FAS)**, and the **European Innovation Partnership (EIP)** on Agricultural Production and Sustainability already established within the CAP implementation could be fostered. These instruments allow Member States to share knowledge and expertise and then draw conclusions concerning advice and research needs for wider use within Europe.

1. INTRODUCTION AND GENERAL INFORMATION

Since the creation of the Common Agriculture Policy (CAP), agriculture in Europe has undergone substantial change. Food security is now ensured in most parts of Europe, but there is evidence that increased production has led to significant harmful environmental consequences in terms of water pollution, greenhouse gas emissions and damage to our natural surroundings (Geiger *et al.*, 2010; Kleijn *et al.*, 2011). To face this, the recent CAP reforms have progressively shifted agricultural subsidies away from production support towards support for the delivery of public goods and services (mainly environmentally related). However, an increase of production will be needed to sustain an estimated global population growth from the current level of about 7 billion to 9 billion by 2050 (World Population Prospects, The 2012 Revision Highlights and Advance Tables, United Nations, New York, 2013). Despite the apparently antagonistic pressures to conserve our environment and be careful with our resources (Tilman *et al.*, 2011), the agriculture sector has to face this main challenge and produce more. The way to address this is to look at science and technology for possible answers.

Over the last few decades, many new technologies have been developed for, or adopted to, agricultural use. Examples of these include: low-cost positioning systems, such as the Global Navigation Satellite System (GNSS), proximal biomass and leaf area index determination from sensors mounted on-board agricultural machinery, geophysical sensors to measure soil properties, low-cost remote sensing techniques and reliable devices to store, process and exchange/share the information (Pierce and Nowak, 1999; Gibbons, 2000). In combination these new technologies produce a large amount of affordable, high resolution information and have led to the development of fine-scale or site-specific agricultural management that is often termed **Precision Agriculture (PA).**

1.1. Definitions and expected benefits

Although more complex definitions exist, the simple description of the Precision Agriculture is a way to ***"apply the right treatment in the right place at the right time"*** (Gebbers and Adamchuk, 2010)**.** It is a farming management concept based upon observing, measuring and responding to inter and intra-field variability in crops or in aspects of animal rearing. The first actual definition of PA came from the US House of Representatives (1997), which defined PA as *"an integrated information- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment"*. Such a definition focused on "whole-farm" management strategies using information technology, highlighting the potential improvements on production while reducing environmental impacts. Also, it already envisioned that PA was applicable not only to cropping systems, but to the entire agricultural production system (*i.e.* animal industries, fisheries, forestry).

The **Site-Specific Crop Management (SSM)** approach is *"a form of PA whereby decisions on resource application and agronomic practices are improved to better match soil and crop requirements as they vary in the field"*. The variations indicated in such a definition are not limited to spatial (*i.e.* within-field variability) but also comprise observations throughout a season or between seasons. Actual PA implementation in the 1980's started when farmers integrated newly-developed fertilisers capable of deploying variable rate application (VRA) technology with maps that showed the spatial variability of soil chemical properties. PA is also related to more recent approaches linked to climate change resilience, such as **Climate Smart Agriculture (CSA)**, aiming at developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change (FAO, 2013).

It is widely accepted that better decision making in agriculture should provide a wide range of benefits. From the **economic** point of view, a review of 234 studies published from 1988 to 2005 showed that precision agriculture was found to be profitable in an average of 68% of the cases (Griffin and Lowenberg-DeBoer, 2005). In an agriculture market where gross margin and profitability are getting tighter, farmers are looking for technologies that reduce costs without decreasing production. Although this is probably the primary reason for farmers to adopt such a farm management approach, it is not the only justification. In fact, in large parts of Eastern EU 28 countries, the aim is to increase production, and here direct economic benefits are likely to be larger.

The application of information technologies into PA methods has clear benefits to optimise production efficiency and to increase quality, but also to **minimise environmental impact and risk,** which includes undesirable **variability caused by the human operator**. PA nowadays is seen as an *"environment friendly system solution that optimizes product quality and quantity while minimizing cost, human intervention and the variation caused by unpredictable nature"*. In fact, all new definitions of PA include terms related to risk, environmental effects and degradation, as they are key concerns in the late 20th and early 21st centuries. PA becomes a management practice of increasing interest because it links to key drivers directly related to worldwide issues such as **Sustainable Agriculture & Food Security** (Gebbers & Adamchuk, 2010).

There is some evidence from research which shows that **environmental degradation** is reduced when PA methods are applied, including increased fuel use efficiency resulting in lowering carbon footprints. Some other examples include nitrate leaching in cropping systems, demonstrating that variable rate application methods were successful in reducing groundwater contamination and that PA methods may reduce erosion when precise tillage is conducted. Therefore, PA is seen as a way to help **meet the measures defined in environmental legislation** present in countries such as USA and Australia. In fact, this issue was proposed within the EU, as PA was identified as a way to meet future EU directives in Member States to reduce agro-chemicals (Zhang *et al.*, 2002).

Precision Agriculture presents also some benefits for **social and working conditions**. For instance, auto-steer systems are available for a variety of tractor models making the work less fatiguing. Also, the evolution of precision dairy farming technologies provide tremendous opportunities to improve delivery of automatic individual cow management applications and thus reduce labour requirements such as milking two times per day, and there are also arguments of increased animal welfare.

1.2. Background technologies and components of PA

The implementation of PA has become possible thanks to the development of **sensor technologies** combined with **procedures** to link mapped variables to appropriate farming **management actions** such as cultivation, seeding, fertilization, herbicide application, and harvesting.

For what concerns technologies, progress has been possible due to the rapid development, miniaturization and improved accuracy of the **Global Navigation Satellite System (GNSS)** technology since 1999. In fact, GNSS technology (of which GPS is the most commonly used at present) is now widely used in many farms for tasks related to geo-positioning (*e.g.* auto-steer systems) and production of geo-reference information (*e.g.* yield mapping). GNSS has enabled the expansion of machinery guidance, auto-steering and **controlled traffic farming (CTF)** systems. Such methods enable machinery to drive along repeatable tracks with accuracy, reducing errors made by the operator, reducing fatigue and permitting more timeliness of operations. Another important element is the use of **Variable Rate Technology (VRT)** that allows precise seeding, optimization on planting density and improved application rate efficiency of herbicides, pesticides and nutrients, resulting in cost reduction and reducing environmental impact.

Many sensors are currently available and used for data gathering or information provision as part of the PA implementation. These devices are designed for both *in-situ* and on-the-go recording. Devices exist to assess the **status of soils**, such as apparent electrical conductivity (ECa) sensors, gamma-radiometric soil sensors, and soil moisture devices, among others. Others record **weather information** or micro-climate data (thermometer, hygrometer, etc.). Particular importance is given to sensors developed to quantify the physiological status of crops (*e.g.* Nitrogen sensors). These sensors are based on **remote sensing** principles, gathering point- or spatial-based data where the spatial resolution, that is the size of the pixels digitally imaged, can vary from less than 2cm to over 10 metres. Sensing across various wavelengths (visible, near infrared, thermal) using multispectral and hyperspectral cameras on board **airborne and satellite platforms**, often has the goal to derive vegetation indices which explain the crop canopy condition (*e.g.* chlorophyll content, stress level) and its variability in space and time. Special interest is devoted lately to the use of low-cost light-weight **unmanned aerial vehicles (UAV)** often called drones, but now more correctly termed **remotely piloted aerial systems (RPAS),** initially developed for military purposes which are now being applied in civil applications. RPAS are already available and operational, enabling the generation of very-high resolution (2 to 10 cm) farm-level imagery. Availability from satellite platforms is generally at lower resolution (0.5 to 10 m) and is generally more costly, whilst the new EU COPERNICUS programme should provide easier and cost-free access to satellite data but only at 10m or lower resolution.

There is a need of knowledge and skill on how to transform, through **Geographic Information Systems (GIS)**, data collected by different sensors and geo-referenced into maps to provide information on crop physiological status and soil condition status. Additional skills and knowledge are required concerning how to use the large, heterogeneous data sets and information gathered to assess the effects of weather, soil properties on production, and to develop management plans to increase efficiency and adjust inputs in following years. In particular, models are needed in order to understand the causalities and interrelations between plant, soil and climate before inputs can be spatially adjusted. These **Farm Management Systems** are made accessible to farmers through consulting, advisory and training services and/or directly through dedicated software products. Table 1 shows an overview of Precision Agriculture technology and applications.

Finally, the most important actor in the adoption of Precision Agriculture technology is the **farmer**. This started in the early 90's by the most business oriented farmers with an initial enthusiasm followed by a certain level of discouragement due to the lack of support and the relatively low profitability obtained. The adoption of this approach relies currently almost entirely on the private sector offering devices, products and services to the farmers. **Public service advice is generally very limited.**

Table 1 – An overview of Precision Agriculture technology and applications

Technology	Objective of development	State of Technology
Human-Machine-Interface instruments	Terminal suitable for all PA applications	Stand-alone terminals for every single application
Ownership of data	Facilitate the exchange of information between farmers, between farmers and contractors or suppliers and between the government and farmers	Data should be the property of the machine owner, but machine manufacturers use them for internal evaluation
Machine Guidance	Avoid overlapping following same tracks automatically for every field operation, driver relief, reduce chemicals and fuel	Driver assistance, steering support, automatic driving
Controlled Traffic Farming	Using the same tracks to minimise soil compaction.	Driver assistance, steering support, automatic driving
Recording of farm machinery movement	Machine surveillance, operators safety, optimization of processes	Data needed to measure and store machinery operations
Sampling location	Offline determination of soil quality, status of ground swell (pH-value, phosphor, potash, magnesium), soil composition	Detailed information about the soil fertility and transmitted diseases for optimal management and to fulfil legislation
Biomass monitoring	Mapping the state of plant growth and amount of nitrogen needed	Location-specific continuous or discrete crop phenology observations, optical sensors for canopy status and nitrogen content
Sensor and sensor fusion development	Automated data fusion of different sensor information for real-time decisions based on multi-layer datasets	Sensors for measurement of several parameters that are later integrated into products.
Machine Vision Systems	Guaranteeing the safety and security of food. Combining this data with producers' operation records (for example, when, where, and what kind of chemicals were sprayed, what kind of fertilizers were conducted)	Monitoring and classifying/grading fruit or vegetables.
Remote sensing (RS) techniques	Relating these images to yield potential, nutrient deficiencies and stresses	Recent aerial or satellite imagery
Variable rate application / technology	Application of seeding, fertilizing and spraying according to accurate mapping of soil and plant information	Enables specific treatment of areas within a crop parcel with variable levels of production.
Harvest monitoring	Localised harvesting information about crops and machine status to improve yield	Harvesting information (instant wet and dry readings, crop density, cutting and harvesting and information about yield)
Individual livestock tracking in a small scale	Information about animal health status and grazing behaviour, virtual fencing, understanding grazing pressure	Monitoring systems for the animals through GNSS receivers, storing position data at regular intervals
Tracking livestock transporting	Complying with legal regulations of animal welfare	Record the movement of vehicles
Electronic submission of area aid applications	Compliance of legal regulations	GNSS receivers allow the measurement of an area, the perimeter of a parcel or changed portions of a boundary
Farm Management and Decision Support	Software solution for farmers for automatic documentation, telemetry, decision support, machine control	Data management and decision support solutions existing from machine manufacturers and from providers of precision farming services

2. APPLICATION OF PRECISION AGRICULTURE

KEY FINDINGS

- Precision Agriculture is used most and most advanced amongst arable farms, particularly large ones with large field sizes in the main grain growing areas of Europe, and where a business approach (to maximise profitability) has long been practised.
- The most successful example of PA on arable land is the use of Controlled Traffic Farming (CTF), which has been able to reduce machinery and input costs up to 75% in some cases, whilst also increasing crop yields.
- In conventional farming, fertilizers and crop control substances are applied uniformly over fields, leading to over-application in some places and under-application in others. PA methods enable fertilizers to be spatially applied to optimize the application using Variable Rate Application (VRA) methods. The profitability of such methods is debatable, depending upon a range of factors.
- Adoption of PA in fruits and vegetables and viticulture is more recent than in arable farming, with a rapid increase in the adoption of machine vision methods.
- The high-value and high-risk to quality of these products makes a strong case for applying PA technologies. An example is PA methods in viticulture (Precision Viticulture, PV) where grape quality assessment and yield maps obtained from remote sensing and field instruments avoid mixing grapes of different potential quality during harvest.
- In high-value fruit and vegetable crops, precision irrigation methods are developing rapidly in order to save water, increase yields and improve quality. Water use efficiency is increased through deficit irrigation strategies and may use field and airborne remote sensing thermal sensors.
- Precision Livestock Farming (PLF) relying on automatic monitoring of individual animals is used for animal growth, milk and egg production and detection of diseases, as well as for monitoring animal behaviour and their physical environment.

2.1. Precision Farming on arable land

The use of PA techniques on arable land is the most widely used and most advanced amongst farmers. Perhaps the most successful example is the use of Controlled Traffic Farming (CTF). Farmers in Australia and UK (Tulberg *et al.*, 2007; Bowman, 2008) have been able to reduce machinery and input costs, increasing crop yields. CTF is a whole farm approach that aims at avoiding unnecessary crop damage and soil compaction by heavy machinery, reducing costs imposed by standard methods. Controlled traffic methods involve confining all field vehicles to the minimal area of permanent traffic lanes with the aid of GNSS technology and decision support systems.

The environmental benefits of using CTF are acknowledged in the literature with several examples. A study performed in Denmark showed that compared to standard methods, CTF reduced environmental impacts such as eutrophication (nutrient leaching in surface and ground water). Reductions are enabled by higher grain yields grown with less soil compaction, which decreases P-compound runoff and in-field soil N_2O and NH_3 emissions, and the use of auto-guidance, which reduces overlap during application of fertilisers and pesticides.

Another important application of Precision Agriculture in arable land is to optimise the use of fertilizers, starting with the three main nutrients Nitrogen, Phosphorus and Potassium. In conventional farming these fertilizers are applied uniformly over fields at certain times during the year. This leads to over-application in some places and under-application in others. The environmental cost is directly related to over-application which allows nitrogen and phosphorus leaching from the field into ground- and surface waters or to other areas of the field where they are not desired. With the use of PA methods, fertilizers can be applied in more precise amounts, with a spatial and temporal component to optimize the application. The technology that allows the farmer to control the amount of inputs in arable lands is the Variable Rate Application (VRA), which combines a variable-rate (VR) control system with application equipment to apply inputs at a precise time and/or location to achieve site-specific application rates of inputs. VRs are decided on the basis of prior measurement, *e.g.* from remote sensing or machine mounted sensors. A complement of components, such as a DGPS receiver, computer, VR software, and controller are integrated to make VRA work.

2.2. Precision Farming within the fruits & vegetables and viticulture sectors

In fruit and vegetable farming the recent rapid adoption of machine vision methods allows growers to grade products and to monitor food quality and safety, with automation systems recording parameters related to product quality. These include colour, size, shape, external defects, sugar content, acidity, and other internal qualities (Njoroge *et al.*, 2002). Additionally, tracking of field operations such as chemicals sprayed and use of fertilizers can be possible to provide complete fruit and vegetable processing methods. This information can be disclosed to consumers for risk management and for food traceability as well as to producers for precision agriculture to get higher quality and larger yields with optimized inputs. In the case of pesticide application in orchards, methods normally consist of spraying constant volumes of plant protection mixtures without considering the actual variability of size and density of the tree crowns. The lack of adjustment to account for the orchard variability often leads to a substantial loss of the mixture. In recent years several new approaches were developed that take into account the actual size of the tree, the condition of the crop, but also the environmental conditions (Doruchowski *et al.*, 2009).

The development and adoption of PA technologies and methodologies in viticulture (termed Precision Viticulture, PV) is more recent than in arable land. However, driven by the high value of the crop and the importance of quality, several research projects already exist in wine production areas of the world including France (Ojeda et al, 2005; Mazetto *et al.*, 2010) and Spain (Ferreiro-Arman *et al.*, 2006). Grape quality and yield maps are of great importance during harvest to avoid mixing grapes of different potential wine qualities. The parcels with greatest opportunities for PV are those which reveal a high degree of yield variation. A high degree of variation will mean higher VRA of inputs and, therefore, greater economic and environmental benefit in comparison with uniform management.

Irrigation or in more general terms the use of water, is increasingly becoming an important issue. In high-value crops, precise irrigation methods are developing rapidly in order to save water while improving yields and fruit quality. In precision viticulture, three main stages of development over the last 20 years occurred: i) sensing systems were initially dedicated to improving existing features on the machinery; ii) machinery were equipped with sensors to adjust operational aspects; iii) advanced systems were deployed that collect high-resolution information (yield, sugar, harvest colour monitoring). Although irrigation has been practised for centuries, precision irrigation has only been used recently as the sector had to respond to societal demands for reductions in water allocation and improvements in efficiency. A major gap still exists between research and on-farm irrigation practice, which is reflected in large differences between actual and potential yield. In most cases, such 'yield gaps' can be attributed to suboptimal management, inappropriate technology and/or lack of training. Irrigation strategies have been proven to successfully increase Water Use Efficiency (WUE) reducing water use. Several strategies have been tested, such as regulated deficit irrigation (RDI), partial root drying (PRD) and sustained deficit irrigation (SDI). The successful use of RDI in fruit trees and vines demonstrated not only increases in water productivity, but also in farmers' profits (Fereres & Soriano, 2007). Since Europe (especially the south-western part) is very much affected by climate change which increases the variability of precipitation and the need for water in the face of increasingly frequent hot southern gusts, precision irrigation may develop in the coming years and play a predominant role in water management.

EXAMPLE STORY - Controlled Traffic Farming (CTF)

● The main benefits associated with CTF are increased profit and improved sustainability. CTF aims to confine soil compaction to minimal areas of permanent traffic lanes, leaving 80-90% of the field area without compaction. The aim is to reduce production costs and increase yields while improving soil health and delivering other positive benefits to the environment.

● A good example is seen in a 1300 ha farm in the UK, with soils mostly clayey river alluvium with some light clay over gypsum, cropping mostly oilseed rape and wheat. Traditional minimum tillage was replaced by no-till. CTF was conducted with RTK correction providing ±2cm accuracy and positioning. Large savings are expected from fuel, lower capital investment and reduced power consumption on the farm.

● The no-till practice is more risky without CTF methods (too much compaction), whilst benefits include a better weed control and inter-row cultivation, reduction in overlaps, reduction in machinery use, better crop establishment, improved soil health and reduced compaction damage. With CTF the new maximum tractor size is 350 instead of 550 hp, contributing again to a cut in fixed costs.

Source: CTF Europe – http://www.controlledtrafficfarming.com/ - Pictures from landwise.org.nz & ctfeurope.dk

2.3. Precision Livestock Farming

Precision livestock farming (PLF) is defined as the management of livestock production using the principles and technology from process engineering. PLF though an integrated management system (IMS) attempts to recognise each individual animal, and is typically applied to the more intensive husbandry of pigs and poultry, and dairying. Processes suitable for the PLF approach include animal growth, milk and egg production, detection and monitoring of diseases and aspects related to animal behaviour and the physical environment such as the thermal micro-environment and emissions of gaseous pollutants. The advance of monitoring and control systems has led to the development of automatic milking machines now being marketed by several European manufacturers. Essentially, automatic attachment of teat-cups connects each cow, at a time of its own choosing, to the vacuum milking line. The cups must be applied firmly but gently to the cows' teats, avoiding damage to the cow and the likely consequent damage to the machine. These voluntary milking systems handle 65 or more cows on an average of 2.7 times per day. New systems include milk monitoring systems to check fat and microbial levels, helping to indicate potential infections, as well as new robotic feeding systems, weighing systems, robotic cleaners, feed pushers and other aids for the stockman such as imaging systems to avoid direct contact with animals.

The economic justification for these expensive units is that they offer each cow the opportunity to be milked more often than the usual procedure (twice a day). This is beneficial for the cows and it increases milk yield. New systems for data monitoring for feed and water consumption can be used to the early detection of infections. Other developments include the monitoring on the growing herd where measurement of growth in real time is important to provide producers with feed conversion and growth rates. Acoustic sensors detect an increase in coughing of pigs as an indicator of respiratory infection. Recent studies discuss that improved management could raise cow yields to 20,000 litres per life time whilst increasing the life expectancy of cows. Higher yield and longer life could reduce agricultural methane emissions by 30%. Quality of feed is difficult to measure but by using a pH bolus in the rumen of sentinel cows the pH can be accurately tracked and feed adjusted as necessary.

Other sensors are now used to provide alerts concerning birthing and fertility. A vaginal thermometer monitors the temperature, imminence of birthing and the breaking of waters, and communicates to the farmer via SMS. Also, a sensor placed on an animal's collar records parameters to detect signs of oestrus and the readiness for fertilisation. An SMS message then allows the farmer to plan for insemination.

The use of GNSS technology has enabled tagging of cows to provide tracking information related to animal behaviour. Monitoring behaviour is relevant for detection of cow fertility or illness. It is also important for providing information on pasture use density and to manage fields accordingly to the information recorded previously. The development of tag technology is in rapid development to increase the accuracy and reduce power consumption. One example is the E-Track project (www.etrack-project.eu) which proved to provide adequate information for remote animal monitoring and management. Virtual fencing uses the GNSS based location of an animal in combination with a sound or electrical stimulus to confine animals inside a predefined geographic area without fixed fences. Other examples of tracking systems used on livestock farming are related to transport of animals. According to the Council Regulation (EC) No 1/2005 on the protection of animals during transport and related operations, it is required that any road vehicle undertaking long journeys transporting livestock must be equipped with a satellite tracking system. Enforcement officers use this as a tool for assessing compliance with the requirements of the Regulation.

EXAMPLE STORY - Precision Livestock Farming

- Precision Livestock farming (PLF) focuses on the automatic monitoring of each individual animal, recording data for the growth, detailed milk and egg production, early detection of diseases, and to understand the animal behaviour and monitor its environment.

- A good example is the continuous monitoring of ruminal pH in cows, as it has been shown to be a very important parameter for nutritional status and the disease Sub-Acute Ruminal Acidosis (SARA). Presence of SARA is in 11-29.3% of early lactation cows and in 18-26.4% of mid lactation cows.

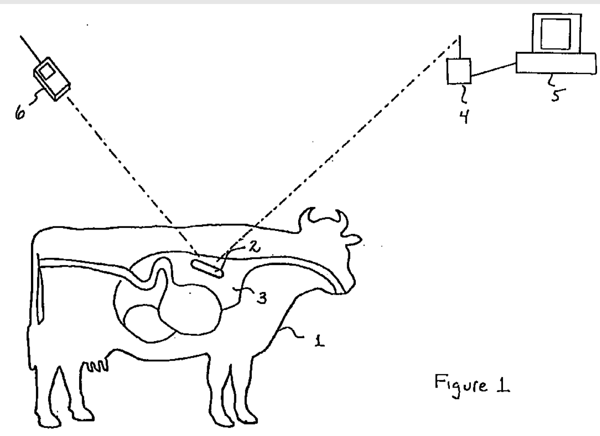
⇒ **Success Story**

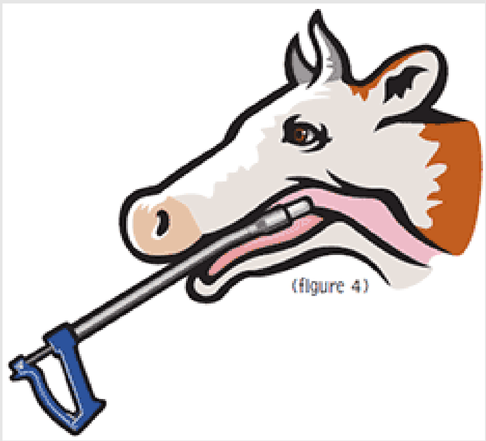
- A trial conducted on eight commercial dairy farms in the South West of England proved the commercial benefit of rumen pH monitoring. Since 2005, boluses that measure pH continuously and using wireless techniques have been used for research purposes.

- The bolus is swallowed comfortably by the cow. The device resides in the sump of the first stomach and in a sensor down position in cows with normal shaped reticulum. The bolus has a temperature switch, which activates only when the temperature is above 31°C, allowing shelf storage of 2-3 years.

- The challenge is to implement feeding management and husbandry practices that avoid or reduce the incidence of SARA. In these case studies in the UK, a wireless rumen pH telemetry bolus was used on eight commercial farms from April to August 2013 in the South West of England

- Six farms have reported a change as result of the data. 60% of farmers and their consultants have seen a monetary benefit for the farm and 100% of farm's advisers have seen a commercial benefit for their company.





Source: www.ecow.co.uk / Pictures from data.epo.org & www.depi.vic.gov.au

3. PROGRESS MADE AND PROSPECTS

KEY FINDINGS

- PA profitability is critical to the adoption decision by farmers. Due to the many complex factors, profitability cannot be demonstrated in all cases under all scenarios.
- The main drivers of PA are, optimized machinery (automatic machine setting, autonomous guidance), minimized overlapping (steering systems), machine monitoring (telemetry), objective information (yield mapping), input optimization (nitrogen sensors, soil sampling, variable rate maps) and reduced stress for the operator (steering systems).
- The costs associated with PA implementation are information costs, expenses involving data processing, software and hardware, and learning costs for the farmer to develop management schemes and calibrate the machinery.
- The potential benefits from PA mainly focus on crop yield improvements, optimization of inputs and improvement of the management and quality of the work. A critical aspect for the PA profitability is farm size, as cost/benefit estimations require a minimum farm size to depreciate the investments over the entire farm.
- In Europe, PA benefits are mostly studied in areas where crop management is highly optimised, whilst PA adoption in areas where crop management is sub-optimal is much scarcer. PA benefits in such areas have the potential to be substantial.
- The economic benefits of guiding systems in the UK for a 500 ha farm were at least at 2.24€/ha. Benefits grow if more complex systems are adopted, which would lead to additional returns of 18-45€/ha for winter wheat.
- Economic savings of nitrogen fertilization using VRA in Germany range between 10€/ha and 25€/ha, depending on the size of the field, with improvements on N efficiency by 10-15% reducing the application without impact on crop yield. However, it is a mixed picture: other studies in Denmark have shown no appreciable economic benefit from using VRA technology for fertilizer application.
- Current limitations are the lack of standards, limitations on the exchange of data between systems, a lack of independent advisory / consultancy services, a lack of guidance or quantification concerning environmental benefits and a need for better knowledge on the causalities and determinants of yield.

3.1. Economic figures of PA in Europe

Assessing the profitability of Precision Agriculture is a key factor. Studies by Swinton & Lowenberg de Boer (1998) already highlighted that determining the profitability of PA is critical for the adoption decision by farmers. Despite this criticality and the availability of several studies on the economics of precision agriculture, the overall conclusions regarding profitability are unclear due to the dependency upon many complex factors that cannot be transferred across crop types or geographical areas. In addition, many studies on the economics of PA are not comparable and, in some cases, there have been unrealistic assumptions resulting in very optimistic evaluations of PA profit for farmers (Bullock & Lowenberg de Boer, 2007). Additionally, although there is extensive literature provided by suppliers there are not many examples of 'objective' tools to quantify the potential profitability for farmers to adopt PA methods. One, described later, is provided in the UK by Home Grown Cereals Authority (HGCA) to estimate the potential economic benefit of PA technologies in a cost-benefit approach that serves the end-user as a decision tool.

3.1.1. Conceptual Framework of the Economic Analysis of PA

The economic analysis of Precision Farming needs to consider the investment by the farmer in the required technology compared to the benefits expected. The profitability is normally described by capital theory criteria such as the net present value. The main problem arising is that the agronomic effects of PA are not easy to predict, therefore the investment analyses are subject to assumptions. The cost types associated with the implementation of PA are:

i) information costs, related to the necessary investments in the technology, including rental fees for specific hardware or machinery;
ii) costs involving data processing, specific licence fees, software and hardware products for data analysis;
iii) learning costs, mainly due to the additional time required for the farmer to develop management schemes, calibration of the machinery, as well as 'lost' opportunity costs due to inefficient use of the PA technology.

The potential benefits from PA mainly focus on i) crop yield improvements; ii) optimization of inputs; and iii) improvement of the management and quality of the work. The actual profitability may vary tremendously, as it depends upon the cost and upon the estimated benefit function of the response of the agricultural system to the implemented PA methods. The latter response can only be assessed with reference to a system without PA technology. For this reason, setting a system with no PA implementation as a reference is needed when assessing the potential profitability of PA for each specific case. This is especially useful in production areas where significant gains in actual production towards potential production can still be achieved.

An important aspect for the profitability of PA is the farm size, as all cost/benefit estimations require a minimum farm size in order to depreciate the fixed-cost investments over the area of the fields and farm. Different publications have assessed this issue when evaluating the adoption of PA across the EU, where the average field size varies significantly. These studies (Frank *et al.*, 2008; Lawes and Robertson, 2011) demonstrate that auto-guidance systems are profitable when they are implemented on 100 to 300 ha fields. Additionally to the field size, another important aspect for a successful adoption is the suitability of the fields for the adoption of PA methods. Where the field size is small, or when the farmer does not own the technology, specialist contractors, sharing of farming methods and cooperative approaches may be suitable for the use of equipment among different farmers.

3.1.2. Results from economic studies on Precision Agriculture

Variable Rate Technologies

The ‘yield monitor’ has been one of the first information driven technology concept (demonstrating within-field yield variability and the heterogeneity of field conditions) that gave rise to Precision Agriculture. After introduction of 300 units in the US in 1993, their use expanded to 17000 in 1997 (Swinton & Lowenberg-DeBoer, 1998). The resulting yield maps show the potential for site-specific crop management methods, both from an economic and environmental point of view. The economic assessment of the adoption of variable rate application methods varies depending upon the type of crop, the geographic area in Europe, the field size and type of agriculture, whether water- or nutrient-limited and upon the actual inputs used. Experimental studies have led to different economic effects depending on the element considered *i.e.* i) variable-rate nitrogen (N) application; ii) phosphorus (P) and potassium (K); and iii) lime application based on soil pH levels.

Economic studies of precision fertilizer management are based on farmers' expert assessment, strip trials and site-specific fertilizer response functions. Comparisons are generally made between the theoretical benefit of the site-specific approach versus the uniform application of fertilizer. These studies (Anselin *et al.* 2004, Meyer-Aurich *et al.* 2008; 2010) concluded that the economic gross advantage of site-specific management of nitrogen fertilizer in Germany ranges between 10€/ha and 25€/ha, depending on the type of sensor used and size of the field, with improvements on N efficiency by 10-15% by reducing the application without impact on crop yield. In such cases, the economic assessment concluded that the size of the field needed to be greater than 250 ha to obtain financial benefits.

Nevertheless, conclusions should be drawn with caution regarding the benefits of the variable rate N application, as several other studies claim that economic and statistical analyses over a period of ten years showed no statistically significant economic advantage of sensor based fertilizer application (Boyer *et al.* 2011). This conclusion is consistent with earlier observations (Liu *et al.*, 2006; Anselin *et al.*, 2004), who calculated profitability below 8€/ha, which hardly covers the costs of application. Studies in Denmark showed no economic effect of sensor based fertilizer redistribution in the field according to high and low yield zones (work by Berentsen cited in Oleson *et al.* 2004). Potential explanations of the small benefits of variable rate nitrogen application may be the slope of the profit function around the economic optimum (Pannell 2006), perhaps due to the fact that the application rate is already near the optimum, therefore VR only has a marginal effect. This is not a valid conclusion for all crops under all growing conditions, as it has been demonstrated that the economic margins of precision fertilizer applications increase with increasing fertilizer and crop prices (Biermacher *et al.* 2009).

Regarding the application of other nutrients, service providers offer sensing methods to derive maps of the spatial variability of the soil nutrient status to derive maps of the variable rate application of P and K. As this is not a task to be conducted every year, and the cost-benefits are clear to farmers, the adoption of variable rate P & K application attracts farmers in northern Europe. Another critical soil parameter is the soil pH, as it influences nutrient availability for plants. An unbalanced pH leads to economic losses and environmental problems. 'On-the-go' soil pH mapping enables the application of lime specifically as a way to improve the homogeneity of soil pH. Variable-rate lime application could increase annual return by 22€/ha based on a study using simulation models for soybean and corn (Bongiovanni and Lowenberg-DeBoer, 2000) in the U.S. and Canada. Wang *et al.* (2003) also showed that variable rate lime application together with N resulted in higher profitability if soil pH varies largely.

EXAMPLE STORIES - Variable Rate Technology (VRT)

- Variable Rate Application (VRA) is a method that combines a variable-rate (VR) control system to apply inputs at a precise location. This is the approach used to achieve site-specific application rates of inputs. Yield maps obtained with yield monitors on board machinery show the potential for site-specific crop management methods, both from an economic and environmental perspective.
- There are examples of success when using VRA methods, mostly in very heterogeneous fields with areas of low yield. Nevertheless, other cases published show little increase in yields, whilst the effort involved in managing inputs can raise costs and therefore there can be little profit incentive. Here we show both cases.

⇒ Success Stories

It is estimated that the economic gross advantage of site-specific management of nitrogen fertilizer in Germany ranges between 10€/ha and 25€/ha. Improved N efficiency raises by 10-15% by reducing the application without impact on crop yield.

Other studies in winter wheat and canola claim larger benefits, ranging from 48€-83€/ha, improving protein content and reduced fuel use due to the enhanced field homogeneity.

⇒ Un-successful Stories

Studies in Denmark claim that economic and statistical analyses over a period of ten years showed no statistically significant economic advantage of sensor-based fertilizer application.

Other studies calculated profitability below 8€/ha, which hardly covers the costs of application. They showed no economic effect of sensor based fertilizer redistribution in the field according to high and low yield zones.

⇒ Comments

This is no clear picture for all crops under all growing conditions. Profit in VRT methods depends upon the crop type, area, and geographic region, amongst other factors. It has been demonstrated that the economic margins of precision fertilizer applications increase with increasing fertilizer and crop prices. In high-value crops, the higher profitability can be achieved with quality specific harvesting based on the sensing of the nutrient status of the crop canopy.

Source: Meyer-Aurich *et al.* (2008; 2010); Boyer *et al.* (2011) – Image from www.farmersedge.ca.

Sensor-based pest management

Site-specific pest control is important for both economic and environmental aspects, as intensive pesticide applications lead to unnecessary costs and environmental effects. Site-specific sensor-based spraying is the way to save inputs whilst preserving the environment, as the application varies depending on the vegetation density and the canopy requirement. Furthermore, PA practices based on frequent observations (*e.g.* microclimate, pest modelling) may lead to changes in the mix of preventive and curative pesticide use and optimisation of their application schedules and frequency. In specific studies on aphids and their natural enemy ladybird beetles in a cereal field, it was observed that the variable rate spraying by sensor controlled technology reduced insecticide use by 13% on average whilst maintaining the biodiversity on agricultural fields (Dammer and Adamek, 2012). Investment costs for site specific fungicide spraying technology were recovered within 2 years on a 1000 ha farm with 60% cereal cultivation. Annual cost savings were 7.20€/ha due to reduced pesticide use, and 5€/ha in machine costs for reducing the pesticide filling requirements. Note that the benefits to biodiversity and the environment should be added to the calculation.

Automatic guidance systems

The investment costs of the guiding systems range from €10,000 for a lightbar system to about €40,000 for a RTK-GPS (Real-Time Kinematic correction) based automatic guidance system (Heege, 2013). The guidance systems offer several benefits and they are well accepted by European farmers. The investments are generally lower than other PA technologies, the risk is lower, and the results obtained are more convincing for the farmer. Additionally, automatic guiding systems are easy to use and they do not require agronomic experience, producing benefits such as profitability, work simplification, and enabling working at night or during low light conditions. For these reasons, automatic guidance systems have significantly developed in the last decade in the US, Australia and in Europe. The minimum area required for lightbar systems to recover the capital cost is 100 to 130 ha, while for an automatic guidance system this rises to 300 to 450 ha (Frank *et al.* 2008, Heege 2013).

The economic benefits of guiding systems in the UK were estimated for a 500 ha farm at least at 2.2€/ha (Knight *et al.*, 2009), but the benefits grow if other more complex systems are adopted, such as controlled traffic farming (2-5%), which would lead to additional returns of 18-45€/ha for winter wheat cultivation. In Germany, economic benefits due to savings of inputs were assessed at 27€/ha for the case of winter wheat. The benefits of automatic guiding systems consist of the reduced overlapping, therefore reducing the cost of inputs (seeds, fertiliser, chemicals, fuel, and labour), but also on the higher yields expected and on the improved soil structure from the reduced area of compaction. Hence, controlled traffic farming methods are clearly established as having economic and also certain environmental benefits. Other benefits important for the farmer are the work speed, work comfort and ability to extend the working hours on the field. An innovative method is the automatic section control, which uses geo-referencing data from a GNSS device to control sections, nozzles, rows or spreading width and pattern of seeding drills and row planters, sprayers and fertiliser applicators such that overlapping is eliminated. The implementation of this method provides economic advantages of up to 28€/ha due to input savings (Shockley *et al.*, 2012). If an auto-guidance system is already installed the economic advantage of the automatic section control is even higher.

EXAMPLE STORY - Precision Irrigation

- In high-value crops precise irrigation methods are developing rapidly in order to save water, improving yields and fruit quality. Europe's irrigated agriculture sector is increasingly pressed to better manage water resources, aiming at increasing the productivity of water used.

- Irrigation deficit strategies increase water use efficiency (WUE) whilst maintaining yield and quality. The strategies include regulated deficit irrigation (RDI), partial root drying (PRD) and sustained deficit irrigation (SDI)

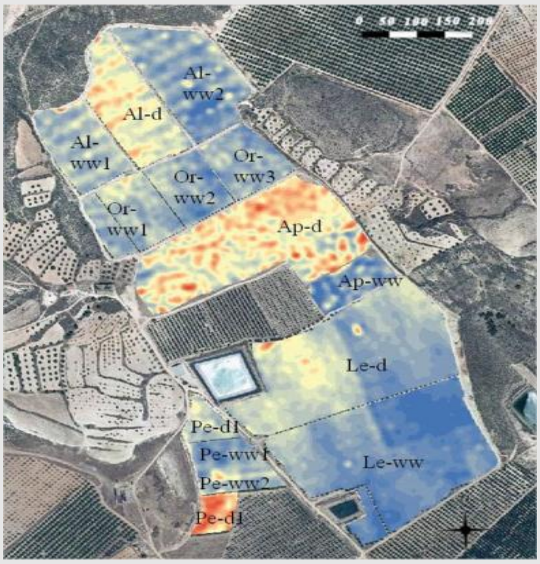
⇒ **Success Story**

- A 70-ha commercial citrus orchard was chosen as a demonstration plot to evaluate the opportunities of regulated deficit irrigation for saving water in southern Spain.

- Remote sensing methods based on manned and unmanned vehicles (UAVs, RPAS) enabled the acquisition of very high resolution (VHR) thermal imagery delivering 30 cm resolution. Flights were conducted weekly, and the thermal imagery processed in less than 24 hours to provide maps of the spatial variability of water stress at the tree level.

- Averaged water use within this orchard was over 3400 $m^3 \bullet ha^{-1}$. Deficit irrigation strategies applied during the summer (from end of June to early September) enabled 25% water savings, maintaining yield level with respect to commercial practices. Irrigation water productivity was increased to 20% when RDI was applied.

- According to the cost of water and power required to run the irrigation of the entire field, savings greater than 44€/ha were obtained when precision irrigation methods were used.

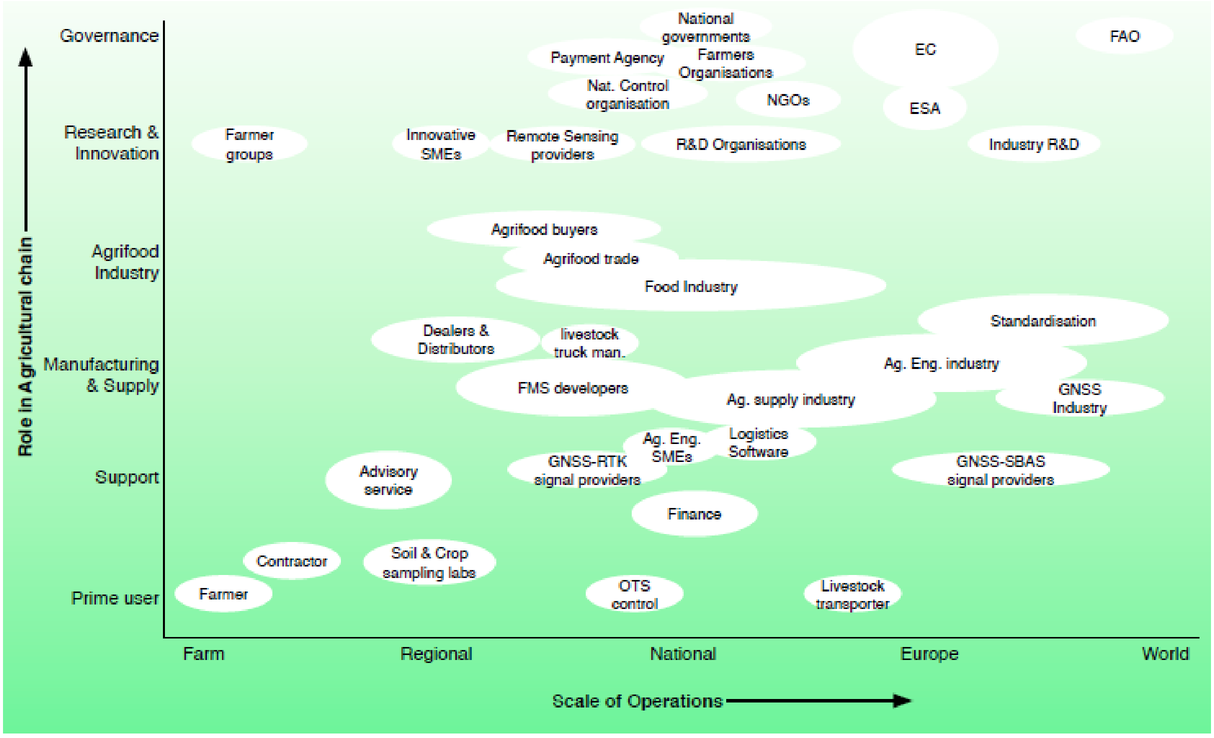


Source: RIDECO-CONSOLIDER Project (Spain) - http://www.rideco-consolider.es/
Image from González-Dugo *et al*. (2013) & quantalab.ias.csic.es.

3.2. The Precision Agriculture business in Europe

There is a lack of general information regarding PA and the business organization. This lack of data is not limited to Europe. In fact, J Lowenberg-DeBoer, in his keynote paper for the 9th European Conference on Precision Agriculture (2013) indicated the sparse data availability on the topic, with manufacturers and dealers rarely revealing sales data. A complete survey on farms in Europe is lacking, and would help to better understand the organization of the PA business in Europe. In the last 10 years, PA has moved from good science to good practice and now 70-80% of new farm equipment sold has some form of PA component inside (CEMA 2014a). In Europe, there are 4,500 manufacturers with a mix of large multinational companies and numerous SMEs producing 450 different machine types with an annual turnover of €26 billion and employing 135,000 people directly and a further 125,000 in the distribution and service network (CEMA 2014b). An overview of the stakeholders in PA at different scales can be seen in Figure 1.

Figure 1 – An overview of stakeholders in the context of Precision Agriculture



Global Navigation Satellite System (GNSS) business in European Agriculture

Information estimated by Topcon Positioning Systems, Inc. suggests that the PA global GNSS market value was $450 million in 2009 and could rise to $1.5 billion in 2017; a 3.33 fold increase. The two recent GNSS Market Reports produced by The European GNSS Agency in 2012 and 2013 indicate that there are about 7 billion GNSS devices in use in the world. Europe and the US will increase from about 1 per person to 3 GNSS devices per person in the coming decade and that this growth indicates significant business opportunities but requires continuous innovation. The GNSS market in agriculture is relatively small, only expecting to be 1.4% of the cumulative core revenue for 2012-2022. The 2013 GNSS Market Report indicates that there is an increasing use of PA in developed countries but also in less industrialised regions. The level of GNSS product accuracy sets the potential application for the business, with low accuracy (c. 2.5m) readily used for asset management, tracking and tracing; medium accuracy (10-30cm) for tractor guidance, via manual control for lower accuracy operations such as spraying, spreading, harvesting bulk crops and for area measurement and field mapping; high accuracy RTK/DGPS systems (2-10cm) for auto-steering systems on tractors and self-propelled machines (harvesters and sprayers) and for precision operations such as planting.

Auto-steering and variable rate technologies (VRT) are considered the main PA technologies to generate GNSS revenue. They are likely to grow much faster than previously estimated and could provide nearly 80% of the GNSS revenues from agriculture. The European GNSS Agency 2012 Market Report estimates that GNSS penetration into EU tractors will rise from around 7.5% in 2010 to 35% in 2020 with sales rising from 100,000 units pa in 2010 to more than 500,000 in 2020 with tractor guidance and VRT being the main applications. The expected reduction in prices for the GNSS/RTK equipment and services will be an important driver for the uptake of PA over the next decade. ESA 2013 estimated that the average device price will drop from €3300 in 2012 to €2400 in 2022. In Europe future growth is expected to be increasingly driven by uptake of GNSS technologies in Central and Eastern Europe where penetration is currently low.

Galileo, the European global satellite-based navigation system, will provide a reliable alternative run by civil, not military authorities as is the case for the US GPS. In a combined Galileo – GPS – GLONASS (the Russian system) use, the higher number of satellites available to the user will offer higher positioning precision. From most EU locations, six to eight Galileo satellites will be visible which, in combination with GPS and GLONASS signals, will allow positions to be determined to within a few centimetres, depending on the service used. The services that are planned to be provided by Galileo will include i) an open service: basic signal provided free-of-charge; ii) a commercial service, with access to two additional encrypted and guaranteed signals, delivering a higher data throughput rate and increased accuracy; iii) a public regulated service, with two encrypted signals with controlled access and high continuity of service for specific users like governmental bodies; and iv) a search and rescue service, that it will contribute to the international COSPAS-SARSAT cooperative system for humanitarian search and rescue activities. To compete with both the DGPS service and the ground-based RTK system, it seems likely that Galileo must offer ii) or iii) above to meet the needs of agricultural users. In any case, the long term availability of DGPS signal is now ensured by the various systems, their interoperability and the standards in place.

Real Time Kinematic Correction Business

For several PA applications it is necessary to meet specific geo-positional accuracies. The implemented solution in 1993 was the Real Time Kinematic correction (RTK), which requires a base station and a data communication system to pass the correction to the machinery, providing +/- 2 cm accuracy. Other methods proposed when trying to avoid a base station is the Precise Point Positioning, which achieves similar levels of accurate positioning with potentially lower capital and running costs, as well as approaches based on precise satellite information which is generated at processing centres, and broadcast to users. The business regarding the RTK correction is provided by operators. The Ordnance Survey in the UK operates a series of reference stations and providing correction signals via cellular networks using GPRS (General Packet Radio Service), the older GSM (Global System for Mobile communication) system or the later 3G (Third Generation) systems. Networks of RTK base stations are operated in restricted areas by dealers for their local customers and by farmer or commercially owned organisations.

Variable Rate Technology Suppliers

The Variable Rate Technology business depends on a technology with one or two stages. The one-stage approach uses sensors and decisions are made on real time. In a two-stage approach, i) a sensor is driven over the crop, such as to record chlorophyll data to determine a nitrogen fertiliser requirement map; and ii) the map is loaded into the controller for a suitable fertiliser applicator to provide variable rate application over the crop. By using a two-stage off-line system one set of sensors can be shared among several farms to reduce the capital cost, relying on a service provider to generate the variable rate map. In the one-stage system, a stand-alone controller converts the sensor data into a VR setting without requiring coordinate information or even requiring a guidance system. The data recorded are used as input into a management system for quality assurance, legal compliance with CAP or national requirements for "greening" or nutrient levels.

Telematic Services

This includes tracking devices using GNSS to send data via GPRS to show the position of the equipment for management purposes. These type of services allow real time view of the machinery at the office, including position, ground speed, threshing drum speed, coolant temperature and duration before maintenance is required, including advising local dealers of maintenance or repairs required. Telematic services use sensors and GNSS devices to measure machinery performance and transmit the information back to an office based computer or mobile phone. The major tractor and harvester manufacturers include telematics support for their equipment and increasingly to provide more information to improve farm efficiency. Services provided include tasks for decision making such as 'combine grain tank needing emptying', or decision support software to advise a tractor-trailer the best path at the right time for unloading.

Mapping Services

Service providers can produce maps of field status covering a range of parameters and make these available to the farmer. These include area and shape, pH levels, phosphorous and other slow changing nutrients, soil texture, soil compaction and weed patches. Such data may be collected by using machinery with coordinate recording equipment and a sample collector system for later laboratory analysis to produce maps. In this context, new service providers offer maps of crop biophysical and chemical composition using hyperspectral imagery acquired by manned or unmanned vehicles. The service provider conducts the flight over the field, processes the imagery and provides the product to the farmer. With the development of new web servers, these maps are accessible through internet in real-time or just a few hours after the flight has been taken place, therefore with rapid processing and turn-around time for decision making. A key development in the future use of satellite imagery is the upcoming European Copernicus programme, for which a full, free and open data policy will apply (as is already the case for the US LANDSAT sensors). The Sentinel-2 satellite constellation will have 10 m resolution, primarily of interest for frequent coverage of large structured crop production areas. However, new players in the satellite Earth observation market are introducing 'swarm' constellations of high resolution (1-5 m) low-cost sensors, with as many as 24 operating at the same time. This promises a drastic drop in price and wider availability of suitable imagery for PA applications.

Farm Management Information Systems

The decision making in farms where spatial and temporal information are available requires a fusion of several maps along with information regarding input use and predicted yield. Input optimisation is calculated using such field information, but it requires to be related to input costs and output returns to determine the economic profitability of the farm. This cost analysis is the most important parameter in optimising the inputs and needs to be supported by specialist advisors, and decision support systems. Specialist advisors interpret the maps, walk the fields and use software to advise the farmer. The advisors may be part of larger organisations providing additional services, for instance nitrogen sensing or soil properties or are suppliers of integrated farm supplies and agronomy. Other specialist advisors exist for particular services, such as organisations providing crop growth and yield information from satellite, aerial and unmanned systems, and advisors in developing farming systems such as conservation agriculture or controlled traffic farming systems.

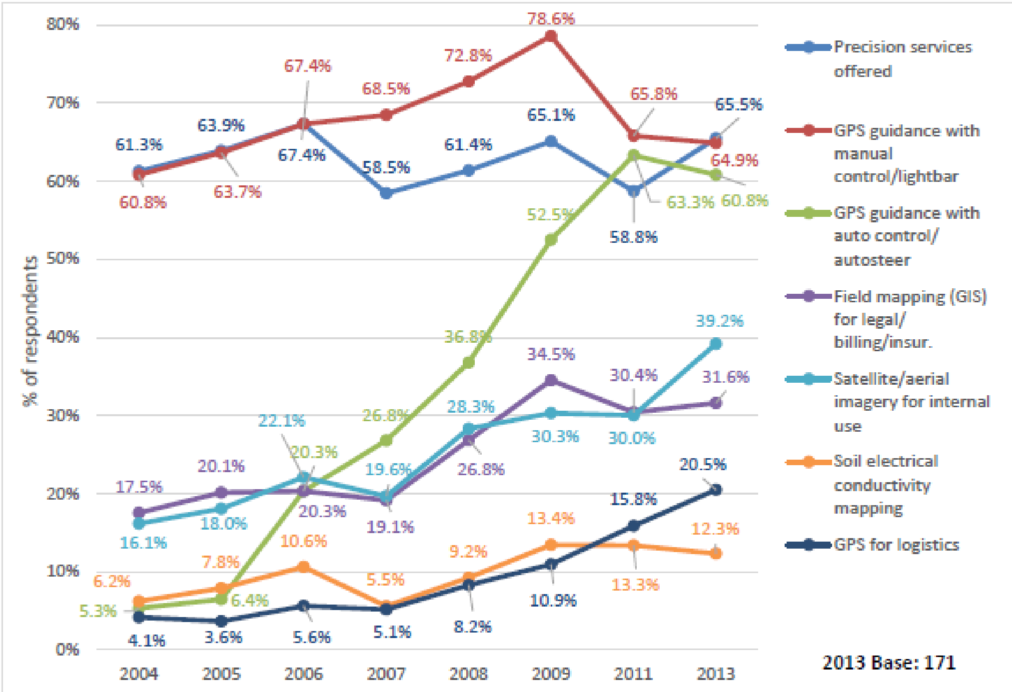
Key Points of PA Business Applied to Arable Cropping

Businesses involved in PA for arable crops include large, well known international machinery companies, major suppliers that may provide certain stand-alone services and equipment, as well as operators and service providers for GNSS services. Tractor manufacturers offer systems for GNSS, guidance, including auto-steer, an operator unit including display and the potential of variable rate and section control. Extra field and crop growth information is provided by specialist providers at the regional level offering support such as laboratories and specific software packages. The management of the spatial data gathered is analysed using software provided by the major international machinery companies or by national suppliers who provide farm management information packages including variable rate analysis software. New cloud-based business services provide data processing and analysis without the need for a computer facility or expertise on farm.

Detailed statistics concerning how the business is organised at the EU level are scarce, and little information is shared by multinational dealers due both to confidentiality and to the large heterogeneity of cases found in Europe. Results from a recent survey of US dealerships shows that more than 80% also provided custom services (Holland *et al.*, 2013, Purdue University): these figures are likely to be indicative for Europe. Figure 2 shows the use of precision technologies over time. Precision services and manual control guidance systems have been the most used and there has been rapid adoption of autosteer guidance systems. Remote sensing services have increased as well as soil electrical conductivity mapping and GNSS for logistics.

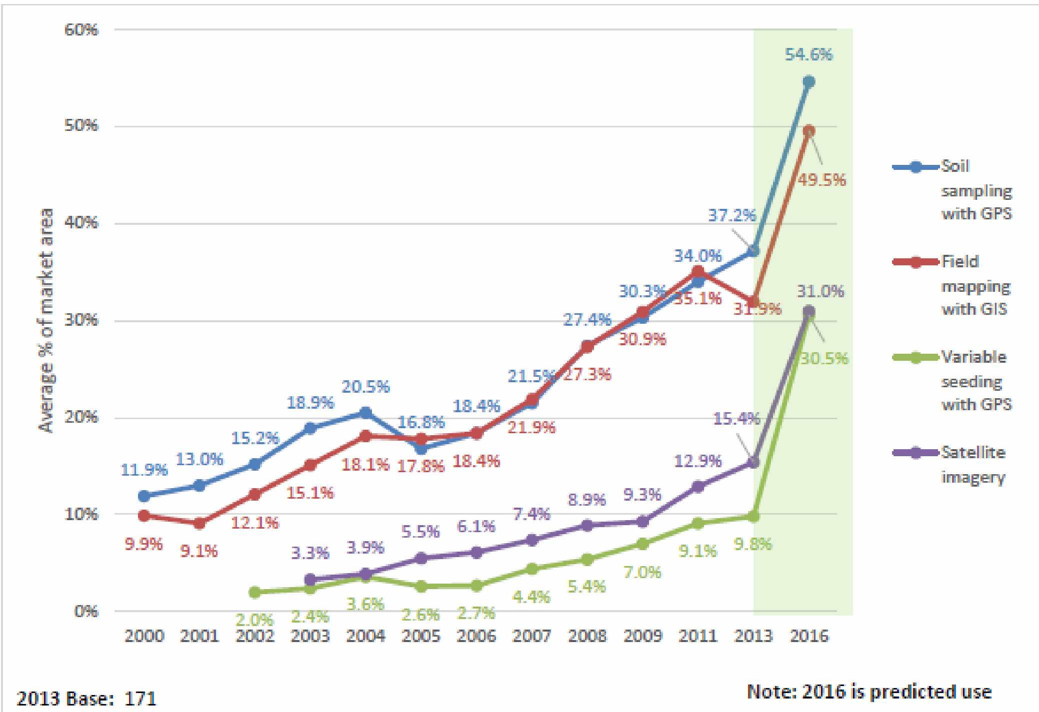
Contract services have increased rather rapidly but they are a function of the available funds of farmers; that is, these services are likely to be reduced in years of poor returns. Soil sampling with GNSS and field mapping are the two most popular services, but, yield monitor data analysis and satellite imagery use has increased in the last few years and show an even greater rise forecast to 2016. The adoption of additional precision services over time (Figure 3) shows a steady increase with an expected rapid increase towards 2016.

Figure 2. Use of precision technology over time



Source: from Holland et al. 2013, Fig. 20.

Figure 3. Precision Agriculture services offered over time



Source: from Holland *et al.* 2013, Fig.47.

3.3. Drivers and constraints for farmers to adopt PA

Investment Behaviour by Farmers in PA related equipment

It is generally accepted that profitability is the main driver for investing in new PA equipment and systems (Tinker and Morris, 2011). In fact, there is a link between knowledge, technology and production increments (Foresight, 2011), as it has been demonstrated that better knowledge and technology has potential to increase crop yields, while an investment in research and development is critical to produce more food in an environmentally sustainable manner.

The investment in new machinery and PA technologies is more likely to happen when existing farm machinery needs to be replaced, or when there is a need for a change on the farming system or the farm management information system. Nevertheless, profitability is not the only driver for investing in new machinery, as the decision may be also be influenced driven by environmental or labour regulations. In such cases, more accurate and technologically advanced systems may be seen as the only way to comply with higher standards of protection of the natural environment and the welfare of workers. Additionally, new investments can be encouraged by the transfer of technologies from other sectors such as GNSS and computer science or robotics, which can also encourage new investments, offering comparative advantage to early adopters. In summary, there are four main factors playing a role in the investment decision on new technology which have an impact on profit: commodity prices, labour prices, energy prices, and adherence to environmental regulation. In addition, there are other factors that may have an important impact on the decision, such as individual farmer circumstances and motivation, which are influenced by age, commercial orientation, tenure, inheritance and succession. Other factors, such as migration between Eastern / Western EU or the opening of land markets in the East to external investors, may have an effect on the adoption of PA methods.

Drivers and Constraints

The perception and reception of precision farming varies according to the actor within the Precision Agriculture sector, from the farmer to the scientist to the suppliers and manufacturers involved. Main drivers for the acceptance of PA technologies include reduced stress for the driver (steering systems), optimizing machine utilization (automatic machine setting, autonomous machine guidance), minimized overlapping costs (steering systems), machine monitoring (telemetry), objective information gained through greater quantities of information (yield mapping, greater use of simpler sensors), and optimizing the inputs (nitrogen sensors, geo-referenced soil sampling, VR maps). In the use of GNSS for auto-guidance systems, the farmers see the results easily, which are an encouragement to further investment. In terms of IT technology, new and future developments on cloud computing incorporating the centralized data storage and processing services will simplify the work to be conducted by the farmer. A fully automated deployment, acquisition and analysis of processed data can be achieved assuming that privacy issues and commercial data protection are properly addressed.

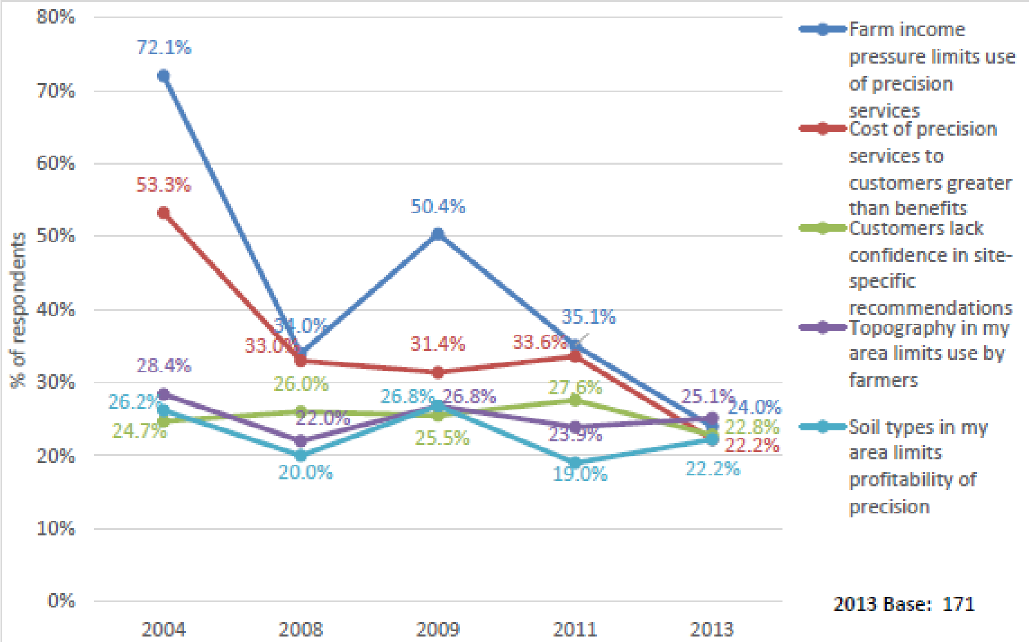
Regarding limitations, from the scientific point of view it is suggested that the lack of standards and the limitations on the exchange of data between systems prevents the adoption of machinery and instrumentation from different brands and companies. In addition, the farmer lacks independent advisory / consultancy services as there is a lack of validated agronomic models for variable rate technology to help make decisions upon the investments required.

From the private sector point of view, multi-national manufacturers suggest that one critical issue that prevents the adoption of PA methods is "the lack of independent field testing to help with decision making for equipment and system purchases". Another important issue advocated by multi-national machinery sellers is that the most important drivers are those that reinforce the push to greater efficiency, and therefore the use of inputs more effectively, with a general focus on the environmental benefits but with little or no quantification. Regarding limitations, a major problem is the investment cost, which is low for cost-effective products, but, prevents the adoption by farmers when the investment is high, such as in the case of variable rate technology. Private companies also agree that the lack of standards and protocols to communicate between machinery and tools / instruments is a problem. A major objective is to reduce the number of displays in the tractor, therefore, the farmer is able to control machinery and tools in a coordinated way. There have been attempts to solve this issue, but limitations still exist, and the farmer before deciding to purchase PA equipment needs to know from the manufacturer whether that equipment can easily communicate with other components of the PA hardware, especially the terminal.

An additional limitation concerns the access to independent services linked to Government bodies, co-operatives and farmer associations where the farmers can get additional information in order to make decisions. While in most EU countries these advisory services do not exist, a good example is found in the UK with HGCA (http://www.hgca.com/beprecise). HGCA is one of six statutory levy funded bodies in England that have a mandate to provide independent research, technology transfer and training for farmers and encourage the take-up of PA technologies in arable cropping. The levies collected from the agricultural products are used for research, promoting products and good farming practices. As part of the training, lectures, demonstrations and research projects to gather independent information are made available to farmers. Also an online tool, effectively a 'Precision agriculture calculator', is available for a farmer to self- estimate the cost-benefits of PA adoption according to the specific nature of his farm and to the specific PA system that he is contemplating. Although this is not intended to provide a Farm Advisory Service, this is a good example that could provide elements of a model for FAS organisations in the EU for providing independent advice. These activities are supported by the English farmers' association.

In the previously discussed publication by Holland *et al.* (2013) the view of US dealers and service providers regarding potential limitations to adopting PA techniques (Figure 4) are reported. This shows that the barriers are farm income, cost of precision services, lack of confidence in site-specific techniques, topography and soil types. Most striking is that the financial barriers (farm income, cost of services) have significantly reduced from 2004 to the present day.

Figure 4. Customer responses regarding issues that create a barrier to expansion / adoption of PA over time



Source: from Holland *et al.,* 2013, Figure 57.

Comments on Constraints and Drivers for Europe

Experience from the Netherlands indicates that the main driver is having a proven added value for different applications. When the profit is demonstrated and the first adopters are convinced, the rest will follow. The organiser of the British HGCA farmer training found that the drivers include environmental factors particularly in the Nordic countries and that Eastern Europe is a high user of PA, but theft is a concern. In such cases, constraints were the system cost, technical knowledge, smaller fields and a lack of fundamental knowledge of what PA can do to optimise inputs. In Switzerland, farmers look for solutions to improve efficiency of operations, decreasing production costs. Hand-held crop sensors have not proven profitable and are hardly used.

In Australia McCallum and Sargent (2008) indicated that there has been a rapid adoption of GNSS guidance and autosteer systems, with about 30% of large-scale fields sown and/or sprayed using GNSS technology. On the contrary, PA technologies such as yield mapping and variable rate methods were less common with <1% of adoption. One of the main justifications for such low adoption is the lack of evidence that variable rate technology provides adequate financial return. In a recent publication (Atzori *et al.*, 2013) discussed the adoption of PA technologies for the dairy cattle farm management sector, considering a survey by Bewley and Russel (2010) of dairy farmers' opinions. They showed that the critical point of adoption rate of PA technology in Italian dairy farms is represented by the farmer's education. In addition to the farmer's education level, Pierpaolia *et al.* (2013) showed that farm size, expected reduction in costs, higher revenues to provide a suitable cost/benefit ratio, the total income, land tenure, level of computing skills, access to information and location were important factors influencing the adoption of PA. Other studies conducted have demonstrated that usefulness and ease of use are central aspects for the adoption, provided that these aspects do not cause a significant increase in the cost. The study by Pierpaolia (2013) suggests that new markets will be created offering consultancy other than simply the sale of technologies.

3.4. Viability of Precision Agriculture for EU farmers

It is generally accepted that Precision Agriculture is an inevitable fact, as new information technologies will impact farming in Europe and worldwide. The open question is which technologies will be adopted and at what speed. It is also considered that the adoption of PA is lagging behind its initial expectations (Griffin *et al.* 2010; Reichardt and Jürgens, 2009; Mandel *et al.* 2011). In some cases, precision farming technologies did not deliver the promised advantages, and many farmers were disappointed and reluctant to invest in precision farming (Rutt, 2011). Some of the major constraints for the adoption of Precision Farming highlighted in several studies were the complexity of the technology, incompatibility of components, time requirements, and the lack of profitability (Khanna, *et al.* 1999; Griffin *et al.*, 2004; Reichardt and Jürgens, 2009; Robertson *et al.* 2012).

The assessment and quantification of environmental benefits is almost totally lacking in the literature. Some farmers do consider these benefits as part of their overall viability decision, based upon their personal values. But apart from general qualitative statements there is no quantified environmental benefit assessment that can underpin an investment decision: this appears a significant omission that could be addressed by developing a methodology and/or tool to be available for the decision process. Some other environmental benefits are at different scales (geographical or time) than just for individual farm management. There is a general need to assess the public benefit of better environmental friendly practices impacting at the level of the watershed or the small region.

Other studies suggest that the main barriers for the adoption of precision agriculture generally appear in the later stages of the innovation processes (Busse *et al.* 2013). This has implications on issues such as the lack of financing for long-time validation, low demand due to the lack of investment by farmers, insufficient communication and co-operation between actors and, very importantly, a gap in knowledge transfer between science and the practical applications. An example of the lack of adoption of site-specific fertilizer management, especially nitrogen, is the low economic margin, which does not justify costly investment in some cases. This is probably the reason for low adoption rates, although it may change with increasing crop prices and lower technology prices.

While in the early days the crop yield monitor was seen as the first step to PA, suppliers of equipment consider that the regulations linked with obligatory soil monitoring open new possibilities for the adoption of PA. These type of tasks can be conducted very efficiently with GNSS and the new sensors offered in the framework of PA. Other methods, such as section control, have the potential to implement efficient protection approaches in vulnerable zones due to the reduced overlapping and control of sections, nozzles, rows and spreading following accurate trajectories guided by GNSS.

PA is effectively a suite of methods, approaches and instrumentation that farmers should examine in detail to decide which is the most suitable for their business. In a report by Knight *et al.* (2009) the cost/benefit of many of the components of this *"suite"* were discussed, suggesting what is needed for each case. The growth in the adoption of PA in countries such as the UK has shown that between 2009 and 2012 the proportion of farms using PA increased. The increase for GNSS was greatest, from 14% to 22%, for soil mapping from 14% to 20%, for variable rate application from 13% to 16% and for yield mapping from 7% to 11%. The two most common reasons for adopting precision farming techniques were to improve accuracy in farming operations (76% of farms in 2012) and to reduce input costs (63% of farms in 2012). Almost half of farmers in 2012 who do not use any technique said they are not cost effective and/or the initial setup costs are too high, 28% said they were not suitable or appropriate for the type or size of farm and a similar 27% said that they were too complicated (tables 2 and 3).

These figures for England seem to suggest that farmers consider PA a viable solution for them. Nevertheless, it seems that there is a long way to go before the majority is convinced. The British HGCA body is firmly in the opinion that PA is a viable solution, but training and cost/benefit analysis are critical. In a recent study, Schieffer and Dillon (2013) used a whole-farm model based on a Kentucky grain farm to investigate the effects of PA adoption on production choices under various agro-environmental policy frameworks. The study concluded that as PA techniques are more widely used then the economics of farm management will change, affecting how farms respond to agro-environmental policies, particularly those that rely on financial incentives.

Table 2. Reasons for using PA techniques in England

	2009		2012	
Reason	% of holdings	95% CI	% of holdings	95% CI
Improve accuracy	85	± 4	76	± 3
Reduce input costs	78	± 4	63	± 3
Improve soil conditions	55	± 5	48	± 3
Improve operator conditions	36	± 5	36	± 3
Reduce greenhouse gas emissions	n/c	n/c	17	± 2
Equipment already installed	9	± 3	n/c	n/c
Other reason	4	± 2	3	± 1

Based on responses from 518 farms in 2009 and 1084 in 2012 that use at least one precision farming technique.

n/c: Data not collected.

(a) The 2009 results have been reanalysed here to only include farms that use at least one technique. However the 2009 and 2012 results are still not directly comparable due to the way in which the question was asked. The 2009 question asked for reasons why farms already use or would consider using precision farming techniques, whereas the 2012 question just asked for reasons why farms already use them. This explains why the 2009 results are generally higher than those from 2012.

Source: from Department for Environment Food and Rural Affairs (2013).

Table 3. Reasons for not using PA techniques in England

	2012	
Reason	% of holdings	95% CI
Not cost effective and/or initial setup costs too high	47	± 3
Not suitable or appropriate for type or size of farm	28	± 2
Too complicated to use	27	± 2
Not accurate enough	2	± 1
Other reason	8	± 1

Based on responses from 1454 farms that do not use any precision farming techniques.

Source: from Department for Environment Food and Rural Affairs (2013).

4. CAP 2014-2020 POLICY INSTRUMENTS AND PRECISION AGRICULTURE

4.1. Policy instruments that can address Precision Agriculture

Appropriate policy-making addresses challenges, defines objectives (*e.g.* reducing greenhouse gas emissions) and designs relevant instruments to efficiently meet these particular objectives. PA is a relevant technology to improve decisions concerning agricultural processes. It has a strong potential to help EU agricultural policy meeting its objectives to enhance competitiveness (of the agricultural sector) and improve sustainability and effectiveness (*i.e.* reducing its impact on the environment and using natural resources in a sustainable manner). Regulation, in generic term, can be a driver or enabler for innovation, fostering the uptake of a technology: for example in another field, the type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and the development of low fuel consumption engines and catalytic converters. However, for a relatively technical domain such as PA with a limited coverage in usage, it is felt that knowledge dissemination and fostering the sharing of experience are powerful instruments to be put in place. In this context, strategies are examined on how PA development could be supported or addressed within the CAP.

Since 1999, CAP payments have been structured in **two pillars**, direct payments and market measures and rural development, both assisted by a Farm Advisory Service (FAS) that can include Farm Advisory System(s). This structure remains valid for the CAP 2014-2020. However, under the new CAP, specific objectives have been set, several of them could be relevant for PA, amongst which: 'enhancing farm income', 'improving agricultural competitiveness', 'fostering innovation', 'providing environmental public goods', and 'pursuing climate change mitigation and adaptation'. Whilst the 1^{st} pillar payments are composed of: (i) a basic payment to support farmers' incomes in return for them respecting standards and keeping the land in good condition (minimum agriculture activity and cross-compliance), and (ii) a green direct payment (mandatory) to put in place greening measures, supports through the 2^{nd} pillar (**Rural Development**) is done through voluntary schemes. These schemes are implemented through national and/or regional **rural development programmes (RDPs)** which set out the actions to be undertaken and the corresponding allocation of funding for these measures.

Since PA benefits are not universal across Europe but rather specific to local conditions and to the farming systems in place, it is felt that rural development measures are suitable to play a role in fostering the development of this technology. However, it is the **responsibility of Member States** to define the measures they want to be co-financed in their RDPs, following a structural analysis (SWOT) to identify their needs, priorities and actions to undertake. Rural Development managing authorities in the MS may decide whether some PA techniques could be relevant for their regional characteristics and specificity. For example, auto-guidance steering may be proved to be beneficial only for intensive crop production regions, eventually bringing there agri-environmental benefits.

Within the range of Pillar II measures available within ***Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013***, several of them are available for MS to support PA development through their RD programmes:

- **Article 17 (Investments in physical assets)**

The measure aims at farm modernisation and intensification. Furthermore, the scope of the measure is now expanded to cover concerns related to climate and the environment, for example, increased support rates for investments linked to agri-environment-climate measures. This measure could help with purchasing PA technology through a co-funding mechanism. One of the easiest, simplest and cheapest PA technologies is the auto-guidance system (some 10k € minimum necessary investment) that could lead to cost savings and reduced carbon footprints due to reduced fuel consumption, and also reduce soil compaction by limiting traffic. The success of this technology may be a first step towards the wider adoption of other PA equipment within the EU. Indeed, VRT sprayers can lead to yield improvement by optimising inputs and addressing within-field variability directly. At the same time, a reduction in soil leaching and/ or excess content in soils (of pesticides, herbicides, N, P and K) can be achieved. VRT can help farmers comply with regulations, such as N amount in Nitrate Vulnerable Zones or no spreading on buffer strips. VRT sprayers for precision irrigation can lead to water saving, labour saving and energy saving while increasing production by avoiding water stress. VR spreading efficiency can be improved by investing in N-sensors or soil moisture sensors allowing real-time adjustment of the quantities to add and spread.

- **Article 28 (Agri-environment-climate)**

This measure supports farmers willing to carry out operations related to one or more agri-environment-climate commitments, shifting towards more environmentally sustainable farming systems. It is also possible to propose measures that engage the whole farming system in holistic approaches where farmers are paid for applying a number of agronomic practices in combination. It can concern commitments for both livestock and cropping systems. PA may provide agronomical and environmental justifications for that measure.

- **Article 35 (Co-operation)**

Support is granted to promote forms of co-operation involving at least two entities. Co-operation can relate to pilot projects, joint action undertaken with a view to mitigating or adapting to climate change and joint approaches to environmental practices including efficient water management. PA may contribute to these requirements, in particular as co-operation and sharing material and/or equipment would allow both reduced investment costs while delivering better results over wider areas (*e.g.* a landscape approach requiring collective action from a group of farmers).

Other instruments under the second pillar can enhance competiveness through measures bridging the gap between science and practice via the **Farm Advisory Services (FAS)**, as well as training and innovation programmes. These instruments are aimed at helping the farm sector to adapt to new trends and technologies, thus becoming more resource efficient, cost effective and capable of adapting to emerging challenges. This is particularly relevant for PA techniques. These measures are:

- **Article 14 (Knowledge transfer and information actions)**

Member States could take action to use these funds for vocational training and skills development in the form of workshops, training courses, coaching, information actions and farm visits to foster the uptake of Precision Agriculture. It could facilitate, for instance, the sharing of relevant PA experiences on decision practices and impact measurements.

- **Article 15 (Advisory services, farm management and farm relief services)**

The **FAS** is a system operating in all Member States to which any farmer can have access on a voluntary basis. The FAS consists of many elements including advice, training, information provision, extension services and research. This measure includes advice for the delivery of best agronomic practices and integrated pest management, linked to the economic and environmental performance of the agricultural holding. These elements can be embraced by precision agriculture. Member States could decide to allocate funds to set up a platform dealing with advice, knowledge transfer and customer interface dedicated to Precision Agriculture methods. Indeed, the provision of calculators such as the UK-HGCA 'Be Precise Cost-Benefit Tool' to estimate the potential economic benefit of PA technologies in a cost-benefit approach, could be used as a FAS tool.

- **Title IV European Innovation Partnership for Agricultural Productivity and Sustainability: Article 55 (Aims), Article 56 (Operational groups), Article 57 (Tasks):**

The European Innovation **Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) can play an important role in both developing and mainstreaming precision farming in the EU**.

Operational groups which are funded under article 35 of the RDP are a pivotal element of the EIP-AGRI as they will carry out projects that test and develop new products, practices, processes and technologies in the agriculture, food and forestry sectors in view of fostering more productive and sustainable sectors. The EIP-AGRI is based on an interactive innovation model and the groups should therefore be composed of a number of actors such as farmers, researchers, advisors, and businesses. Projects by Operational Groups working on PA could very well be developed within this framework.

Despite Precision Agriculture having been introduced more than 20 years ago, it is still lacking a wider dissemination in Europe. To this end, the EIP-AGRI has set up a specific Focus Group working on the topic of mainstreaming precision farming. The purpose of the group is to: take stock of the state of the art of practice in the field of its activity; take stock of the state of the art of research in its field; identify needs from practice and propose directions for further research and propose priorities for innovative actions by suggesting potential practical operational groups or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered. The group, which consists of 20 experts from research, farming and industry, will work in close cooperation with the ICT-AGRI ERA-net.

Improved collaboration between farmers, farm service/technology industry and academics can speed up market introduction of PA techniques based on a robust evaluation of economic, agronomic and environmental benefits. The success for implementing a relatively new, complex and sometime expensive technology such as PA will necessitate (i) to critically assess where PA can bring environmental and/or economic benefits (pan European study), (ii) disseminate information, experience, knowledge to all relevant stakeholders (in particular farmers) and (iii) support RD managing authorities when designing their programmes to make sure they will critically assess whether PA could be of interest for them, and in such cases, that they foresee relevant measures in their RD programme.

4.2. Possible added value of Precision Agriculture for production estimates and CAP management

By stimulating the implementation of PA through CAP instruments, the benefit to agricultural processes seems to be mainly driven by innovation and competiveness rationale and to a lesser extent to improving the sustainable management of natural resources. However, PA's technology can also collect and produce a wide range of materials on soil characteristics, weather-related indices, and crop status at land parcel level. These geo-referenced data are more and more often required for policy monitoring (regulatory mechanisms and control), for environmental impact assessment of farm practices or for traceability requirements of agricultural products. However, despite a range of advantages and potential savings in data collection, the mechanism for gathering materials from individual plots/farms via PA has still to be designed.

Below is a preliminary list of potential applications:

- **Crowd sourcing farm data collection**

The wide adoption of PA within the EU territory would enable the possibility to solicit contributions from a large number of farms and organize annually (through a common methodology) the production of statistics from data recorded and from data produced by these farms. This sample of farms may not appear to be statistically representative of the EU 28 farm typology, however there is the potential to use these data to complement surveys such as FSS or LUCAS. The issue of property rights and of who owns and controls farm-level data would need to be addressed.

- **Improvement of crop models**

Data collected and shared from PA may constitute a new information source on the spatial variability of crop performance and thus contribute to a better understanding of the impacts of soil properties, fertilisers/pesticides efficiency, topography, climate and other factors. These elements would provide a better understanding or fine-tuning of crop yield components, improving accordingly yield forecasting models.

In addition, data from PA farms could contribute to improving the crop yield forecast system at wider scale (Europe) in providing 'real time' adjustment of the model, during the crop cycle (*e.g.* soil status, crop status). Relying on crowd sourcing as a first step, may then lead to the constitution of a more formal representative set of farms. The Crop Growth Monitoring System (CGMS) currently used by the JRC in support to DG AGRI to provide reliable and timely spatial information about crop status in Europe could benefit from these real-time calibrations.

- **Supporting the IACS (Integrated Administration and Control System) procedures**

Notwithstanding the need for standardization and harmonization of data exchange and format, information recorded and produced in the frame of PA activities could be used in the IACS, facilitating different administrative and control procedures.

- *Supporting farmers' declaration document*
  The geographical accuracy of agricultural parcel maps produced in PA would be sufficient so that farmers can use them during the submission of their digital application;

- *Supporting administrative documents*
  After verification by Member States administrations, some of these parcels could also be used in the updating process of the Land Parcel Identification System (LPIS);

- *Objective evidence of compliance with legislation*
  The recording and geo location of activities performed in each parcel (Digital farm book: date or timing, quantity of fertilizer/pesticide inputs, etc.) could be used by

farmers as evidence of the respect to cross compliance rules (*e.g.* nitrogen quantity/ha, timing of application for the Nitrate Directive).

- **Geo traceability**

Through PA, almost all (if not all) data and activities are digitally geo referenced. Consequently, it can be rather straightforward to ensure geo-traceability of farm products (*e.g.* farm to fork, cradle to gate) ensuring quick and accurate trace-back and recall when necessary or providing information on agricultural products provenance to the public. This is a growing requirement from food safety agencies, certification bodies, but also from the European consumer. The geo-traceability requirements for Genetically Modified (GM) crops are an example. Clear traceability offers additional insurance against false information or fraud, such as to the organic food sector or to consumers opting for products from short supply food chains (locally produced food labelling in shops). Traceability can also play a role in providing evidences for what concerns compliance with animal welfare rules. The geo-traceability 'added value' that PA can provide, may trigger clear interest for some certification processes.

5. CONCLUSIONS

Considering future societal and environmental needs, the main challenge for EU agriculture will be its ability to ensure a high level of production while improving the protection of natural resources. Precision agriculture is an information-based, decision-making approach to farm management designed to improve the agricultural process by precisely managing each step. In this manner, PA can provide a management approach optimizing both agricultural production and profitability – which is the key goal of most farming enterprises. Additionally, part of profitability can come from the reduced use of inputs (machinery, labour, fertilizer, chemicals, seeds, water, energy, etc.), leading to both cost savings and also environmental benefits. Today, the technological infrastructure of precision agriculture is in place to support a wider implementation.

There are still obstacles to the adoption of precision agriculture by farmers. These include cultural perception, lack of local technical expertise, infrastructure and institutional constraints, knowledge and technical gaps and high start-up costs with in some cases a risk of insufficient return on the investment. Up to now, the private sector suppliers have been the clear driver of PA development and adoption. The support from governments and other public institutions can play an important role in a wider adoption of PA. But, any decision from public bodies to further enable this adoption should take full account and advantage of any pre-existing commercial infrastructure.

Although the possible use of precision technologies in managing the environmental side effects of farming and reducing pollution is appealing, the benefits provided to the environment have been little assessed with no quantified figures available. Some farmers state that improving the environmental aspects of their farm is an important element in deciding to adopt PA technology, but, this most likely comes from their personal values and perceptions. An obvious next step is to have dedicated studies to quantify these environmental benefits since this is currently poorly documented.

The benefits of higher profitability will be immediately seen at the farm level. In contrast, for the environmental situation, impacts will be manifest, not only at farm level, but also in the adjacent landscape (vegetation, streams, run-off areas) and they may take years to appear. Therefore, the idea of public good in a local or regional sense, rather than just benefit to an individual farm, is one that applies to the potential environmental benefits of adopting PA. Hence, the study of the potential benefits needs to add those from the broader scale to those accrued at the farm level.

Promoting precision agriculture through the CAP seems to be economically, environmentally and even socially justifiable. But, further investigation and accompanying measures are necessary to avoid inappropriate technological push where PA is not likely to be successful, and to maximize the potential public benefit by focusing on specific farm types and farming practices. As discussed, support possibilities are available under Pillar II measures but since these require co-funding it is essential to have engagement and commitment of Member States through measures consistent with the intervention logic of their RDP. Successful adoption is expected to follow the phases of exploration, analysis, support and execution. Involvement of MS in the first three phases is necessary before they are likely to endorse funds for execution.

6. RECOMMENDATIONS

1. A **study identifying regions in the EU and the typology of farms** should be made, showing where and in which conditions PA could be potentially implemented with benefits for the farm competitiveness and/or environmental stewardship.

2. **Pilot studies** are advocated to focus on an unbiased enumeration of **potential benefits** (especially concerning the environmental ones) and using these as examples to increase farmers' awareness, particularly to extend their use to a wider range of types and size of farms.

3. Existing measures under the CAP Pillar II are highlighted where funding for PA adoption could occur. **Rural Development managing authorities** in the Member States when designing their programmes should critically assess whether PA could be of interest for them, benefiting from the pilot studies, calculators and other research.

4. **Research and studies are necessary** to improve the knowledge and cost-benefit aspects of PA, especially concerning the environmental impact. Case studies must go beyond farm- and field-specific measures and consider the wider environmental footprint.

5. A **'precision farming calculator'** at the European level should be made available for differing farming systems to include **quantification of environmental benefits** in addition to potential production benefits for the farmer. Adherence to environmental directives should be integrated within the calculation.

6. The **Farm Advisory Services (FAS)** of each Member State can play an important role, providing support and advice to farmers regarding technology and precision farming methods as an independent body not linked with commercial companies.

7. The **awareness, knowledge and technology transfer of PA** should be improved. A focus group under the EIP on Agricultural Productivity and Sustainability is being formatted, concerning 'mainstreaming of precision farming'. The current priorities are to look at data capture and processing, but this could be expanded to encompass evidence-based benchmarking of PA performance and impact evaluation.

8. Access should be ensured to **free and accurate data** products for PA applications. In particular, suitable services from GNSS developments (Galileo) are a priority, but also more easily available data from remote sensing programmes (Copernicus) can be a stimulant to improving PA applications. Member States should be encouraged to provide access to relevant reference data.

9. Finally, a recommendation is to explore the possibility to use PA data for other purposes, such as for **IACS supporting material, crowdsourcing farm data collection or improved inputs to crop modelling** and the resulting benefits.

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