Chapter 12
Perspectives of Precision Agriculture in a Broader Policy Context

Kim Martin Lind and Søren Marcus Pedersen

Abstract Agriculture is faced with contrasting requirements from the broader society. On the one hand, agriculture needs to expand production to be able to feed a growing global population. Furthermore, the developing bio-economy requires agriculture to produce for a range of non-food objectives such as bio-fuel, textile fibres, etc. On the other hand, concerns over the environment, climate, biodiversity and other ecosystem services place restrictions on conventional agricultural production. Precision agriculture can be part of the response to these often conflicting issues by employing technologies that in a precise and targeted approach reduce resource use and increase yield. Furthermore, the growing demand for higher value food products in terms of health and quality require traceability and information about production processes and resource use, which also correspond with the possibilities offered by precision agriculture technology. The general movement towards higher integration in food supply chains is a natural extension of the requirements for traceability and product information, which are integral parts of precision agriculture.

Keywords Precision agriculture • Public goods • Societal trends • Adoption

12.1 Introduction

Precision agriculture (PA) promises to provide a better and more targeted use of inputs and reduce the negative effects to the environment. In particular, auto-steering and the availability of Variable-Rate Application (VRA) equipment at affordable costs produces some promising perspectives. With growing prices of agrochemicals, VRA provides economic benefits to farmers while providing ecological

---

K.M. Lind (✉) • S.M. Pedersen
Department of Food and Resource Economics, Faculty of Science, University of Copenhagen, København, Denmark
e-mail: kim@ifro.ku.dk; marcus@ifro.ku.dk

S.M. Pedersen, K.M. Lind (eds.), *Precision Agriculture: Technology and Economic Perspectives*, Progress in Precision Agriculture,
https://doi.org/10.1007/978-3-319-68715-5_12

benefits with reduced leaching and emissions. In this chapter, we envisage how PA may attain larger yields with lower inputs to meet the standards and policy trends in Europe and other OECD countries.

In the next 20 years, world food production is required to increase by 50% to feed the projected 9.2 billion Earth population in 2050, (FAO 2009). Up to 80% of that increase must come from production intensification. Precision agriculture can be one of the options to deal with the growing demand for food. The size of this variability can be used to demonstrate the suitability of implementing VRA more extensively. Although site-specific techniques have been available to farmers for more than 20 years, the adoption has been relatively slow for most applications. So far, variable-rate N application in cereals is used by 3–8% only of the farmers in Denmark, Germany and Finland (Lawson et al. 2011).

12.2 PA and Wider Societal Trends

Precision Agriculture technologies offer promising perspectives on meeting the demands of and mitigating risks to the global society. In particular, the growing world population requires increases in food production, however, concerns over climate and environment may slow down the growth necessary in productivity. Furthermore, there are concerns about increasing scarcity of and decreasing returns to conventional energy reserves, which in turn could significantly reduce the amount of affordable energy for societal needs and demands. Climate change poses threats to sustainability of natural environments, agriculture and urban areas. Agricultural production for non-food uses, specifically for energy production, requires additional agricultural area in addition to areas needed for expanding food production, for habitation and other urban related activities for a growing population that is increasingly living in large cities.

Rabbinge and Bindraban (2012) identify **six megatrends** in agriculture that overarches global development albeit with varying local or regional effects. The **increase in productivity** is identified as the **first megatrend**. Hitherto, the increases in food production have outpaced the increase in population despite the dire predictions of Malthus (1798). Thus, over decades if not centuries productivity in agriculture has increased in terms of per hectare, per hour of labour, per kg of chemicals applied and for other inputs. In the Netherlands, wheat yields have risen from around 800 kg per hectare in 1400 to 1800 kg in 1900 and increasing to 9000 kg per hectare in 2000, (Bindraban and Rabbinge 2012). Simultaneously, labour input has decreased from about 600 h per hectare in 1400 to 240 h in 1900 and dropping to 12 h per hectare in 2000. Behind these impressive achievements are better and more targeted uses and applications of inputs. Information gathering of the conditions of crops in the fields has led to the ability to vary input and resource use according to differing needs in line with the principles of precision agriculture.

Farmers are generally price takers – meaning that it is difficult for the individual farmer to get a price different from what the market offers. Adoption of a new farming technique enables the individual farmer to reduce cost and or improve yields and thereby profits in the short run. However, after some time other farmers may adopt the techniques and the aggregate output of a given product will increase. Without an increase in demand, prices will fall. In reaction to this, new technologies will be developed to reduce costs. These technologies will be commercialized and adopted by farmers, which in turn provide new supplies and a reduction in output prices. This course of events is known as the agricultural treadmill. It is often observed in the agribusiness sector because most agricultural products are regarded as primary products produced by many producers. As an individual farmer, it can profitable to be among the early adopters of new technology enabling possible favourable returns in the short run (Doll and Orazem 1978). However, in the longer run above-normal profits will decline as more and more farmers implement the technology.

Innovations are often caused by changes in relative factor prices. With higher labour costs, the agricultural sector will be forced to use more capital-intensive factors as a substitute for labour to gain an increase in productivity and profitability. The relative cost of capital compared with labour has shifted the agricultural sector into more specialization with larger farm areas and production units. This trend has been prevalent in Europe and many other regions since the fifties (Pedersen 2003).

Precision agriculture and smart farming technologies have to some extent followed a similar pattern. Precision farming is capital rather than labour intensive and the concept of auto steering and variable treatment aims at saving variable inputs such as fuel, nutrients and to some extent labour and thereby increasing farm productivity.

The **second identified megatrend** in agriculture is the **integration of more advanced industrial and information technologies** in agricultural production. Increasingly, farm machinery is equipped with sensors and GNSS capabilities making information gathering and processing a more and more natural element of farming practices. This development has contributed towards making it possible to identify spatial and temporal variability across fields, soils, crops, pests and weed infestations, and management practices. Precision agriculture technology is considered by farmers mainly because of higher expected profitability, (Reichardt and Jürgens 2008). The main reason for the low rate of adoption of precision agriculture in Germany was found to be the high cost of the technology. Nevertheless, more and more PA-technologies such as positioning systems and sensors are embedded in new farm machinery and equipment. Therefore, gradually over time it is expected that PA-technologies will increasingly be adopted with ongoing investments. Figure 12.1 shows the evolution of the number of tractors in Europe, USA, Brazil, China and Sub-Saharan Africa (SSA), where tractor density on agricultural land is used as a proxy for the intensity of capital investments in agriculture, (Jepsen et al. 2015).

The figure shows that investments in technology can take place fairly rapidly. In Europe, the number of tractors has increased from 3 to 8 per 100 ha of arable land from 1960 to 1990 as a part of the mechanization in Europe. In 2005, this number has been reduced to 7 tractors per 100 ha in Europe. Within Europe there are major differences because of differences in the farm area per farmer amongst different European countries. With relatively large farms in for instance the UK, France and some East European regions and small farms in Southern Europe.

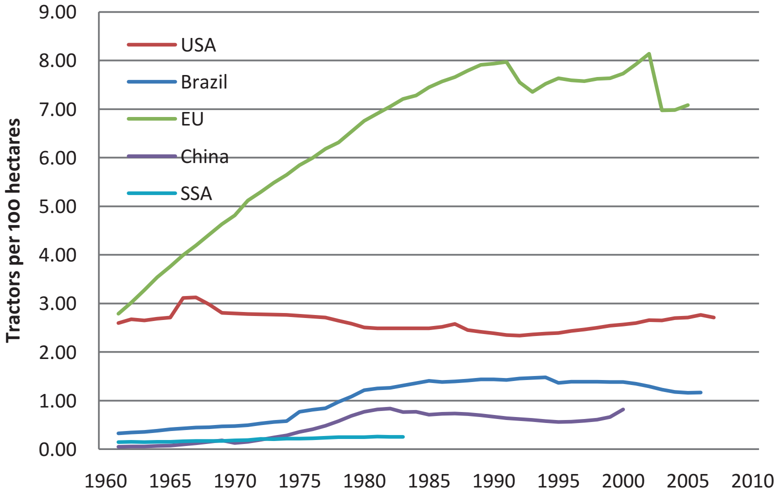

Fig. 12.1 Tractors per 100 ha of arable land (Source: World Bank Development Indicators)

In South America, Brazil more than doubled the number of tractors per hectare in the 1970s. Likewise, the USA can also be seen to have substantial technological investments in certain periods, but on average the number of tractors have been between 2–3 tractors per 100 ha, which to some extent is caused by relatively large farm holdings in the USA. Hence, when the technology is considered beneficial or profitable enough, farmers are willing to undertake significant investments.

This development is not only about increasing numbers of larger and larger farm vehicles. The current development of computers and microchips is likely to speed up the development in precision agriculture. Moore's law says that the number of transistors in a dense integrated circuit doubles approximately every 2 years. Basically, it means that the capacity of microprocessors doubles every second year. A similar trend is seen with regard to the number of pixels per unit costs and other developments in computers and electronics. This trend will provide opportunities for the development of smart farming technology that does not rely exclusively on large machines. In addition, big data have become a term for gathering, storing and analysing large and complex data sets, Marz and Warren (2015), which is being used to analyse and interpret enormous data files at high speeds. Eventually, it is expected that various agricultural processes will benefit from progress in data processing techniques such as weed recognition, soil mapping, plant requirements, etc. Furthermore, this trend is likely to lead to more advanced systems in the future such as autonomous systems at progressively lower costs.

The development towards **integration of the whole food supply chain** is identified as a **third megatrend**. This development enables producers, processors and distributors to comply with sanitary and phytosanitary standards, reduce environmental impacts and target consumer requirements thereby increasing value added in the supply chain. *Traceability* has become a tool for securing safety and quality of the food products in addition to adding value for customers, who increasingly demand information of location and process characteristics, (Dabbene et al. 2014).

Precision agriculture enables retailers and final consumers to trace and control each action in the supply chain and on the field. Traceability has become an argument by manufacturers of GPS-related equipment for adopting precision farming technologies. Although, PA can be a tool to trace the commodity from "field to fork", it will still require an effort to follow and certify the commodity vertically in the food supply chain. From other farm commodities, we have experienced a price premium for organic products and crops with certain local brands. Similarly, it may be possible to obtain a premium for certifying traceability. Nevertheless, it is a presumption that the final consumers are willing to pay for certified traceability. From a stakeholder workshop in Denmark it was concluded that consumers may find PA too complex to understand and explain as a concept of value. Participants at the workshop found it difficult to "brand the concept of precision farming" in the supermarkets compared with for instance organic products (Pedersen et al. 2002).

Other ways of obtaining an extra premium could be from **selective harvesting** if there is a timely variation in crop quality and maturity. In that case, PA can help to identify which subfield is ready to be harvested in order to obtain higher prices of the final product. Selective harvesting requires optimized route planning systems and sophisticated models to predict crop harvest time.

Multifunctionality of agriculture forms a **fourth megatrend**. Agriculture produces a number of outputs in addition to the immediate production objective of the farmer. Consequently, the farmer is required to meet environmental and other objectives demanded by society. These objectives include biodiversity, landscape management, animal welfare, rural settlement and other public goods. In developed countries, such concerns are increasingly shaping agricultural policies, see e.g. Rizoy (2004), where traditional agricultural support is reallocated towards provision of public goods and increased sustainability of agriculture. *Sustainability* issues are high on the political agenda. Precision agriculture has a strong potential to help agricultural policy to meet its objectives by enhancing competitiveness and improving sustainability and effectiveness (i.e. reducing agriculture's impact on the environment as well as using natural resources in a sustainable manner) (EP 2014).

Europe provides 25% of cereal production worldwide (FAO 2012) and winter wheat (*Triticum aestivum* L.) is the most important crop produced in Europe on 56 million hectares. In Europe, the total use of nitrogen is about 20 million tons of which the cereal production uses more than 10 million tons. Currently, most nitrogen application in winter wheat is carried out as uniform application, and often by using the most demanding part of the crop to define the rate of N-application, which often causes leaching or emissions on areas where the nitrogen is not taken up (Robertson et al. 2008). To achieve large grain yields, N additions are necessary, especially in areas with small soil organic matter content. A study from the Netherlands has shown that with the implementation of variable-rate application techniques, cereal yield can be increased by 10% (D. van der Schans et al. 2008). Other studies have shown that by changing the application from uniform to site-specific application based on measured crop needs, savings can be realised in the

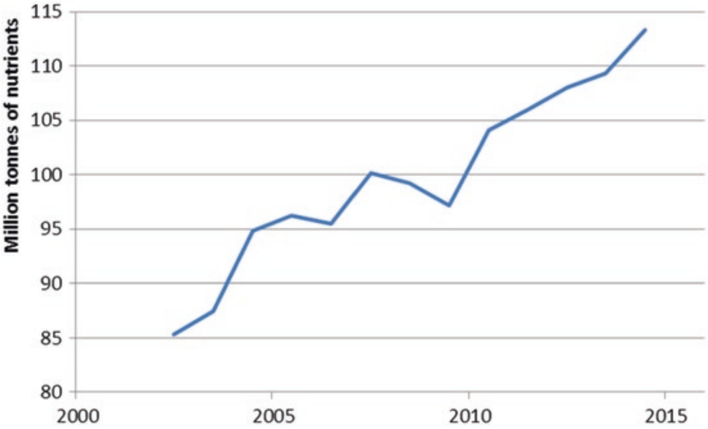

Fig. 12.2 Global production of nitrogen fertilizers 2002–2014 (Source: FAOSTAT)

order of 5% and up to 50% of N in cereals (Scharf et al. 2011; Basso et al. 2012), depending on local soil and production conditions. Additional benefits could come from a reduced usage of nitrogen as well as an increase in grain protein content. Other studies from Denmark have shown little or moderate yields from variable-rate N application based on crop and soil simulation models (Pedersen 2003).

Environmental stress generally increases with more intensive agriculture, which in turn is seen as a prerequisite for productivity increases. Consequently, chemicals such as pesticides, herbicides, insecticides in addition to fertilizers are used increasingly. Figure 12.2 shows the evolution of the global production of nitrogen fertilizers.

Public pressure on the agricultural sector to reduce the negative environmental impact from nitrate leaching, excessive supplies of pesticides and water will increase. Several legal regulations in different regions have been imposed, including quotas and levies on nitrogen application, treatment indices and taxes for pesticides, time limits for irrigation, and recently more focus has been put on phosphorus application (Gachango et al. 2015a; Pedersen 2003 and Pedersen et al. 2013).

The figure shows an increase in nitrogen production of more than 2 million tonnes per year on average. This growth may be necessary to secure the increases in global food production that is required to meet the demands of a growing global population, FAO (2009), however, the substantial yearly increases in nitrogen use presents challenges for the environment and for water resources.

Western nitrogen fertilizers in different forms imported into Europe increased from 6.2 million tons in 2002 to 10.6 million tons in 2014 and Western Europe is currently a net importer of nitrogen (FAOSTAT).

Generally, nitrogen is applied uniformly across fields regardless of site-specific needs and balances. Precision agriculture offers a more targeted approach where sensors detect and identify nitrogen deficiencies much more precisely, which potentially leads to reductions in redundant nitrogen use without complementary decreases in yield. Hence, PA can alleviate stress to the environment and help secure more sustainable agricultural production.

Another example is water consumption in agriculture, (Fraiture and Wichelns 2010). The global demand for water in agriculture will increase over time with increasing population, rising incomes, and changes in dietary preferences. Moreover, increasing demands for water by industrial and urban users, and water for the environment will intensify competition of the limited resources. Precision irrigation can reduce water consumption in high-value crops significantly. In a study of water usage in a citrus orchard (González-Dugo et al. 2013), precision irrigation was able to reduce water use by 25% without reductions in yield. Especially in dry and semi-dry areas, site-specific irrigation is likely to get more attention.

The **fifth megatrend** in agriculture identified by (Rabbinge and Bindraban 2012) concerns **food and health issues**. More and more food consumption is linked to health issues, (Szakaly et al. 2011). Food diets are designed towards specific uses based on diseases, deficiencies and genetic traits. Management of crops and animal husbandry can be improved and optimized by using information gathering sensors mounted on agricultural machinery. Individual animals and plants can, thereby, be monitored and conditional actions related to plant and animal health can be automated or form part of the basis for subsequent farm manager decision making, (OECD 2016). This development is projected to evolve into the management of product quality with increased value added in agricultural products. As precision agriculture may help to reduce nitrate leaching into ground waters, it can be a means to improve the quality of table and drinking water. It may further enable farmers to reduce the application of pesticides, which in turn also affects crop quality and improves drinking water.

The increasing attention given to sustainable agriculture is in part a response to what is seen as the harmful effects of large-scale industrial agricultural systems on the environment and on human health, Horrigan et al. (2002); Gold (2016). Sustainable agriculture includes organic practices and focuses on relatively small integrated farms with less reliance on chemical inputs. Precision Agriculture provides opportunities for decreasing chemical inputs through e.g. site-specific applications and mechanical weeding. Nevertheless, industrial agriculture has achieved high yields, which are reduced in sustainable and organic farming practices. Thus, more land is needed to provide similar production quantities. This is a crucial point in the debate concerning whether land for nature and biodiversity should be segregated from land for production or whether these considerations should be integrated into the production systems, Tscharntke et al. (2012).

The **bio-based economy** is a **sixth megatrend**. A public goods-oriented bio-based economy is based on production paradigms that rely on biological processes and, as with natural ecosystems, use natural inputs, expend minimum amounts of energy and do not produce waste because all materials discarded by one process are inputs for another process and are subsequently reused in the ecosystem, EC (2011). A prominent example is the expansion of bio-based energy production such as ethanol production however, biological products have a variety of different uses which are being explored, Vanholme et al. (2013).

Precision agriculture fits naturally into several of these megatrends. Increasing productivity and reducing resource use is at the root of precision farming. Identifying spatial and temporal variation provides possibilities for the targeted use of resources instead of uniform application, which can lead to significant savings, and is an integral part of the procedures for identifying potential resource reductions. Furthermore, precision agriculture can provide much of the information gathering and traceability necessary for improved integration in the food supply chain. Consequently, the first three megatrends identified in agriculture are well in line with the objectives and capabilities of precision farming technology. Precision agriculture has a strong potential to function as a vehicle allowing farmers to achieve the objectives set by policy makers and society in general concerning environmental and climate issues while simultaneously improving efficiency and competitiveness.

Precision agriculture has the potential to reduce resource use and increase yields by enabling farmers to collect information and improve farm management through better decision-making processes. In particular, variable-rate application promises to reduce environmental stress by using chemicals, fertilisers, water and other resources in a targeted approach. However, variable-rate application technology has yet to demonstrate significant economic benefits for farmers leading to low investment in this technique. Possible environmental gains are often not priced in the markets, which can justify support to obtain the wider societal benefits of positive externalities and public goods production associated with PA. This would be in line with the changing objectives of the Common Agricultural Policy in the EU over the last couple of decades.

Nitrogen is a key to increase productivity and economic returns in crop production. Nitrogen Use Efficiency (NUE) by crops is globally low (between 30 and 50%) (Baligar et al. 2001; Delgado et al. 2010). The need to improve nitrogen efficiencies aimed at reducing the negative environmental impact from losses of nitrogen have been emphasised in relation to surface water, leaching and atmospheric loss, which again contribute to climate change (Li et al. 2007; Dubrovsky et al. 2010; IPCC 2007).

Eutrophication problems in surface water impose negative effects on ecosystems. In practice, only about half of the N fertiliser that is added to today's cropping systems is taken up by the crop (Smil 1999; Robertson and Vitousek 2009). The other 50% remains in the soil or seeps out through the air or water pathways (Mosier et al. 2001).

Fertilisers are important to intensify agricultural production and to ensure food security for the growing population. However, the general public will no longer accept the negative environmental consequences of using fertilisers.

There is a pressure among farmers to **comply with the legislation** (such as Water Framework Directives, Nitrates Directive and River Management Plans) as well as national legislation.

Images from remote sensing show large differences in canopy development that subsequently lead to variation in yield (Primicerio et al. 2012). Crop yield, protein content and nitrate leaching are all functions of nitrogen application. A goal for the farm manager is to improve the financial viability of the farm. For the surrounding society, the goal is to improve overall welfare by reducing negative environmental effects such as nitrate leaching and nitrous oxide emissions. Nitrate leaching from root zone to water and streams is a common consequence of intensive crop production, and the higher the application amounts the greater the leaching. All EU countries are, according to the EU Water Framework Directive, obliged to set up river management plans for their river catchment areas. These plans are detailed descriptions of how targets that are set for the catchment and river basins are to be reached. A recent analysis from the Danish catchment area "Limfjorden" has shown that the marginal costs of reduced nitrogen nitrate leaching from agriculture is around 20–30 € per kg nitrogen N leached to the recipient (Ørum and Jacobsen 2013). Similar costs were found in (Gachango et al. 2015b); The leaching may be regulated by using nitrogen quotas, set aside or other means or by using Variable Rate Nitrogen Application (VRA).

A potential reduction of 2–4 kg N leaching per ha from variable-rate N application with considerable soil variation may be possible. This might lead to an environmental monetary value of EUR 40–120 per ha (Pedersen and Pedersen 2002). Several studies on the performance of VRA have focused on static or historic differences in crop yield and soil type. However, a few models include risk assessment in relation to future precipitation and vegetation indices measured in real time during the growing season. By including these variables it might be possible to reduce nitrate-N leaching even further with more sophisticated models.

12.3 Policy Trends in Europe

Precision agriculture might be able to contribute to achieving the objectives of the EU common agricultural policy by integrating at a large scale across Europe a group of advanced technologies that will enhance resource use efficiency (N fertilizer), while increasing grain quality and yields. Precision farming could potentially contribute to improved farm incomes in addition to improving the competitiveness of the agricultural sector by enabling agriculture to improve efficiency. Through the integration of existing PA technologies, PA may foster green growth through innovation, highlighting the role of agriculture in preserving natural resources and in contributing to the solution of global environmental challenges as well as preserving local natural habitats and environmental goods.

In Europe, the **CAP-reform** process beginning in 1992 has increasingly changed the focus of agricultural policies from traditional production support towards broader societal goals based on multifunctionality and sustainability, Jensen et al. (2009). The CAP has been restructured to two pillars, where the first covers traditional agricultural support and the second is support founded on community preferences. Thus, pillar 2 policies are implemented through national or regional rural development programmes, which are based upon at least four of the six common EU priorities, EC (2013):

1. Fostering knowledge transfer and innovation in agriculture, forestry and rural areas.
2. Enhancing farm viability and competitiveness of all types of agriculture in all regions and promoting innovative farm technologies and sustainable management of forests.

3. Promoting food chain organisation, including processing and marketing of agricultural products, animal welfare and risk management in agriculture.
4. Restoring, preserving and enhancing ecosystems related to agriculture and forestry.
5. Promoting resource efficiency and supporting the shift towards a low carbon and climate resilient economy in agriculture, food and forestry sectors.
6. Promoting social inclusion, poverty reduction and economic development in rural areas.

The set of priorities listed and the range of measures under pillar 2 listed in **Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013** offer opportunities for supporting investment in and dissemination of precision agriculture technology. Moreover, the regulations open possibilities for supporting knowledge transfer, advisory services, training and extension by which information of PA technology and decision support tools can be disseminated among farmers. The requirements for documentation of environmentally-friendly agricultural production for instance in relation to the EU directives concerning nitrate and pesticides provide arguments for supporting implementation of PA technology. Specifically, variable-rate application technology has hitherto not been shown to provide appreciable economic benefits, which would otherwise induce investments by farmers in this technology. Therefore, if the societal values from the environmental and climatic benefits that can be obtained by variable-rate application are to be realised, subsidies for this technology are needed and could be provided through pillar 2 measures. The economic benefits of controlled traffic farming and auto-guiding systems are documented better, thus these technologies should disseminate organically across agriculture.

Precision agriculture will contribute to **a more resource efficient Europe** because it will increase N efficiency and fuel efficiency, reducing reliance on the import of fertilizers that is very energy-dependent. Consequently, the application of technologies that improve N use efficiency is important to improve raw material supply in Europe.

- **Precision agriculture**: directly addresses major EU policies such as the Water Framework Directive, the Nitrates Directive, the Ground Water Directive and the Common Agricultural Policy. Precision agriculture will in its most advanced form become a decision making system that integrates real-time crop status information, data based on field history, weather and economic forecasts and a web-based agronomic decision support system. Integration of all these variables will result in improved and better decision making capacity for farm managers.
- **Traceability**: Precision agriculture will allow the farmer to trace the amount of N used, facilitating record-keeping and compliance with EU environmental regulations including vulnerable areas.
- **Usability:** Precision agriculture places the farmer at the centre of the system by providing a real-time service specifically tailored to the end-user needs and aimed at facilitating decision making, but still relying on farmers' perception.

- **Module-ability:** Precision agriculture will integrate several pre-existing modules that could be substituted or improved according to the end-users' needs and technology availability (local crop models, local decision making systems, local UAV providers.

The need for a European approach is justified by: nitrogen fertilization has a high priority in the European environmental legislation as reflected in the **Water Framework Directive,** which describes the targeted level of good qualitative status of all water bodies such as a good biological status and a good chemical status, and The **Nitrates Directive** that aims to reduce pollution by nitrate leaching.

Furthermore, the **Common Agricultural Policy** and in particular the **cross compliance scheme, the greening measures** and **the rural development programme** couple subsidies to farmers with mandatory minimum levels of agro-environmental criteria.

According to the EU Directive on the sustainable use of pesticides, it is stated that EU Member States must take measures to promote low pesticide inputs and better pest management. Member States should also produce a system for the implementation of integrated pest management that ensures farmers have sufficient information, tools for pest monitoring and advisory services on pest management. Here again PA could fulfil these objectives.

The EC **Air Quality Framework Directive from 2008** and **KYOTO protocol** for the reduction of CO_2 emissions aim to reduce the use of fossil fuels. Precision Agriculture and auto-steering systems might help to reduce overlaps and thereby fuel consumption by around 5% (Jensen et al. 2012).

The EC Habitats Directive on the conservation of natural habitats and of wild fauna and flora: Here the adoption of site-specific weed management may improve the natural habitats and wild fauna and flora in relation to reduced use of herbicides.

> Weed management is not only targeted to address the needs of the crops but also on economic, environmental and other social aspects in accord with the requirements from the UN Sustainable Development Goals. These are translated into "Good Agricultural Practices" on a global and multinational level by the FAO and EU.

12.4 Stakeholder Involvement

Precision agriculture involves people from a wide range of disciplines including agronomists, remote sensing experts, environmental consultants, agricultural engineers, economists, farmers' advisors, etc. It requires a wealth of knowledge including local and regional farming conditions. All this expertise can rarely be found in a single European country, thus it requires international cooperation to provide the best technology development and decision support tools. A number of stakeholders should be included to improve the adoption of PA systems: policy makers, industry and society, farmers' associations and cooperatives. In addition, public and private advisory services, national, regional and representatives of agricultural authorities (ministries, departments and agencies) have interests related to CAP greening regulations and cross compliance regulations.

Organizations in the field of sustainable agriculture; Research networks and initiatives on precision agriculture and organization, agricultural machinery are also likely to be impacted by the development of the technology. Thus, Commercial exploitation and training of users of PA systems will have to be organised and receive training and extension material developed with plans to improve technology transfer of PA technologies within the following areas:

- Remote sensing applications, including Satellite, Aerial and UAV image applications to help to improve:
- In-field and groundbased detection of nitrogen content in plants
- Groundbased weed detection and weed mapping
- Soil conductivity mapping and (pH) maps to aid lime application
- Weed and fertilizer maps and DSS for fertilizer and pesticide applications

Moreover, precision agriculture and new technology products have to be compliant with the **Environmental Technology Verification programme** of the European Union. In addition, PA should also be in line with the Cross Compliance aspects of the CAP, including Greening, complying with the Statutory Management Requirements as well as maintaining **Good Agricultural and Environmental Conditions** (GAEC).

Social innovation PA will contribute to the digital agenda in the EU by delivering innovative and high-tech services to farmers that will introduce ICT in agriculture, thus contributing to bridging the digital gap in the EU among farmers. This agenda will also help to attract new students to the agricultural colleges and to farm business as such.

Students that have previously been reluctant to enter the farm business may be attracted with a combined interest in both modern technology and traditional farming practices.

12.5 Opportunities for Small and Medium Size Companies

Precision agriculture may also provide market opportunities in the short and medium term given the following:

The current prospects for the PA market to grow are significant in the coming years because of larger farm holdings, professionalization and modernization of technology and technical developments in Information Technology with faster computers for data handling. For instance, Byrne et al. (2013) project a continued rapid pace of advances in semiconductor technology, a key ingredient in the IT evolution, which is an essential part of PA-technology. Furthermore, the rate of decline in prices of microprocessors show no signs of levelling off.

Start-ups and small business companies emerging from precision agriculture migth develop in the short and medium term as a consequence of the dissemination of PA systems. These emerging companies will be closely related to the structure of the agricultural economies of the different countries involved. Local advisors that use PA technologies with agronomic knowledge can provide green IT jobs to young people that are entering the job market.

Local machinery cooperatives will provide PA machinery needed for the application of the N fertilization plan.

In general, precision agriculture technologies might also contribute to building a commercial farm advisory system with combined knowledge on technological, agronomic and economic aspects from various research and development projects throughout Europe. In other parts of the world we see similar developments. In the **US, agricultural policies** have developed in tandem with the CAP through successive farm bills towards a focus on public goods and sustainability issues, although at lower levels than in the EU. The agri-environmental policies include new technologies such as precision agriculture as part of best management practices, Reimer (2015). Public investments and policy reforms will support landscape management practices to be used by farmers and ranchers for sustaining food and ecosystem security. Although U.S. farms have provided increasing supplies of food and other products, they have also been major contributors to global greenhouse gases, loss of biodiversity, natural resource degradation and public health problems, Reganold et al. (2011). Furthermore, it is recognised that to improve sustainability of U.S. agriculture, practices and technologies that address specific production or environmental concerns associated with mainstream conventional farming systems, new approaches are needed that include 2-year crop rotations, precision agriculture with geospatial technologies that describe field variation, classically bred or genetically engineered crops and reduced or no tillage.

12.6 Concluding Remarks

Agriculture is faced with contrasting opposing requirements from the broader society. On the one hand, agriculture needs to expand production to be able to feed a growing global population. Moreover, agriculture is required to produce for several other objectives including energy, textiles, chemicals, and so on. On the other hand, concerns over the environment, climate, biodiversity and other public goods place restrictions on conventional agricultural production. Precision agriculture can be part of the response to these often conflicting issues. Furthermore, the growing demand for higher value food products in terms of human health and quality that require traceability and information about production processes and resource use corresponds with the possibilities offered by precision agriculture technology. The general movement towards greater integration in food supply chains is a natural extension of the requirements for traceability and product information.

Regardless of the societal benefits, the main purpose for investing in new technology is an increase in profitability. For controlled traffic farming and auto-guidance systems, the economic benefits are significant and well documented. However, the promising properties of variable-rate application have so far been realised only by subsidising dissemination of the technology. In Europe, the trend in the reform of the common agricultural policy towards supporting the multifunctionality of agriculture including environmental and climate friendly production provides opportunities for supporting investments in PA technology. Hence, PA's promises of increasing production with reductions in resource use can become available to farmers in Europe.

References

Baligar VC, Fageria NK, He ZL (2001) Nutrient use efficiency in plants. Commun Soil Sci Plant Anal 32:921–950

Basso B, Sartori L, Cammarano D, Grace PR, Fountas S, Sorensen C (2012) Environmental and economic evaluation of N fertilizer rates 1 in a maize crop in Italy: a spatial and temporal analysis. Biosyst Eng 113:103–111

Bindraban PS, Rabbinge R (2012) Megatrends in agriculture – Views for discontinuities in past and furure developments. Glob Food Sec 1:99–105

Byrne DM, Oliner SD, Sichel DE (2013) Is the information technology revolution over? March 27, 2013. Available at SSRN: https://ssrn.com/abstract=2240961 or https://doi.org/10.2139/ssrn.2240961

Dabbene F, Gay P, Tortia C (2014) Traceability issues in food supply chain management: A review. Biosyst Eng 120:65–80

de Fraiture C, Wichelns D (2010) Satisfying future water demands for agriculture. Agric Water Manag 97:502–511

Delgado JA, Del Grosso SJ, Ogle SM (2010) 15546 N Isotopic crop residue cycling studies and modeling suggest that IPCC methodologies to assess residue contributions to N2O-N emissions should be reevaluated. Nutr Cycl Agroecosyst 86:383–390

Doll JP, Orazem F (1978) Production economics, theory with applications, 2nd edn. Wiley, New York

Dubrovsky NM, Burow KR, Clark GM, Gronberg JAM, Hamilton PA, Hitt KJ, Mueller DK, Munn MD, Puckett LJ, Nolan BT, Rupert MG, Short TM, Spahr NE, Sprague LA, Wilbur WG (2010) The quality of our nation's waters – nutrients in the nation's streams and groundwater, 1992–2004. Circular-1350, U.S. Geological Survey

European Commission (2011) Bio-based economy in Europe: state of play and future potential – Part 2. Directorate-General for Research and Innovation, Food, Agriculture & Fisheries, & Biotechnology

European Commission (2013) Overview of CAP reform 2014-2020. Agricultural Policy Perspectives Brief no 5

European Parliament (2014) Precision agriculture: an opportunity for EU farmers – potential support with the CAP 2014-2020. Directorate-General for Internal Policies, Food, Agriculture and Rural Development

FAO (2009) How to feed the world in 2050. Food and Agriculture Organization of the United Nations, Rome

FAOSTAT (2012) www.faostat.fao.org

Gachango FG, Andersen LM, Pedersen SM (2015a) Adoption of voluntary water-pollution reduction technologies and water quality perception among Danish farmers. Agric Water Manag 158:235–244

Gachango FG, Pedersen SM, Kjærgaard C (2015b) Cost-effectiveness analysis of surface flow constructed wetlands (SFCW) for nutrient reduction in drainage discharge from agricultural fields in Denmark. Environ Manag 56(6):1478–1148

Gold MV (2016) Sustainable agriculture: the basics. Ch. 1. In: Etingoff K (ed) Sustainable agriculture and food supply scientific, economic, and policy enhancements. Apple Academic Press, Oakville

González-Dugo V, Zarco-Tejada PJ, Nicolás E et al (2013) Using high resolution UAV thermal imagery to assess the variability in the water status of five fruit tree species within a commercial orchard. Precis Agric. https://doi.org/10.1007/s11119-013-9322-9

Horrigan L, Lawrence RS, Walker P (2002) How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environ Health Perspect 110(5):445–456

IPCC (Intergovernmental Panel on Climate Change) (2007) Summary for policymakers. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge. https://www.ipcc-wg1.unibe.ch/publications/wg1ar4/ar4-wg1-spm.pdf

Jensen MS, Lind KM, Zobbe H (2009) Enlargement of the European Union and agricultural policy reform. J Eur Integration 31:329–348

Jensen HG, Jacobsen LB, Pedersen SM, Tavella E (2012) Socioeconomic impact of widespread adoption of precision farming and controlled traffic systems in Denmark. Precis Agric 13:661–677

Jepsen MR et al (2015) Transitions in European land-management regimes between 1800 and 2010. Land Use Policy 49:53–64

Lawson LG, Pedersen SM, Sørensen CAG, Pesonen L, Fountas S, Werner A (2011) Four nation survey of farm information management and advanced farming systems: a descriptive analysis of survey responses. Comput Electron Agric 77(1):7–20

Li X, Hu C, Delgado JA, Zhang Y, Ouyang Z (2007) Increased nitrogen use efficiencies as a key mitigation alternative to reduce nitrate leaching in north China Plain. Agric Water Manag 89:137–147

Malthus TR (1798) An essay on the principle of population. J. Johnson, London

Marz N, Warren J (2015) Big Data: Principles and best practices of scalable realtime data systems. Manning Publications Co., Shelter Island

Mosier AR, Bleken MA, Pornipol C, Ellis EC, Freney JR, Howarth RB, Matson PA, Minami K, Naylor R, Weeks KN, Zhu Z (2001) Policy implications of human-acceleratednitrogen cycling. Biogeochemistry 52:281–320

OECD (2016) Farm management practices to foster green growth. OECD Publishing, Paris

Ørum JE, Jacobsen BH (2013) Økonomisk konsekvens ved ændret kvælstofregulering – med udgangspunkt i Limfjorden. Notat til Natur- og Landbrugskommissionen. (Economic assessment of models for regulation of nitrogen leaching – case water catchment area Limfjord). Institute of Food and Resource economics, University of Copenhagen

Pedersen SM (2003) Precision farming – technology assessment of site-specific input application in cereals. Department of Manufacturing Engineering and Management, Technical University of Denmark. Ph.D dissertation, 343 p

Pedersen SM, Pedersen JL (2002) Economic and environmental impact of site specific N-Application – based on different weather conditions and arable crops. In: Robert PC (ed) Proceedings of the 6th international conference on precision agriculture. Minneapolis, pp 1814–1825

Pedersen SM, Pedersen JL, Gylling M (2002) Perspektiverne for præcisionsjordbrug. Danish research institute of food economics, FOI working paper no. 6/2002

Pedersen SM, Boesen MV, Ørum JE (2013) Institutional and structural barriers for implementing on-farm water saving irrigation systems. Food Econ 9(sup5):11–26

Primicerio J, Gennaro SFD, Fiorillo E, Genesio L, Lugato E, Matese A (2012) A flexible unmanned aerial vehicle for precision agriculture. Precis Agric 13:517–523

Rabbinge R, Bindraban PS (2012) Making more food available: promoting sustainable agricultural production. J Integr Agric 22:1–8

Reganold JP et al (2011) Transforming US agriculture. Science 332:670–671

Reichardt M, Jürgens C (2008): Adoption and future perspective of precision farming in Germany: results of several surveys among different agricultural target groups. February 2009, 10(1):73–94

Reimer A (2015) Ecological modernization in US agri-environmental programs: trends in the 2014 Farm Bill. Land Use Policy 47:209–217

Rizoy M (2004) Rural development and welfare implications of CAP reforms. J Policy Model 26:209–222

Robertson GP, Vitousek PM (2009) Nitrogen in agriculture: balancing the cost of 722 an essential resource. Annu Rev Environ Resour 34:97–125

Robertson MJ, Lyle G, Bowden JW (2008) Within-field variability of wheat yield and economic implications for spatially variable nutrient management. Field Crop Res 105:211–220

Scharf PC, Shannon DK, Palm HL, Sudduth KA, Drummond ST, Kitchen NR, Mueller L, Hubbard VC, Oliveira LF (2011) Sensor-based nitrogen applications out-performed producer-chosen rates for corn in on-farm demonstrations. Agron J:1683–1691

Smil V (1999) Nitrogen in crop production: An account of global flows. Glob Biogeochem Cycles 13:647–662

Szakály Z, Szente V, Kövér G, Polereczki Z, Szigeti O (2011) The influence of lifestyle on health behavior and preference for functional foods. Appetite 58(1):406–413

Tscharntke T, Clough Y, Wanger TC, Jackson L, Motzke I, Perfecto I, Vandermeer J, Whitbread A (2012) Global food security, biodiversity conservation and the future of agricultural intensification. Biol Conserv 151(1):53–59

Van der Schans D, Nammen JJ, van der Klooster A, Molenaar K, Krebbers H, Korver R, van Roessel G, Meertens L, Truiman J (2008) Toepassing GPS en GIS in de akkerbouw – Nut en rendement van toepassingen op het gebied van geolandbouw. Praktijkonderzoek Plant & Omgeving B.V., Business-unit AGV, PPO nr. 3250062000

Vanholme B, Desmet T, Ronsse F, Rabaey K, Van Breusegem F, De Mey M, Soetaert W, Boerjan W (2013) Towards a carbon-negative sustainable bio-based economy. Front Plant Sci 4:174

World Bank (2017) Word development indikators database,www.worldbank.org