## *Chapter 6*

# Is precision agriculture the start of a new revolution?

*Precision agriculture is a whole-farm management approach with the objective of optimising returns on inputs, while improving agriculture's environmental footprint. Precision farming is a relatively new management practice which has been made possible by the development of information technology and remote sensing. A wide range of technologies is available, but the most widely adopted precision farming technologies are knowledge-intensive. Information on precision agriculture adoption is based on sporadic and geographically dispersed surveys as countries do not regularly collect data. Although the main focus of precision agriculture has been on arable crop production, precision farming technologies are also applicable to the entire agro-food production system (i.e. animal industries, fisheries, forestry). This chapter examines the concept and use of precision farming in OECD countries, the key impediments to nurturing its green growth potential, and its impact on resource efficiency and productivity.*

## Key messages

- Data on farmers' use of precision-agriculture technology are sparse as countries do not usually collect such data.
- Adoption of precision-agriculture technologies is limited to only a few countries and sectors (mainly arable crops).
- The most widely adopted precision farming technologies are GPS guidance.
- Significant efficiency and resource productivity gains can be achieved on arable crops, particularly where intra-field variability in yield is high.
- Knowledge and technical gaps, high start-up costs with a risk of insufficient return on investment, and structural and institutional constraints are key obstacles to the adoption of precision agriculture by farmers.
- Precision agriculture has a substantial role to play in fostering green growth in agriculture in OECD countries, but the prevalence of small-size farms in several countries makes widespread adoption problematic.

## Applying the right treatment in the right place at the right time

Precision farming is a relatively new management practice which has been made possible by the development of information technology and remote sensing. Precision agriculture entails the application of technologies and agronomic principles to manage the spatial and temporal variability associated with all aspects of agricultural production – both crops and livestock (Box 6.1).

In particular, precision farming, defined as a systems approach to optimise crop yields through systematic gathering and handling of information about the crop and the field, has the potential to contribute to nutrient management by tailoring input use and application more closely to ideal plant growth and management needs.

Understanding of the precision agriculture concept is often limited to variable rate technologies, which enable a site-specific supply of agricultural inputs. But technological possibilities associated with precision farming cover a great range – from automatic data acquisition and documentation over site-specific fertilisation, to optimised fleet management (Auernhammer, 2001). The term encompasses many technologies providing more precise information about the managed resources and at the same time allowing the farmer to respond to in-field variations by allocating inputs, such as fertiliser and irrigation, in a targeted manner, rather than coming out indiscriminate field-level operations, with sub-optimal efficiency.

Crop management and aspects of animal rearing can be optimised, through the use of information collected from sensors mounted on-board agricultural machinery (soil properties, leaf area, animal health), or derived from high-resolution, remotely sensed data (plant physiological status). Over the years, emphasis has changed from simply "farming by soil", through variable-rate technologies, to vehicle guidance systems and will evolve to product quality and environmental management. The definition of precision agriculture is still evolving as technology changes and our understanding of what is achievable grows (McBratney et al., 2005).

Although the main focus of precision agriculture up to date has been on arable crop production, precision farming technologies are also applicable to the entire agro-food production system (i.e. animal industries, fisheries, forestry). The use of precision agriculture techniques on arable land is the most widely used and most advanced amongst farmers. Precision agriculture is most advanced amongst arable farmers – particularly those with large farm sizes – in the main arable-crop growing areas of

Europe, the United States and Australia, who have well developed business models to maximise profitability.

Perhaps the most successful example of precision farming, on arable land is the use of Controlled Traffic Farming (CTF) technology – a whole-farm approach that aims at avoiding unnecessary crop damage and soil compaction by heavy machinery caused by standard methods, thereby reducing costs.[1] In particular, farmers in Australia and the United Kingdom have been able to reduce machinery and input costs up to 75% in some cases, while at the same time increasing crop yields (Tulberg et al., 2007; Bowman, 2008).

Precision-agriculture technologies are applied to a wide range of field and horticultural crops, such as: maize, soybean, potato, wheat, sugar beet, sugarcane, barley, sorghum, cotton, oat, rice, wine grape, citrus, bananas, tea, date palm, tobacco, olive, tomato and kiwifruit (Bramley, 2009). The development and adoption of precision-agriculture technologies and methodologies in viticulture are more recent than has been the case for arable land. Precision-livestock farming focuses on: the automatic monitoring of individual animal, milk and egg production; the early detection of diseases; and monitors animal behaviour, productivity and the physical environment (such as the thermal micro-environment and emissions of gaseous pollutants).

The precision agriculture management approach currently relies almost entirely on the private sector, which offers services, devices and products to the farmers. Public-sector involvement is generally very limited, notwithstanding the growing policy interest in the role of innovations for increasing productivity sustainability. An example of a recent public initiative aimed at the "mainstreaming of precision farming" is the creation of a focus group in the European Union under the European Innovation Partnership on Agricultural Productivity and Sustainability. The initial priorities of the group are to look at data capture and processing, but it is envisaged that the process will be expanded to encompass evidence-based benchmarking of precision-agriculture performance and impact evaluation.

Available data on adoption rates are fragmented and often dated because countries do not regularly collect data on the use of precision agriculture, while manufacturers and precision agriculture dealers rarely revealing their sales data. Evidence on the use of precision agriculture relies mainly on information from sporadic and geographically dispersed surveys; an accurate measurement of the rate of adoption and the various technological practices is thus problematic.

### Box 6.1. What is precision agriculture?

Precision agriculture is a broad term. For some, it means using the auto-steer capability in their tractor and for others it means applying site-specific herbicide using a pre-programmed map. Over the years, the emphasis has moved from variable-rate technologies to vehicle guidance systems to yield mapping. The term first came into popular use with the introduction of Global Positioning Systems (GPS) and Global Navigation Satellite Systems (GNSS), and other methods of remote sensing, which allowed farm operators to create precision maps of their fields that provide detailed information on their exact location while in-field. Five main groups of technologies used in precision agriculture can be distinguished:

- Geographical Information Systems (GIS): software to manage spatial data.
- Global Positioning Systems (GPS): which provide the topographic information of the positions used in GIS although for in-field accuracy differential, GPS is needed.
- Sensors to make measurements of soil properties, pests, crop health, etc. in order to vary management operations accordingly. They are either placed on the field and their signal picked up by hand-held devices or devices placed on tractors, or are part of remote sensors, which take aerial or satellite photographs.
- Yield Monitoring: measures the crop yield during harvest, providing a yield map with information on production and variability.
- Variable Rate Technology: this combines a variable-rate control system in order to apply inputs at a precise location. This is the approach used to achieve site-specific application rates of inputs.

*Source*. Adapted from Zarco-Tejada et al. (2014), *Precision Agriculture: An opportunity for EU farmers – potential support with the Cap 2014-200*, www.europarl.europa.eu/RegData/etudes/note/join/2014/529049/IPOL-AGRI_NT(2014)529049_EN.pdf.

In summary, the results of analysed adoption studies show similar tendencies for selected OECD countries:

- Adoption rates of precision agriculture technologies have not been as rapid as previously envisaged
- Adoption rates of auto guidance systems are higher compared with variable rate technologies
- The percentage of farmers who have adopted data collection (diagnostic) techniques is higher than the percentage of farmers who are actually using this information for site-specific management.

The overall conclusion of the available studies is that farm-level adoption of precision agricultural technologies has been low, uneven – both geographically and temporally – and often lags behind the initial expectation (e.g. Bramley, 2009; Evans et al., 2013; Lamb et al., 2008; Reichardt and Jürgens, 2009; Griffin et al., 2010; Mandel et al., 2011).

Notwithstanding the low adoption rate, the number of farmers using precision agriculture technologies has been growing steadily over the last decade: in Germany, from 2001 to 2006 the proportion of farmers using precision agriculture grew from 7% to 11%, while the rate of un-informed farmers dropped from 46% to 28% (Reichardt et al., 2009); among the grain growers of Australia, it increased from 5% in 2006 to 20% in 2012 (Robertson et al., 2012), and a survey in Ohio (United States) showed that by 2010 39% of all farms and 48% of farmers with gross sales over USD 100 000 had already adopted precision agriculture (Diekmann and Batte, 2010).

In the European Union, uptake remains modest, and is mostly concentrated on the large and more business-oriented farms in the main grain growing areas of the EU (Zarco-Tejada et al., 2014). Use of nitrogen sensors for fertiliser application is very high, probably because it helps farmers to comply with the EU nitrate regulation and also because it receives government support. There is growing interest in GPS guidance, especially in areas with relatively large farms, such as eastern Germany and farmers are also becoming aware of the possibilities of CTF technology on arable land.[2] Adoption of precision agriculture for fruits and vegetables and viticulture is more recent than for arable farming, with a rapid increase in the adoption of machine vision methods.[3] In high-value fruit and vegetable crops, precision irrigation methods are being developed in order to save water, increase yields and improve quality, while automatic monitoring of individual animals is used for animal growth, milk and egg production and the detection of diseases, as well as for monitoring animal's behaviour and physical environment.

The basic patterns observed so far in the adoption of precision agriculture technologies are likely to continue into the foreseeable future: adoption is likely to expand faster in those places where input use in agriculture is already relatively efficient and in labour-scarce, land-abundant countries (e.g. Australia, the United States, Canada), with rates of adoption accelerating when commodity prices are high and interest rates low: adoption is likely to expand more slowly in land-scarce, but labour- and capital-abundant countries (e.g. Europe) (Swinton and Lowenberg-DeBoer, 2001).

The following paragraphs present examples of the rates of adoption for selected OECD countries (Australia, the United States, United Kingdom and Germany) and an attempt will be made to identify country specific trends in terms of adopted technologies and crops, respectively.

### *Australia: A leader of GPS guidance technology*

A survey by Robertson et al. (2012) finds that 20% of Australian grain growers have implemented precision agriculture technologies to manage variable inputs. Jochinke et al. (2007) surveyed farmers from the Wimmera Conservation Farming Association in 2006 and found that 42% of members had adopted precision agriculture technologies. Detailed results of the survey are listed in Table 6.1. As shown in this table, steering and auto-guidance systems belong to the most important implemented precision agriculture technologies. Jochinke et al. (2007) mention that their results are comparable to the situation in other regions in Australia.

As noted earlier, Australia has led the way in use of GPS guidance (the CTF approach). The use of the Control Traffic Farming (CTF) has been reported to reduce fuel consumption by a further 50% from Zero-Till systems (Tullberg, 2009). Yet, data available from an Australian Bureau of Statistics survey indicates that CTF is now being implemented by only about 25% of farms.[4]

**Table 6.1. Precision agriculture tools used by Wimmera Conservation Farming Association members in 2006**

| Precision agriculture tool | | All respondents (%) (N=146) |
|---|---|---|
| **Steering/guidance** | | |
| Auto-steer | 2 cm | 16 |
| Auto-steer | 10 cm | 13 |
| Auto-steer | < 100 cm | 2 |
| Visual guidance-sub 1 m, including light bars | | 27 |
| Marker arms | | 1 |
| **Other** | | |
| Yield maps | | 14 |
| Aerial photos | | 3 |
| Electromagnetic 38 or Gamma radiometric soil surveys | | 3 |
| Sowing equipment with variable rate technology | | 2 |
| Auto depth on sowing equipment | | <1 |

*Source*: Adapted from Jochinke, D.C., B.J. Noonon, N.G. Wachsmann and R.M. Norton (2007), "The adoption of precision agriculture in an Australian broadacre cropping system—Challenges and opportunities", *Field Crops Research*.

There is public sector research in precision agriculture for viticulture, as well as an interest in precision agriculture for sugar, which is being driven by economic and environmental concerns. Tullberg et al. (2007) have described the high adoption rates of this technology in Australian cropping systems.

*United States: Increasing adoption of yield monitoring technology*

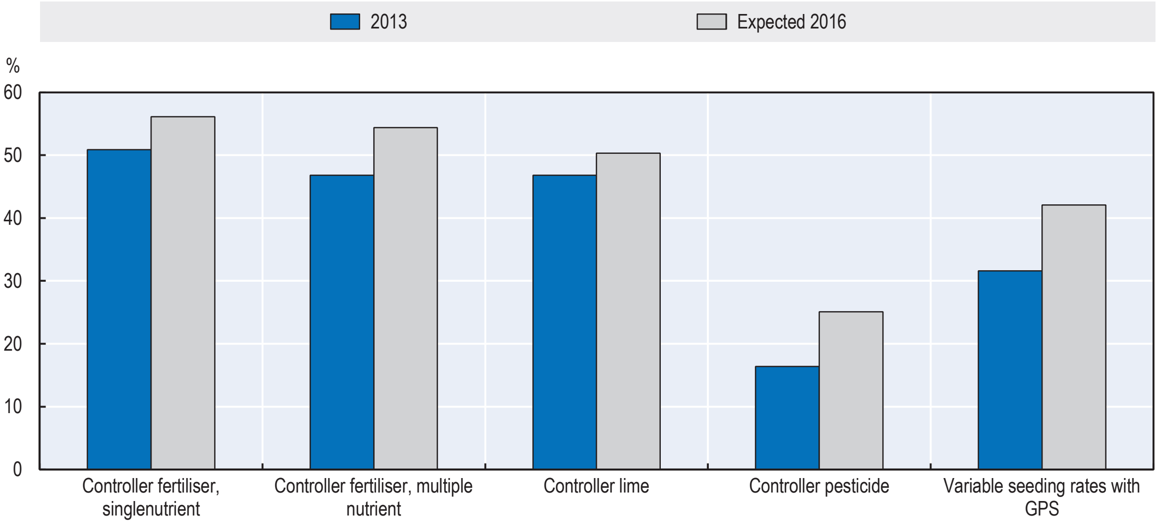
Using Agricultural Resource Management Survey (ARMS) data collected over the past 10 years, an USDA/ERS report found that adoption by farmers of the main precision information technologies – yield monitors, variable-rate applicators and GPS maps – has been mixed (Schimmelpfenning and Ebel, 2011). While yield monitoring – often a first step in the utilisation of precision technology for grain crop producers – has grown most rapidly (being used on over 40% of grain crop area), farmers have mostly chosen not to complement this yield information with the use of detailed GPS maps or variable-rate input applicators that capitalise on the detailed yield information. Farm operator education, technical sophistication and farm management acumen are among the factors cited in the report that could be contributing factor in this adoption lag.

The study reports that yield monitors are being adopted more quickly by farmers who practice conservation tillage. Adoption of guidance systems, which notify farm equipment operators as to their exact field position, is showing a strong upward trend, with 35% of wheat producers using it by 2009. Farmers who adopted of yield monitors achieved higher maize and soybean yields than non-adopters. Even though the adoption of GPS mapping is less prevalent than yield monitors, both maize and soybean farmers achieved higher yields nationwide when GPS was used. Likewise, when variable-rate technology was used to apply fertiliser, higher yields were obtained for both crops. Average fuel expenses, per area planted, for both maize and soybean are lower for farmers who use yield monitors. Variable-rate technology for fertiliser application is associated with lower fuel expenses for both maize and soybeans.

The precision agriculture services dealership survey, conducted biennially, provides an extensive data source on the use of precision agriculture technologies and offers of related services by US dealerships (Holland et al., 2013). Figure 6.1 illustrates that in 2013 more than 50% of surveyed crop input dealers in the US offered variable rate application services for single nutrients. For multi-nutrient applications, dealerships reported slightly lower adoption rates. The projections for 2016, made by survey participants, show expectations of increased demand in areas of variable rate seeding and variable rate pesticide use.

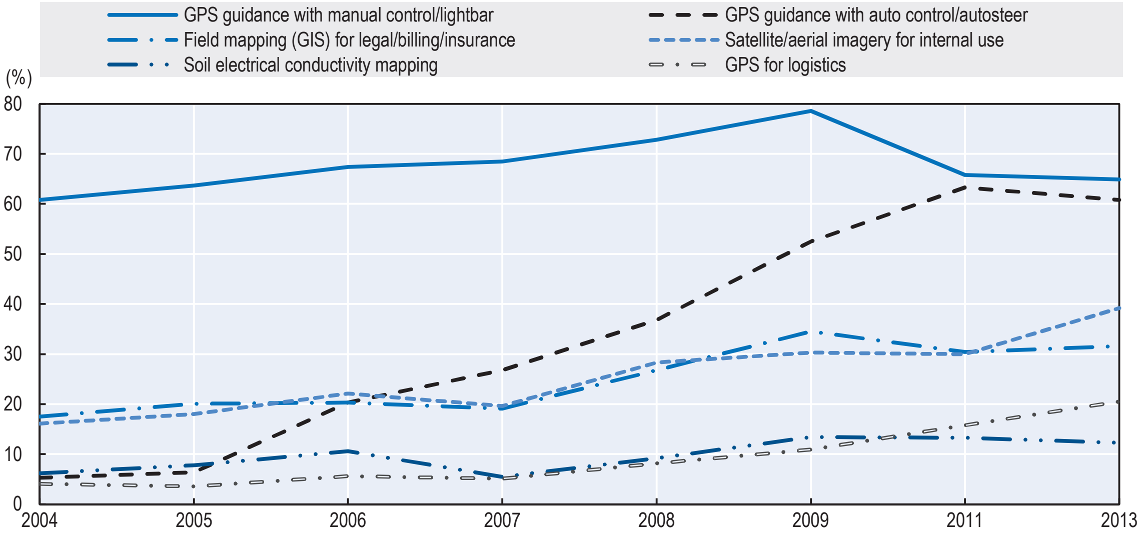
Figure 6.2 shows the adoption of precision technologies by service providers from 2004-13. GPS guidance with auto control (auto-steer) shows the highest positive changes in terms of adoption rates over time. Other technologies, like field-mapping or GPS for logistics, show increasing adoption rates, albeit, on a much lower level compared to GPS guidance with auto control (auto-steer).

**Figure 6.1. Variable rate application of precision technology**



*Note:* 171 survey respondents in 34 states.
*Source*: Adapted from Holland, J.K., B. Erickson and D.A. Widmar (2013), *2013 Precision Agricultural Services Dealership Survey Results*.

**Figure 6.2. Adoption of precision agriculture technology over time by service providers**



*Note. 171 survey respondents in 34 states.*
*Source*: Figure 20 in Holland, J.K., B. Erickson and D.A. Widmar (2013), *2013 Precision Agricultural Services Dealership Survey Results*.

### *Germany: Increasing adoption by farmers*

Reichardt and Jürgens (2009) provide the most current and comprehensive data regarding the adoption of precision agriculture technologies by German farmers. Their study showed that the percentage of precision farmers increased from about 7% in 2001 to more than 10% in 2007. The study found that most farmers who have adopted precision farming technologies are more active in terms of data collection techniques compared to variable rate application techniques.

### *United Kingdom: Increasing adoption by farmers*

In England, GPS technologies, particularly auto-steering and auto-guidance systems, were adopted by 22% of surveyed farms in 2012. Adoption of other precision agriculture applications (soil sampling technologies, variable rate application techniques or yield mapping) increased between 2009 and 2012 (Table 6.2).

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 the farmers in the 2012 survey who did not use any technique claimed that they were not cost effective and/or the initial setup costs were too high; 28% said they were not suitable or appropriate for the type or size of farm concerned; and a similar 27% said that they were too complicated.

**Table 6.2. Proportions of farms using precision farming techniques**

| | 2009 | 2012 |
|---|---|---|
| **Technique** | **% of holdings** | |
| GPS (Global Positioning System)* | 14 | 22 |
| Soil mapping | 14 | 20 |
| Variable rate application | 13 | 16 |
| Yield mapping | 7 | 11 |
| Telemetry | 1 | 2 |

*Note*. Based on responses from a minimum of 1392 farms in 2009 and 2731 in 2012.

*Source*: Adapted from Department for Environment, Food and Rural Affairs (DEFRA) (2013), *Farm Practices Survey Autumn 2012- England*, www.gov.uk/government/uploads/system/uploads/attachment_data/file/181719/defra-stats-foodfarm-environ-fps-statsrelease-autumn2012edition-130328.pdf (last accessed 4 February 2014).

## Important efficiency and resource productivity gains

Farmers who have already adopted precision agriculture technologies or are planning to adopt it have done so mainly because of the expected higher profitability (Diekmann and Batte, 2010; Reichardt et al., 2009). The use of precision agriculture technologies contributes to enhanced technical and allocative efficiency, incorporating advanced information sources and techniques for more efficient management. Precision agriculture inherently increases resource productivity by using natural resources more efficiently.

As noted earlier, 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, precision agriculture can provide a management approach, optimising both agricultural production and profitability, and reducing the use of inputs (machinery, labour, fertiliser, chemicals, seeds, water, energy, etc.), leading to improvements in productivity, the management and quality of the work, and also environmental benefits.

Precision agriculture aims to use either less inputs to generate similar crop yields, or the same amount of inputs resulting in higher crop yields due to more efficient input use. Typically, precision agriculture is associated with investments allocated to land use. The costs associated with precision agriculture 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. On the other hand, fuel and fertiliser expenses might be expected to decline with adoption of precision technologies, as compared with conventional farming. The various technologies contribute to the technical and allocative efficiency in different ways and profitability may vary tremendously.

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 technology methods, such as optimising fertiliser or pesticide use to areas of need, the success varies greatly according to the specific factors of the application.

Several studies have reported no appreciable economic benefit resulting from the use of variable rate technology for fertiliser application. The economic benefits of the adoption of variable rate application methods varies, depending upon the type of crop, the geographic area, the field size and type of agriculture, whether it is 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. variable-rate nitrogen application, phosphorus and potassium).

A mixed picture can be drawn from experiences with variable rate applications of nitrogen in the United States, Australia and Denmark, as such applications may not necessarily result in lower fertiliser application rates (Box 6.2). A different picture is given with the challenge of a site-specific supply of phosphorus and potassium. From an agronomic point of view, in arable systems, phosphorus and potassium fertiliser can be applied every few years, according to the nutrient status of the soil, and it is often unnecessary to adjust the fertiliser supply to the actual needs of the current crop.

Thus, precision agriculture concepts for phosphorus and potassium are generally more related to the status of the soil. Especially for bigger fields, service providers can offer mapping of soil nutrient status, which can be used as a recommendation for phosphorus and potassium fertiliser application.

A similar situation arises with site-specific application of lime. Soil pH is an important agronomic parameter, which can vary substantially across fields. The soil pH directly influences nutrient availability for plants because nutrients in the soil become soluble only within a certain pH range. An imbalanced pH leads to economic losses and environmental problems. Thus, variable rate application of lime can optimise nutrient availability for all parts of the field. Soil mapping or on-the-go soil pH sensing systems can be used to map the spatial distribution of pH in the field and prescribe the appropriate lime application rates (Bongiovanni and Lowenberg-DeBoer, 2000; Wang et al., 2003).

Precision weed and pest management can contribute to a drastic reduction the application of pesticides and thus contribute to increased efficiency of their use. Automatic guidance systems are well known to increase input efficiency by avoiding application overlaps. The economic advantages are well documented and contribute to the success of precision agriculture technology (Knight et al., 2009).

For example, the investments required for the implementation of automatic guidance systems are generally lower than other precision agriculture 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, by reducing input costs (seeds, fertiliser, chemicals, fuel and labour) and increasing yields, work simplification and speed, work comfort and ability to extend the working hours on the field.

Nevertheless, precision agriculture technologies are designed for optimal input use rather than increased output per ha. Also, production functions are mostly unaffected by precision agriculture technologies, with the exception of precision irrigation, which generally enables higher crop yields.

### Box 6.2. Economic impacts: What does the empirical evidence show?

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 cases (Griffin and Lowenberg-DeBoer, 2005). The USDA/ERS report found that in the United States: i) corn and soybean yields were significantly higher for yield monitor adopters than for non-adopters nationally; ii) corn and soybean farmers using yield monitors had lower per-acre fuel expenses; iii) average per-acre fertiliser expenses were slightly higher for corn farmers who adopted yield monitors, but were lower for soybean farmers; iv) average fuel expenses were lower, per acre, for farmers using variable-rate technologies for corn and soybean fertiliser application, as were soybean fuel expenses for guidance systems adopters; v) adopters of GPS mapping and variable-rate fertiliser equipment had higher yields for both corn and soybeans (Schimmelpfenning and Ebel, 2011). Godwin et al. (2003) showed that in 2001 low-cost precision farming technology could be profitable on farms of 80 ha farm size or over, while the breakeven area for integrated systems was 250 ha. As cereal and N fertiliser prices have doubled since then, while the cost of the technology has remained stable, the breakeven area has decreased and the profitability of precision farming on medium-sized farms has improved. This trend is likely to continue. The assumption that uptake is going to increase in the future is also supported by the findings that precision farming adopters are more likely to be younger (Diekmann and Batte, 2010) and to have college or university degrees (Diekmann and Batte, 2010, Reichardt et al., 2009) – the general trend is towards an increasing level of education and younger generations are going to be more familiar with information technology.

***Variable rate technologies***

Thöle and Ehlert (2010) analysed a mechanical crop biomass sensor (“crop meter”). They found that the use of the sensor could improve N efficiency by 10-15%, reducing N fertiliser applications without impacting crop yield. A German provider for precision farming technologies reported a 5% higher crop yield in winter wheat with the same amount of fertiliser applied and a 5% increase in crop yield, with 12% reduction of fertiliser applied.[1] Dillon and Kusunose (2013) illustrate that, with theoretical considerations for fertilising maize in the United States, a variable rate approach may not necessarily result in lower fertiliser application rates. A similar mixed picture can be drawn from experiences with variable rate applications of nitrogen in Australia, Denmark and elsewhere (Lawes and Robertson, 2011, Biermacher et al., 2009, Boyer et al., 2011; Berentsen et al., 2002, cited in Oleson et al., 2004).

Studies by Anselin et al. (2004) and Meyer-Aurich et al. (2008, 2010) concluded that the economic gross advantage of site-specific management of nitrogen fertiliser in Germany ranges between EUR 10 per ha and EUR 25 per 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. Other studies claim that economic and statistical analyses over a period of ten years showed no statistically significant economic advantage in sensor-based fertiliser application (Boyer et al., 2011). This conclusion is consistent with earlier observations (Liu, Swinton and Miller, 2006; Anselin et al., 2004), who calculated profitability below EUR 8 per ha, which hardly covers the costs of application. Studies in Denmark showed no economic effect from sensor based fertiliser redistribution in the field according to high- and low-yield zones (work by Berentsen, cited in Oleson et al., 2004).

***Automatic guidance systems***

The economic benefits of guiding systems in the United Kingdom were estimated for a 500 ha farm to be, at least, at EUR 2.2 per 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 EUR 18-45 per ha for winter wheat cultivation. In Germany, economic benefits due to savings of inputs were assessed at EUR 27 per ha for the case of winter wheat.

1. www.agricon.de/nc/de/produkte-leistungen/sensoren-agronomie/effekte-im-getreide?cid=2743&did=1718&sechash=fb130ca9

The positive effects of precision agriculture on the natural resource base can be further achieved with precision pest management. Another positive effect of precision agriculture can be expected from controlled traffic farming, where less driving is needed, which releases the land allotted to driving tracks for crops in a more resource efficient way, and with less soil compaction from heavy farm machines.

The use of precision agriculture technologies needs to result in higher revenues to cover the costs of the technologies. However, even if precision information is accurate, poorly timing the application of inputs can negatively impact the environment. For example, Morari et al. (2013) have indicated that high quality standards for wheat grains may create incentives to fertilise wheat at very high rates in order to capture economically attractive premiums for high quality wheat.

Precision agriculture technologies could be used to secure this economic potential. Meyer-Aurich et al. (2010) showed incorrect fertiliser decisions can be costly if quality of the output, in addition to yield, is influenced by the application rate. Considering quality enhances the opportunity for site-specific management to be profitable, as the benefits of variable rate technology compared to uniform management increases with the degree of heterogeneity. In this case, it is only with the availability of precision agriculture technologies that it becomes possible to achieve a higher quality.

### Positive employment effect in the up- and down-stream sectors, but variable for the on-farm sector

There is limited information available on the effect of precision agriculture on employment or farm labour. However, CropLife's 2013 survey provides indirect trends of precision agriculture on labour off the farm (Holland et al., 2013). It can be supposed that equipment manufacturers, dealers, retailers or input suppliers have a growing demand for employees with a precision agriculture background.

There is anecdotal evidence that precision agriculture technologies require more office time, compared with conventional farming (Möbius, 2012). Meyer-Aurich et al. (2008) provide an economic analysis of precision farming technologies at the farm level and find, depending on farm size and structure, that the implementation of precision agriculture technologies can reduce labour requirements due to the automation potential of variable rate technologies.

This is confirmed by Pedersen et al. (2006), who conclude that autonomous systems are capital-intensive, but less labour-intensive, as they are more flexible than conventional systems and may significantly reduce labour costs and restrictions on the number of daily working hours. Kingwell and Fuchsbichler (2011) showed that under Australian conditions labour input, and therefore cost, could be reduced through CTF compared with conventional farming systems. However, Maheswari et al. (2008) found that labour cost per ha (for vegetable production) may increase significantly with the adoption of precision agriculture compared with conventional farming.

The adoption of precision farming practices has impacts on the management and organisation of the farming system. This includes the implementation of on-farm IT systems and processes. Depending on the approach, this could include services from precision agriculture service suppliers and extension services. Precision agriculture practices, such as guidance systems, may increase the availability of labour, which has an indirect effect on other farming practices. Furthermore, the adoption of precision agriculture technologies may have impact on the farming practices of neighbouring farmers through land or technology leasing (Batte, 2003).

In summary, it can be presumed from the available information that precision agriculture technologies have a positive employment effect in the up- and down-stream sectors, whereas the on-farm effects may be negative due to the automation potential of precision agriculture technology. Nonetheless, it can be expected that precision agriculture technologies will increase on-farm workforce productivity. Give the limited research results in this area, research will need to analyse the employment effects of precision agriculture in more detail.

### Improved environmental footprint of agriculture

Although the possible use of precision technologies to manage the environmental side effects of farming and to reduce pollution is appealing, little assessment has been made on the benefits provided to the environment and no quantified figures are available.

Some research has shown that site specific management of inputs such as fertilisers and chemicals that are required by precision agriculture technologies can reduce the environmental footprint of agriculture. For example, by providing an opportunity to reduce physical overlap between machinery passes, precision farming reduces GHG emissions and lowers diffuse water pollution from fertilisers, agro-chemicals and fuel. GPS mapping and guidance systems can reduce the need for over-spraying by precisely defining the borders of previously sprayed areas.

Other examples include nitrate leaching in cropping systems, demonstrating that variable rate application methods were successful in reducing groundwater contamination and that precision agriculture methods may reduce erosion when precise tillage is conducted. A literature review on the environmental effects for whole field or conservation tillage with precision agricultural practices is provided by Bongiovanni and Lowenberg-Deboer (2004).

## Impediments to nurturing the green growth potential

Precision agriculture remains in the early stages of adoption and the suite of information technologies are not expected to be adopted universally across and within countries. The high cost and complexity of the technology, farm-operator education and farm management acumen, as well as failure to deliver the expected economic benefits in some instances, are among the main factors which have hindered wider adoption as cited in several studies (Khanna et al., 1999; Griffin et al., 2004; Reichardt and Jürgens, 2009; Robertson et al., 2012; Rutt, 2011). More widespread adoption would largely depend on the extent to which precision agriculture technologies become less expensive, and/or easier to install and maintain.

### *Farm structural characteristics are critical drivers of adoption*

Precision agriculture 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. Farm-level factors such as farm size, field size, field geometry, and soil heterogeneity play a prominent role in the adoption of precision agriculture technologies and therefore strongly influence its growth potential. Since one of the goals of variable rate technology is to manage in-field soil heterogeneity, it is clear that a reasonable amount of observable soil heterogeneity is a prerequisite. However, if precision farming technology results in low to moderate changes in input levels at a given location within a field, there is a high probability that improved profits will be very low.[5]

Regarding farm size, economies of scale are an important issue when calculating the economic benefit and discussing the adoption of cost-intensive precision agriculture technologies, as cost/benefit estimations require a minimum farm size in order to depreciate the investment over the entire farm (Kingwell and Fuchsbichler, 2011). In the European Union, studies demonstrate that auto-guidance systems are profitable when they are implemented on fields of 100-300 ha (Frank et al., 2008; Lawes and Robertson, 2011).[6]

Another important aspect for successful adoption is the suitability of the fields for the implementation of precision agriculture methods. Where field size is small, or when the farmer does not own the technology, specialist contractors, sharing of farming methods and co-operative approaches may be suitable ways to introduce precision farming technologies.

Wagner (2009) provided cost estimations for three different technological approaches for site-specific nitrogen fertilisation (Table 6.3). Annual costs of a sensor system decreased from EUR 21.38 per ha, assuming a cropping area of 250 ha, to only EUR 5.35 per ha for a cropping area of 1 000 ha. As a consequence, many reports show that increasing farm size has a positive effect on the probability that precision agriculture technologies are adopted (e.g. Roberts et al., 2004; McBride and Daberkow, 2003).

**Table 6.3. Estimated costs for three site-specific fertilisation strategies**

| | Map | Sensor | Net |
|---|---|---|---|
| Hardware/ software | Terminal with GPS (EUR 4 800), yield monitor for the harvest combine (EUR 8 500), GIS- Software (EUR 1 500) | Yara-N-Sensor® with terminal and installation (EUR 22 350) | Yara-N-Sensor® with terminal and installation (EUR 22 350), yield monitor for the harvest combine (EUR 8 500) |
| **Annual costs*** | **EUR 3 010** | **EUR 4 545** | **EUR 6 274** |
| Additional information | - | - | Electrical conductivitiy measurements (EUR 5, once within 6 years) |
| **Annual costs per ha*** | **-** | **-** | **EUR 1.02** |
| Service provider | Map preparation (EUR 2/ha) | Annual system check (EUR 800) | Data processing, decision rules preparation (EUR 2/ha) annual system check (EUR 800) |
| **Annual costs*** | **EUR 2/ha** | **EUR 800 p.a.** | **EUR 2/ha + EUR 800 p.a.** |
| Cost/ha (area 250 ha) | EUR 14.04 | EUR 21.38 | EUR 31.31 |
| Cost/ha (area 500 ha) | EUR 8.02 | EUR 10.69 | EUR 17.17 |
| Cost/ha (area 1000 ha)** | EUR 5.01 | EUR 5.35 | EUR 10.09 |

* Calculated according to the annuity method, depreciation time six years for hardware and software, interest rate 6%.

** The second combine necessary for 1 000 ha is not equipped with a yield monitor.

*Source*: Wagner, P. (2009), “The economic potential of Precision Farming – An interim report with regard to nitrogen fertilization”, in E.J. van Henten et al. (2009), *Precision Agriculture ’09*.

### *High level of farmer expertise is required*

Precision farming is an agricultural system approach that demands a high level of expertise due to its information-intensive and embodied-knowledge features. The concept of precision farming is primarily based on data collection, data processing and variable rate application of inputs. The challenge in using precision agriculture technology to its fullest potential is in incorporating all the data into a workable plan for an individual field. With the overwhelming amount of data that can be collected from seeding through which harvest, translating this data into useable information may require more time than some farmers are willing to invest.

Low awareness, time requirements to get used to the technology, lack of technical knowledge, incompatibility of machines from different manufacturers, the high cost of the technology and the difficulty in quantifying the benefits of precision farming are among the main barriers mentioned most frequently by farmers in the United States, Europe and Australia (Diekmann and Batte, 2010; Reichardt et al., 2009; Reichardt and Jurgens, 2009).

Farmers using this technology can be overburdened by its complexity. An enabling policy environment can play an important role in facilitating farmers’ uptake of precision agriculture by providing support and advice to farmers within the wider agricultural knowledge and innovation system (AKIS) of the country, where multiple stakeholders interact. Acquisition and transfer of precision farming knowledge should be as simple as possible. Several studies of precision farming conducted in the United States, the United Kingdom, Denmark and Germany identified the high costs involved and the time-consuming learning process required as the primary factors behind the slow dissemination of precision-farming knowledge.

For farm information technologies, Fernandez-Cornejo et al. (2001) find that farm operators who study beyond high school have a 15% greater likelihood of adopting precision technologies. Griffin et al. (2004) consider the adoption of precision agriculture to be “human capital intensive”. These observations could be related to an element of technology adoption that has been noted in other agricultural settings: learning-by-doing. Aversion to risk has been shown to have a large negative impact on the adoption of information technologies, contributing more than all other factors combined (Fernandez-Cornejo, et al 2001).

Factors that slow adoption in some regions are related to social capital and the strength of information networks. Kutter et al. (2011) analysed social factors, such as the role of communication and co-operation with regard to the adoption of precision farming technologies. In terms of communication, they studied various information sources and communication channels and their impact on adopting precision agriculture technologies. Additionally, joint investments, agricultural contracting and data out-sourcing were investigated as possible forms of co-operation.

Based on qualitative interviews, Kutter et al. (2011) came to the conclusion that professional literature, field days, and exhibitions played a key role as communication instruments. Furthermore, they concluded that co-operation between contractors, farmers and industry was important to advance the adoption process.

These conclusions are in line with Aubert et al. (2012), who also pointed out the importance to co-ordinate all stakeholders (farmers, input suppliers, equipment manufacturers and dealers) in order to improve adoption of the technology. Such co-ordination could be organised by co-operatives or farmers associations (Aubert et al., 2012). McBride and Daberkow (2003) observed that personalised technical support (e.g. from crop consultants/input suppliers) was extremely important in terms of the probability that precision farming technologies would be adopted at the farm level (see also Bramley and Trengove, 2013).

Aubert et al. (2012) recognised training programmes as important in the adoption process of precision agriculture technologies. Zhang et al. (2002) also found that educational programmes involving various stakeholders (researchers, industry, extension specialists and consultants) were needed to speed up the implementation of precision agriculture technologies. Reichardt et al. (2009) came to similar conclusions, underlining the importance of teaching precision farming at vocational and technical schools in order to improve implementation.

Further relevant social and socio-economic factors discussed in the literature were farmers' education and age (see Adrian et al., 2005; Aubert et al., 2012; Walton et al., 2008). McBride and Daberkow (2003) showed that the probability of precision agriculture adoption declined with age. However, Aubert et al. (2012) found no correlation between the age of farmers and adoption rates.

With regard to education, higher levels of education influence the probability of adoption (Aubert et al., 2012; Reichardt and Jürgens, 2009; McBride and Daberkow, 2003), since the technology is sophisticated and often complicated to use. However, Pannell et al. (2006) argued that participation in technology-relevant training courses may be more important than the level of education, when predicting adoption.

*High start-up costs hinder adoption*

The relative advantage of precision agriculture technologies compared to conventional agriculture (e.g. uniform input management) is an important factor influencing adoption (Aubert et al., 2012), and, therefore, the growth potential of the technology. The relative advantage can have economic, social, or environmental dimensions (Pannell et al., 2006).

In terms of economic relative advantage, it can be stated that for most variable rate technologies, farm level economics currently shows mixed results, resulting from: high technology and learning costs, the complexity of the technology, missing compatibility of technology components, sub-optimal or missing decision algorithms, and the limiting effect of flat pay-off functions. For instance, according to the method of managing nitrogen fertiliser used, the site-specific, annual technology costs (not including the learning cost) vary between EUR 3 010 and EUR 6 274 (Table 5.3). This is a large capital investment to make, in order to achieve more precisely managed nitrogen fertiliser application.

An early review of 108 studies provided by Lambert and Lowenberg-DeBoer (2000) shows that 63% of the analysed studies reported positive net returns from precision agriculture approaches. However, 11% of the studies showed negative returns, and 26% indicated mixed results (Lambert and Lowenberg-DeBoer, 2000). Although this review is now 14 years old, it still reflects the economic situation of precision agriculture (Table A6.1).

Another important factor influencing the relative advantage and therefore the growth potential of precision agriculture applications is the availability of appropriate decision algorithms. These algorithms make collected site-specific data relevant in terms of site-specific management. Without decision algorithms, farmers are unable to transfer collected site-specific information into site-specific management. There is a complex interaction of agronomic, disease, and soil moisture factors in site-specific management. For example, soil agronomy can impact soil moisture movement and the prevalence of disease on a fine scale within any individual field.

The algorithms mentioned above can be set to meet different criteria. For instance, yield maximisation may not be the goal on all sections of a field. Programs for field operations are being developed to minimize costs on pre-determined sites that are known to be lower yielding within a farmer's fields. McBride and Daberkow (2003) and Reichardt and Jürgens (2009) provided empirical evidence for this argument. They showed that the percentage of farmers who adopted data collection (diagnostic) techniques was much higher than the percentage of farmers who actually used this information for site-specific management. Wagner (2009) highlighted the importance of decision rules for the economics of precision farming. Gandorfer et al. (2011) also stated that the development of decision algorithms with economic objectives was a major determinant for the future of precision agriculture applications.

Finally, Aubert et al. (2012) clearly showed that most of the factors discussed above were very important for the adoption decision. To a large extent, these findings are also confirmed by survey results from Reichardt and Jürgens (2009), presented in Table 6.4.

Overall, the circumstances described above lead to the low adoption levels of many variable rate technologies. In contrast, the more discernible relative economic and social advantage of auto guidance systems or automatic section control of sprayers leads to much higher levels of adoption.

From an environmental point of view, it could be suggested that precision agriculture technologies provide relative advantages if underlying decision algorithms follow or include environmental considerations. However, the relative advantage in environmental terms does not seem to be (at least currently) a main driver for adoption (Reichardt and Jürgens, 2009).

**Table 6.4. Reasons why farmers hesitate to implement precision farming (more than one possible answer)**

| Answers | 2001* (N=126) | 2003 (N=137) | 2005 (N=167) | 2006 (N=47) |
|---|---|---|---|---|
| Machinery is still too expensive | 42.1 | 44.1 | 62.9 | 63.8 |
| The techniques of precision farming are very complicated | 6.3 | 5.1 | 11.4 | 8.5 |
| The benefit of PF-techniques is not yet proved | 11.1 | 9.6 | 9 | 4.4 |
| Waiting until PF is no longer problematic | 28.6 | 20.6 | 24 | 25.5 |
| I will use PF but I have no time | 15.4 | 9.6 | 13.2 | 6.4 |
| My fields are too small | 15.4 | 18.4 | 17.4 | 46.8 |

Values are expressed in %.
* Surveys were conducted from 2001 to 2005 at the Agritechnica fair and in 2006 at the DLG field days.

*Source*: Adapted from Reichardt, M. and C. Jürgens (2009), "Adoption and future perspective of precision farming in Germany: Results of several surveys among different agricultural target groups", *Precision Agriculture*.

## *Notes*

1. CTF methods involve confining all field vehicles to the minimal area of permanent traffic lanes with the aid of GNSS technology and decision support systems.
2. The growing interest in Europe in the CTF technology is reflected in the creation of an European association aiming at fostering its development (www.controlledtrafficfarming.com).
3. An example is PA methods in viticulture, where grape quality assessment and yield maps obtained from remote sensing and field instruments avoid mixing grapes of different potential quality during harvest.
4. Data source is the ABS ARMS survey, *Number of agricultural businesses using controlled traffic farming*.
5. This means that even quite large deviations from optimal management decisions of inputs (e.g. nitrogen) may make little absolute difference to the expected payoff. In other words, the payoff function is flat near the optimum, often over quite a wide range (Pannel, 2006).
6. Regarding resource efficiency and individual treatment of land areas, plants or animals, it is important to gain awareness of variation within the field or animal herd. On small farms, simple applications based on, for example, mobile phones and identification tags are often adequate to create awareness about the site or animal specific variation, and these applications can guide the user in decision-making (e.g. Cunha et al. 2010; Delgado et al., 2013; So-In. et al., 2014). Treatments may include manual control when seen necessary if automated solutions are too expensive.

## *Bibliography*

Adrian, A.M., S.H. Norwood and P.L. Mask (2005*), "*Producers' perceptions and attitudes toward precision agriculture technologies", *Computers and Electronics in Agriculture,* Vol. 48, No. 3.

Anselin, L., R. Bogiovanni and J. Lowenberg-Deboer (2004), "A spatial econometric approach to the economics of site-specific nitrogen management in corn production", *American Journal of Agricultural Economics*, Vol. 86, No. 3.

Aubert, B.A., A. Schroeder and J. Grimaudo (2012), "IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology", *Decision Support Systems*, Vol. 54, No. 1.

Auernhammer, H. (2001), "Precision farming - The environmental challenge", *Computers and Electronics in Agriculture*, Vol. 30, Nos. 1-3.

Bachmaier, M. and M. Gandorfer (2009), "A conceptual framework for judging the precision agriculture hypothesis with regard to site-specific nitrogen application", *Precision Agriculture*, Vol. 10, No. 2.

Batte, M. (2003), "Precision farming and land leasing practices", *Journal of the ASFMRA,* Vol. 66.

Batte, M. (1999), "Precision farming - Factors influencing profitability", Northern Ohio Crops Day meeting, Wood County, Ohio, 21 January, http://aede.osu.edu/sites/drupal-aede.web/files/PrecisionFarming.pdf.

Berentsen, J., A. Thomsen, K. Schelde and O. Hansen (2002), "Ny strategi for GPS-gødskning nmed sensor", *Agrologisk*, Vol. 3, No.2, pp. 26-27.

Berntsen, J., A. Thomsen, K. Schelde and O. Hansen (2002), "Ny strategi for GPS- gødskning med sensor", *Agrologisk*, Vol. 3, Issue 2.

Biermacher, J.T., B.W. Brorsen, F.M. Epplin, J.B. Solie and W.R. Raun (2009), "The economic potential of precision nitrogen application with wheat based on plant sensing", *Agricultural Economics*, Vol. 40, No. 4.

Bloomer, D. and J. Powrie (2011), "Precision agriculture: Doing the right thing in the right place at the right time", in D. Bloomer and J. Powrie (eds.), *A Guide to Smart Farming*, Landwise, Feilding, New Zealand.

Bongiovanni, R. and J. Lowenberg-DeBoer (2004), "Precision agriculture and sustainability", *Precision Agriculture,* Vol. 5, pp. 359-87.

Bongiovanni, R. and J. Lowenberg-Deboer (2000), "*Economics of Variable Rate Lime in Indiana", Precision Agriculture*, Vol. 2, pp. 55-70.

Bowman, K. (2008), "Economic and environmental analysis of converting to Controlled Traffic Farming", Proceedings, 6th Australian Controlled Traffic Farming Conference*,* Dubbo, NSW, Australian Controlled Traffic Farming Association, www.ctfsolutions.com.au/ebm3-doc/132275/Bowman%20Economics.pdf.

Boyer, C.N., B. Wade Brorsen, J.B. Solie and W.R. Raun (2011), "Profitability of variable rate nitrogen application in wheat production", *Precision Agriculture,* Vol. 12.

Bramley, R. (2009), "Lessons from nearly 20 years of precision agriculture research, development, and adoption as a guide to its appropriate application", *Crop & Pasture Science,* Vol. 60.

Bramley, R. and S. Trengove (2013), "Precision agriculture in Australia: Present status and recent developments", *Engenharia Agrícola,* Vol. 33, No. 3.

Bullock, D. S. and J. Lowenberg-DeBoer (2007), "Using spatial analysis to study the values of variable rate technology and information", *Journal of Agricultural Economics*, Vol. 58, No. 3.

Cunha, C., E. Peres, R. Morais, A. Oliveira, S. Matos, M. Fernandes, P. Ferreira and M. Reis (2010), "The use of mobile devices with multi-tag technologies for an overall contextualized vineyard management", *Computers and Electronics in Agriculture*, Vol. 73, pp. 154-164.

Dammer, K. (2005), *Demonstration der Langzeitwirkung bedarfsorientierter Fungizidbehandlung mit dem CROP-Meter*, Bornimer Agrartechnische Berichte, Heft 41 Eigenverlag, Potsdam.

Department for Environment, Food and Rural Affairs (DEFRA) (2013), *Farm Practices Survey Autumn 2012- England,* Department for Environment, Food and Rural Affairs, www.gov.uk/government/uploads/system/uploads/attachment_data/file/181719/defra-stats-foodfarm-environ-fps-statsrelease-autumn2012edition-130328.pdf (last accessed 4 February 2014).

Delgado, J., K. Kowalski and C. Tebbe (2013), "The first Nitrogen Index app for mobile devices: Using portable technology for smart agricultural management", *Computers and Electronics in Agriculture*, Vol. 91, pp. 121-123.

DeJonge, K.C., A.L. Kaleita and K.R. Thorp (2007), "Simulating the effects of spatially variable irrigation on corn yields, costs, and revenue in Iowa", *Agricultural Water Management,* Vol. 92, pp. 99-109.

Department for Environment, Food and Rural Affairs (2013), *Farm Practices Survey Autumn 2012-England,* www.gov.uk/government/uploads/system/uploads/attachment_data/file/181719/defra-stats-foodfarm-environ-fps-statsrelease-autumn2012edition-130328.pdf (last accessed 4 February 2014).

Diekmann, F. and M. Batte (2010), "2010 Ohio farming practices survey: Adoption and use of precision farming technology in Ohio", Report No. AEDE-RP-0129-10.

Dillon, C.R. and Y. Kusunose (2013), *Dispelling Misperceptions regarding Variable Rate Application, Precision Agriculture '13,* J.V. Stafford, Wageningen Academic Publishers.

Evans, R.G., J. LaRue, K.C. Stone and B.A. King (2013), "Adoption of site-specific variable rate sprinkler irrigation systems", *Irrigation Science*, Vol. 31.

Fernandez-Cornejo, J., S. Daberkow and W. McBride (2001), "Decomposing the size effect on the adoption of innovations: Agrobiotechnology and precision agriculture", *AgBioForum*, Vol. 4, No. 2.

Frank, H., M. Gandorfer and P. Noack (2008), "Ökonomische Bewertung von Parallelfahrsystemen", in R. Müller, H. Sundermeier, L. Theuvsen, S. Schütze and M. Morgenstern, Referate der 28, GIL-Jahrestagung in Kiel 2008.

Gandorfer, M., A. Meyer-Aurich and M. Kapfer (2011), "Ökonomische Aspekte von Precision Farming - aktueller Stand und Perspektiven", *Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie,* Vol. 20, pp. 34-43.

Gebbers, R. and V.I. Adamchuk (2010), "Precision agriculture and food security", *Science*, Vol. 327.

Gerhards, R. and H. Oebel (2006), "Practical experiences with a system for site-specific weed control in arable crops using real-time image analysis and GPS-controlled patch spraying", *Weed Research*, Vol. 46.

Godwin, R., T. Richards, G. Wood, J. Welsh and S. Knight (2003), "An economic analysis of the potential for precision farming in UK cereal production", *Biosystems Engineering*, Vol. 84.

Griffin, T., R. Bongiovanni and J. Lowenberg-DeBorer (2010), "Worldwide adoption of precision agriculture technology: The 2010 update", paper presented at the 10th International Conference on Precision Agriculture, Denver, CO, 22 July 2010.

Griffin, T. and J. Lowenberg-DeBoer (2005), "Worldwide adoption and profitability of precision agriculture: Implications for Brazil" *Revista de Política Agrícola*, Vol. 4, www.embrapa.br/publicacoes/tecnico/revista-Agricola/rpa-de-2005/pol_agr_04-2005-p-pg-embrapa.pdf.

Griffin, T., J. Lowenberg-DeBoer, D. Lambert, J. Peone, T. Payne and S. Daberkow (2004), "Adoption, profitability, and making better use of precision farming data", *Staff Paper*, Numbers 04-06, Department of Agricultural Economics, Purdue University, http://ageconsearch.umn.edu/bitstream/28615/1/sp04-06.pdf.

Holland, J.K., B. Erickson and D.A. Widmar (2013), *2013 Precision Agricultural Services Dealership Survey Results*, Department of Agricultural Economics, Purdue University, West Lafayette.

Jochinke, D.C., B.J. Noonon, N.G. Wachsmann and R.M. Norton (2007), "The adoption of precision agriculture in an Australian broadacre cropping system—Challenges and opportunities", *Field Crops Research,* Vol. 104, Nos. 1-3, pp. 68-76.

Khanna, M., O. Epough and R. Hornbaker (1999), "Site-specific crop management: Adoption patterns and incentives", *Review of Agricultural Economics*, Vol. 21, No. 2.

Kingwell, R. and A. Fuchsbichler (2011), "The whole-farm benefits of controlled traffic farming: An Australian appraisal"*, Agricultural Systems*, Vol. 104, pp. 513-21.

Knight, S., P. Miller and J. Orson (2009), "An up-to-date cost/benefit analysis of precision farming techniques to guide growers of cereals and oilseeds", *HGCA Research Review 2009*, No. 71, Home-Grown Cereals Authority (HGCA), www.hgca.com/media/276988/rr71-final-project-report.pdf (last accessed 10 February 2014).

Kutter, T., S. Tiemann, R. Siebert and S. Fountas (2011), "The role of communication and co-operation in the adoption of precision farming*"*, *Precision Agriculture*, Vol. 12, pp. 2-17.

Lamb, D.W., P. Fraizer and P. Adams (2008), "Improving pathways to adoption: Putting the right P's in precision agriculture", *Computers and Electronics in Agriculture*, Vol. 61, No. 1.

Lambert, D.M. and J. Lowenberg-DeBoer (2000), *Precision agriculture profitability review*, West Lafayette, Site Specific Management Center, School of Agriculture, Purdue University, http://agriculture.purdue.edu/SSMC (last accessed 10 February 2014).

Lawes, R.A. and M.J. Robertson (2011), "Whole farm implications on the application of variable rate technology to every cropped field", *Field Crops Research*, Vol. 124, pp. 142-48.

Liu, Y., S. Swinton and N. Miller (2006), "Is site-specific yield response consistent over time? Does it pay?", *American Journal of Agricultural Economics*, Vol. 88, issue 2.

Maheswari, R., K.P. Ashok and M. Prahadeeswaran (2008), "Precision farming technology, adoption decisions and productivity of vegetables in resource-poor environments", *Agricultural Economic Research Review*, Vol. 21, pp. 415-24.

Maine, N., J. Lowenberg-DeBoer, W.T. Nell and Z.G. Alemu (2010), "Impact of variable-rate application of nitrogen on yield and profit: A case study from South Africa"*, Precision Agriculture*, Vol. 11, pp. 448-63.

Mandel, R., R. Lawes and M. Robertson (2011), "What's preventing growers from implementing precision agriculture (PA)?", in J. Paterson and C. Nicholls, *Agribusiness Crop updates 2011*, Perth, pp. 148-52.

Marchant, B., M. Oliver, T. Bishop and B. Whelan (2013), "The economics of precision agriculture", in M. Oliver, T. Bishop and B. Marchant, *Precision Agriculture for Sustainability and Environmental Protection,* Routledge, Abington, UK.

McBratney, A., B. Whelan and T. Ancev (2005), "Future directions of precision agriculture", *Precision Agriculture*, Vol. 6, pp. 7-23.

McBride, W.D. and S.G. Daberkow (2003), "Information and the adoption of precision farming technologies", *Journal of Agribusiness*, Vol. 21, Issue 1.

Meyer-Aurich, A., M. Gandorfer and A. Heißenhuber (2008), "Economic analysis of precision farming technologies at the farm level: Two German case studies", in O.W. Castalonge, *Agricultural Systems: Economics, Technology, and Diversity,* Nova Science Publishers, Hauppage NY, United States.

Meyer-Aurich, A., A. Weersink, M. Gandorfer and P. Wagner (2010), "Optimal site-specific fertilization and harvesting strategies with respect to crop yield and quality response to nitrogen", *Agricultural Systems*, Vol. 103.

Morari, F., S. Loddo, P. Berzaghi, J.C. Ferlito, A. Berti, L. Sartori, G. Visioli, N. Marmiroli, D. Piragnolo and G. Mosca (2013), "Understanding the effects of site-specific fertilization on yield and protein content in durum wheat", in J.V. Stafford, *Precision Agriculture '13*, pp. 321-27, Wageningen Academic Publishers.

Möbius, J. (2012), "Görminer Landwirtschaftsbetrieb Peenetal", *Neue Landwirtschaft*, Vol.7, p. 45.

Olesen, J., P. Sørensen, I. Thomsen, J. Eriksen, A. Thomsen and J. Berntsen, J. (2004), "Integrated nitrogen input systems in Denmark", in A. Mosier, J. Syers and J. Freney (eds) (2004), *Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment*, Island Press, Washington; Covelo, London.

Pannell, D.J. (2006), "Flat earth economics: The far-reaching consequences of flat payoff functions in economic decision making", *Review of Agricultural Economics*, Vol. 28, No. 4.

Pannell, D.J., G.R. Marshall, N. Barr, A. Curtis, F. Vanclay and R. Wilkinson (2006), "Understanding and promoting adoption of conservation practices by rural landholders", *Australian Journal of Experimental Agriculture*, Vol. 46, No. 11.

Pedersen, S.M., S. Fountas, H. Have and B.S. Blackmore (2006), "Agricultural robots – System analysis and economic feasibility", *Precision Agriculture*, Vol. 7, pp. 295-308.

Pierce, F.J. and P. Nowak (1999), "Aspects of precision agriculture", *Advances in Agronomy*, Vol. 67.

Reichardt, M. (2010), "Precision Farming in der deutschen Landwirtschaft – eine GIS – gestützte Analyse", Dissertation, Ruhr-Univeristät, Bochum, www-brs.ub.ruhr-uni-bochum.de/netahtml/HSS/Diss/ReichardtMaike/diss.pdf (last accessed 4 February 2014).

Reichardt, M. and C. Jürgens (2009), "Adoption and future perspective of precision farming in Germany: Results of several surveys among different agricultural target groups", *Precision Agriculture*, Vol. 10, pp. 73-94.

Reichhardt, M., C. Jürgens, U. Klöble, J. Hüter and K. Moser (2009), "Dissemination of precision farming in Germany: Acceptance, adoption, obstacles, knowledge transfer and training activities", *Precision Agriculture*, Vol. 10, pp. 525-45.

Roberts, R.K., B. English, J. Larson, R. Cochran, C. Goodman, S. Larkin, M. Marra, S. Martin, W. Shurley and J. Reeves (2004), "Adoption of site-specific information and variable-rate technologies in cotton precision farming", *Journal of Agriculture and Applied Economics*, Vol. 36, No. 1.

Robertson, M., R. Llewellyn, R. Mandel, R. Laws, R. Bramley, L. Swift, N. Metz and C. O'Callaghan (2012), "Adoption of variable rate fertiliser application in the Australian grains industry: Status, issues and prospects", *Precision Agriculture*, Vol. 13, pp. 181-199.

Rutt, K. (2011), *Precision Farming braucht einen Neuanfang*, DLG-Mitteilungen9/2011.

Schimmelpfenning, D. and R. Ebel (2011), "On the doorstep of the information age - Recent adoption of precision agriculture", U.S. Department of Agriculture, Economic Research Service, *Economic Information Bulletin,* No. 80, www.ers.usda.gov/media/81195/eib80_1_.pdf.

Schneider, M. and P. Wagner (2008), Ökonomische Effekte der teilflächenspezifischen Bewirtschaftung auf betrieblicher Ebene, in A. Werner, F. Dreger and J. Schwarz, *Informationsgeleitete Pflanzenproduktion mit Precision Farming als zentrale inhaltliche und technische Voraussetzung für eine nachhaltige Entwicklung der landwirtschaftlichen Landnutzung – Preagro II*, www.preagro.de/Veroeff/preagro_Abschlussbericht_2008.pdf.

Shockley, J., Dillon, C. R., Stombaugh, T. and S. Shearer (2012), "Whole farm analysis of automatic section control for agricultural machinery", *Precision Agriculture*, Vol. 3; pp. 411-420.

So-In, C., S. Poolsanguan and K. Rujirakul (2014), "A hybrid mobile environmental and population density management system for smart poultry farms", *Computers and Electronics in Agriculture*, Vol. 109, pp. 287-301.

Swinton, S.M. and J. Lowenberg-DeBoer (2001), "Global adoption of precision agriculture technologies: Who, when and why?", in G. Grenier and S. Blackmore (eds), *3rd European Conference on Precision Agriculture*, pp. 557-62, Agro Montpellier (ENSAM), Montpellier.

Thöle, H. and D. Ehlert (2010), “Biomass related nitrogen fertilization with a crop sensor”, *Applied Engineering in Agriculture*, Vol. 26, No. 5.Tullberg, J., A. McHugh, B. Gharee Khabbaz, C. Scheer and P. Grace (2011), “Controlled traffic/permanent bed farming reduces GHG emissions”, in the 5th World Congress of Conservation Agriculture (WCCA), “Resilient Food Systems for a Changing World”, 26-29 September 2011, Brisbane, Australia.

Tullberg, J. (2009), “CTF and climate change”, paper presented to 6th Australian Controlled Traffic Farming Conference, Dubbo, New South Wales, 12-14 August 2008, www.actfa.net/further_reading/documents/Tullberg.Jeff.pdf.

Tullberg, J., D. Yule and D. McGarry (2007), “Controlled traffic farming – From research to adoption in Australia*”, Soil and Tillage Research*, Vol. 97.

Vellidis, G., B. Oritz, J. Beasley, R. Hill, H. Henry and H. Brannen (2013), “Using RTK-based GPS guidance for planting and inverting peanuts”, in J.V. Stafford (ed.), *Precision Agriculture ’13,* 9th European Conference on Precision Agriculture, Wageningen Academic Publishers.

Wagner, P. (2009), “The economic potential of Precision Farming - An interim report with regard to nitrogen fertilization”, in E.J. van Henten, D. Goense and C. Lokhorst (eds) (2009), *Precision Agriculture ’09*, 7th European Conference on Precision Farming, Wageningen Academic Publishers.

Walton, J.C., D. Lambert, R. Roberts, J. Larson, B. English, S. Larkin, S. Martin, M. Marra, K. Paxton and J. Reeves (2008), “Adoption and abandonment of precision soil sampling in cotton production”, *Journal of Agricultural and Resource Economics*, Vol. 33, No. 3.

Wang, D., Prato, T., Qiu, Z., Kitchen, N. and K. Sudduth (2003), “Economic and environmental evaluation of variable rate nitrogen and lime application for claypan soil fields”, *Precision Agriculture*, Vol. 4.

Watson, S., E. Segarra, R. Lascano, K. Bronson and A.M. Schubert (2005), “Guidelines for recommending Precision Agriculture in southern crops”, *Journal of Extension*, Vol. 43, No. 2, Article No. 2RIB7, www.joe.org/joe/2005april/rb7p.shtml.Yule, D. and W. Chapman (2011), “Controlled traffic farming - More productivity, sustainability and resilience”, paper presented to the 5th World Congress of Conservation in Agriculture incorporating 3rd Farming Systems Design Conference, Brisbane.

Zarco-Tejada, P., N. Hubbard and P. Loidjani (2014), *Precision Agriculture: An Opportunity for EU Farmers – Potential Support with the CAP 2014-2020*, Policy Department, Structural and Cohesion Policies, Agriculture and Rural Development, European Parliament, www.europarl.europa.eu/RegData/etudes/note/join/2014/529049/IPOL-AGRI_NT%282014%29529049_EN.pdf.

Zhang, N., M. Wang and N. Wang (2002), “Precision agriculture—A worldwide overview”, *Computers and Electronics in Agriculture*, Vol. 36, Nos. 2-3.

# Annex 6.A

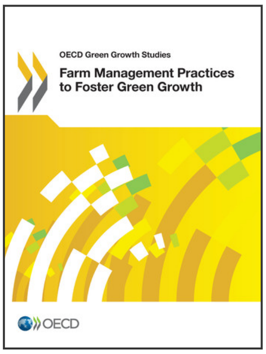
## The economic benefits of precision agriculture

Table 6A.1. Economic benefits of precision agriculture technologies

| Precision agriculture technology | Crop | Location | Economic effect | Source |
|---|---|---|---|---|
| Variable Rate Nitrogen | Winter wheat, canola | Germany | Net profit increase of EUR 16/ha for the Yara N-sensor compared to uniform management,<br>net profit loss of EUR 11/ha for a mapping approach compared to uniform management,<br>technology cost not included | Schneider and Wagner (2008) |
| Variable Rate Nitrogen | Winter wheat | United States (Oklahoma) | Net profit increase (including capital costs for sensing and application) of USD 15 with a variable top-dress sensed nitrogen application system, based on experiments over nine sites and nine years. | Biermacher et al. (2009) |
| Variable Rate Nitrogen | Wheat | United States (Oklahoma) | No profit increase with variable rate nitrogen application, the uniform 90 kg N/ha top-dress N strategy showed on average highest net returns | Boyer et al. 2011 |
| Variable Rate Nitrogen | Maize | South Africa | Variable rate nitrogen application is slightly more profitable compared to conventional management | Maine et al. 2010 |

**Table 6A.1. Economic benefits of precision agriculture technologies** (*continued*)

| | | | | |
|---|---|---|---|---|
| Variable Rate Nitrogen and Lime | Soybean/corn | United States/Canada | Increase of annual return by up to USD 20/ha | Bongiovanni and Lowenberg-DeBoer (2000) |
| Variable Rate Nitrogen and Phosphorus | Cereals | Australia | Positive economic potentials in six out of 20 investigated fields with an additional economic payoff of 15 AUD/ha excluding costs for information gathering and variable rate application | Lawes and Robertson (2011) |
| Variable Rate Pesticide | Winter wheat | Germany | Initial costs for investments for sensor based fungicide spraying technology are around<br>EUR 13 000 and could be covered within approximately 2 years on a 1 000 ha farm with 60% cereal cultivation | Dammer (2005) |
| Variable Rate Irrigation | Corn | United States (Iowa) | Precision irrigation was economically in one out of 28 analysed cases | DeJonge et al. (2007) |
| Auto-guidance | Cereals and oilseeds | England | Economic benefits of guiding systems were estimated for a 500 ha farm at least at GBP 2 /ha | Knight et al. (2009) |
| Auto-guidance | Peanuts | United States (Georgia) | Economic benefits of using auto-steer compared to conventional steering is approximately<br>USD 34/ha | Vellidis et al. (2013) |
| Automatic section control | Corn/soybean | United States (Kentucky) | Economic advantages of up to USD 36/ha due to input savings | Shockley et al. (2012) |
| Controlled Traffic Farming | Winter wheat | England | Additional returns of GBP 16-40/ha | Knight et al. (2009) |
| Controlled Traffic Farming | Various crop rotations | Australia | Approximately 50% profit ncrease (farm level) | Kingwell and Fuchbichler (2011) |



**From:**

# Farm Management Practices to Foster Green Growth

**Access the complete publication at:**

https://doi.org/10.1787/9789264238657-en

---

**Please cite this chapter as:**

OECD (2016), “Is precision agriculture the start of a new revolution?”, in *Farm Management Practices to Foster Green Growth*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264238657-8-en