Chapter 1
Precision Agriculture – From Mapping to Site-Specific Application

S.M. Pedersen and K.M. Lind

Abstract This chapter gives an introduction to Precision Agriculture (PA) with a short historic pathway of the development and the status of current available technologies. Part of this description also provides an overview of some of the economic barriers and technical obstacles when applying variable-rate application. This chapter also notes that the adoption of several specific variable-rate application technologies have been modest in recent years. However, in contrast the adoption of auto-steering has been significant in the last decade. The last section describes the overall aim of the book and an overview of each chapter in the book. Each chapter address a different topic starting with an overview of technologies that are currently available, followed by specific Variable-Rate Technologies such as VRT fertilizer application, VRT pesticide application, site-specific irrigation management, Auto-steering and Controlled Traffic Systems. Finally, the chapter looks into new developments of autonomous systems with an example of robotic seeding, farm information management in precision agriculture and different methods on the adoption of PA. The last chapter focuses on how PA can fulfil the current policy trends on environmental regulations.

Keywords Precision agriculture • Adoption • History • Economics

1.1 Introduction

The introduction of tractors and combine harvesters has changed many farms from small labour-intensive units where the individual farmer had detailed knowledge about each field to large farm holdings with large fields to monitor. In some countries, farms can reach several thousand hectares of arable land. This trend was

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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_1

further driven by the introduction of commercial fertilizers and chemical weed control practices that pushed the development towards even more labour-saving production processes and larger fields. The larger the individual farm and fields became, the less knowledge the farm manager had about each field.

The introduction of precision farming is to some extent a step back in time. On the one hand, PA is aimed at large holdings with a farm and capital structure that enables them to invest in expensive systems. On the other hand, it is a means to get farm management back to small scale farming processes with detailed knowledge about small units and management zones and enable farmers to treat each unit, whether it is a piece of land or an animal, with the same care as farmers did in previous times. This development is facilitated by the help of smart technologies that allow the farmer to gain detailed knowledge about the field and subsequently to treat the field accordingly.

> Precision farming can be defined as *the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality* (Pierce and Nowak 1999).

Precision agriculture is described in the literature by various terms such as Precision farming (PF) , Site-Specific input Application (SSA), Site-Specific Agricultural Technology and Variable-Rate Treatment (VRT). In the following, these terms will be used synonymously. A broader term is Smart Agriculture that also appears to cover later technical developments such as auto steering systems, controlled traffic farming and autonomous systems like agricultural robots.

As a management tool, precision agriculture consists of four elements: geographical positioning (GPS), gathering information, decision support and variable-rate treatment. Yield mapping could be regarded as a fifth component, in which yield mapping enables the farmer to monitor the actual outcome from varying inputs (Pedersen 2003). However, yield mapping is also a tool that enables information to be gathered about previous years of yield on the field, which can be used as decision support for designing the next input strategy. Figure 1.1 illustrates the link between different technical systems and sensors in precision farming from geographical positioning and sensing systems to decision support, variable-rate input application and route planning.

Recently, several technologies that are related to precision farming have emerged from GPS systems, yield mapping, smart sensors and auto steering systems.

These systems should ideally enable the farmer to increase yield, save nutrients and replace labour time with efficient sensing and decision-support systems that can increase profitability on the farm and reduce the negative environmental impact. In that sense, precision farming follows other cost and labour saving innovations such as reduced tillage and GM crops – the recent developments of semi-autonomous systems and farm robots is likely to speed up that process further.

Precision farming has, since the beginning with the combined introduction of the first general purpose technology GPS (global positioning system) and GIS (geographical information system) with yield meters and maps in the late 1980s,

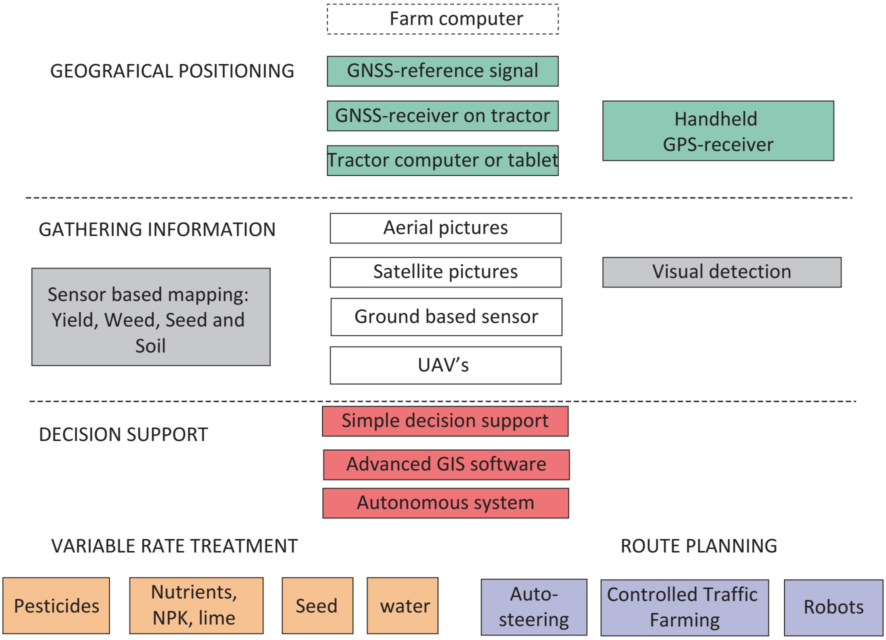

Fig. 1.1 Sensors and technical systems applied in precision agriculture

developed in many directions and the term PF has become quite complex covering many technical solutions.

It is always difficult to set the borders for a book like this as different elements of precision farming may be applied in different cropping systems and with different combinations of technology. There is, however, one core element that seems to be a part of all these individual technologies and that is the GPS or GNSS (global navigation satellite system) that enables site-specific treatment by the farmer.

In this study, we have decided to focus mainly on arable farming and we tend to disregard horticulture and orchards although many precision farming systems have emerged in these areas. In addition, we will mainly address the potential adoption of Precision Agriculture in a European context on farms with medium to large scale fields.

The focus of this book will be on a farm management perspective rather than society perspectives although some of the chapters will explore social values, adoption, environmental impact and sustainability issues. Basically, the book will address two main questions:

Which technologies are available for farmers and will some of these precision farming technologies be profitable for farmers to use? In addition, the book will cover aspects on farmers' adoption and perception of these technologies and the broader impact of PF as a technology to comply with current political trends, which focus on the environment.

With this book we will cover some potential PA technologies only and their economic potential. In the last decade hundreds of new start-up companies have been engaged in developing new sensors, apps and farm management systems that incorporate GNSS, positioning and GIS mapping systems in the agricultural sector. Many of these innovation attempts have reached a commercial level, whereas others are still at the development stage – but in any case a tremendous development has taken place around the world to develop better systems in America, Europe, Asia as well as targeted applications in developing countries. One factor is technology, however, an even more important factor is the deployment of technology.

The potential profitability of selected PA technologies will undoubtedly depend on many variables such as farm and field size, crop types, soil type, soil type, degree of specialization at the farm, on farm labour costs and access to finance and collateral for the individual farmer. In addition, the individual farmer may decide about adoption depending on his current investments in machinery and expected time of replacement. Other elements that may hinder or promote adoption is access to training and extension services related to precision farming technologies.

From a technical point of view, adoption may also be influenced by access to the internet, current speed of computers and on the current mix of farm equipment at the farm.

Since the mid 1980s, precision agriculture has developed from the use of the first GPS system and yield maps to the latest applications with controlled traffic farming with RTK systems and UAVs (Unmanned Aerial Vehicles) mounted with GPS and cameras for crop scouting. Meanwhile, the first attempt has been made to make autonomous or semi-autonomous systems that can carry out tasks to some extent on their own with no or little surveillance. Today, other navigation systems have emerged or are about to be launched in the near future, which might complement the GPS systems. Table 1.1 shows a brief historical pathway of precision farming since its early introduction in the mid 1980s.

Table 1.1 History of precision agriculture

1970–1980	Introduction of GPS as a general purpose technology
	First yield meter mounted on a combine harvester
1984	First yield maps introduced (with GPS)
1991	Application maps (GIS based) introduced and first attempt with variable-rate technology
1995–1998	Groundbased and satellite/aerial sensing systems to measure crop status (chlorophyll content)
1999–2002	Introduction of soil electrical conductivity measurements and aerial/satellite images to measure crop status
2000	Introduction of RTK systems applied in agriculture
2000–2002	First attempt with weed detection systems and precise seeding
2005	systems
2003	Introduction of auto-steering in agriculture
2008	Implementation of first controlled traffic systems among farmers
	Introduction of UAVs (drones) for application maps
2015	Introduction of first robotic systems in high value crops/horticulture

Parallel to this technical and commercial development, several scientific conferences have developed mainly in North America, Australia and Europe and later on in Asia and South America.

European Conference on Precision Agriculture (ECPA), and the International Conference on precision Agriculture in the USA, which is held every second year in Europe and the USA, respectively. They both cover topics on the economics and adoption of precision farming. Other conferences such as the Asian-Australian Conference on Precision Agriculture have likewise taken up topics on economics and farm management in precision farming. In addition, numerous other agricultural engineering conferences and workshops as well as conferences on agricultural economics and Farm Management have taken up issues on economics of PA.

These conferences have to some extent included specific topics on the economic viability of selected precision farming technologies and adoption of precision farming in different regions, especially topics on auto-guidance systems, variable-rate nitrogen and lime application have been numerous. Little attention has so far been on the economic feasibility of variable-rate pesticide application and variable-rate irrigation systems.

A number of books have focused on various forms of precision farming technologies with chapters on economic impacts like Handbook of Precision farming edited by Ancha Srinivasan from 2006 and Precision agriculture for sustainability and environmental protection, edited by Oliver, Bishop and Marchant from 2013, which also address topics on sustainability and economic perspectives. Nevertheless, little attention has been given to assess the broader economic perspectives for farmers adopting precision farming. This book will try to bridge this gap with a focus on the financial and economic viability and adoption of PF among farmers. The book is meant to target readers such as researchers, agricultural engineers, academics, farm advisors and graduate students within the area of crop production and farm management as well as students with an interest in precision farming and farm management.

This book is divided into 12 chapters in which some of the most recent developments and aspects of precision farming are addressed. Although the intention of this book is to give an overview of some of the most promising technologies within precision farming from an economic point of view, each chapter can be read individually if a reader wishes to focus on one particular topic.

Authors will present cases from different countries with a main focus on the perspectives of using precision farming in Europe. Since precision farming as a farm technology will benefit from scale advantages because of relatively large investment costs, the adoption in North America, Australia and other countries with large field areas are among the global front runners and early adopters.

1.2 Current PA Technologies

Precision farming is an information-intense and data intensive concept. Large datasets (Big Data) are required to generate maps as well as to display and make interpretations of specific variables. In this area, new technologies are under development or have been developed during the last decade. To assess the impact and profitability of precision farming, it is necessary to consider farming and farm management as a whole. In some regions, the use of manure and slurry from animals will have an impact on arable farming. In this case, it may be necessary to include the distribution and access of manure and slurry in the models to assess precision farming practices. Organic farming practices are also users of animal manure in a rotational cropping system and should therefore be similarly considered in relation to PA practices. In this book, the focus will be on conventional arable farming and little attention will be given specifically to organic farming practices.

1.3 Variable-Rate Application

The collection of data about spatial variation within the field is important, however, of more importance is how to use this information in variable-rate input application and, furthermore, to manage this input in the most economically efficient way.

If we consider a field with two different soil types A and B with 50% of the entire field each. Soil type A is a nutritional clay soil and soil type B is a sandy soil with a lower yield potential.

In conventional farming, inputs are traditionally distributed uniformly over the entire field with the same amount of input per unit on each site of the field. This method is convenient and requires no site-specific information about the soils.

In principle, precision farming is a matter of distributing inputs site-specifically to gain marginal yield benefits from the same field or to save inputs. With a completely homogenous field, the potential benefits from site-specific application is in principle zero, but with heterogeneous fields it should be possible to gain a benefit according to the variation in the yield potential or input saving potential from each field unit. However, even though each unit has its own yield potential, varying the application of nutrients may not necessarily imply an extra marginal economic benefit. It all depends on the yield slope of the yield response curves and the marginal net benefit of adding an extra input site-specifically, and to what extent the necessary site-specific information is available in order to make that decision.

Figure 1.2 illustrates yield response functions of one input for two soil types A and B. If we assume that the prices and benefits of these inputs and yields per unit are the same, regardless of the application level, then these S-shaped yield response functions may also be regarded as gross margin response functions.

The function is S-shaped to illustrate the diminishing return to increased use of inputs that is common among crop production functions. At some point, a particular

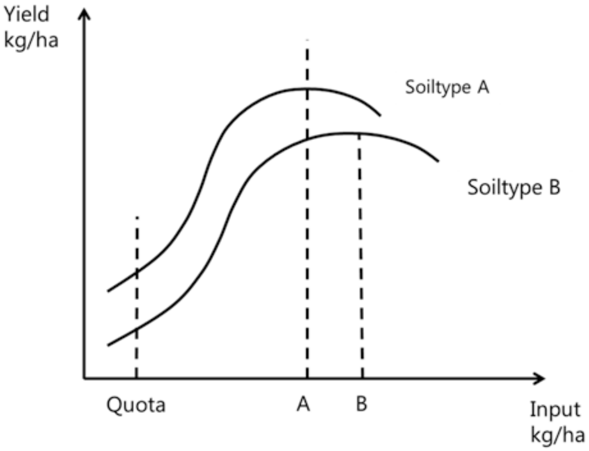

Fig. 1.2 Illustration of a single field with yield response functions of inputs for two soil types A and B

field may not gain extra yield and even get reduced yields and gross margins from adding one extra unit of input. One could imagine that by applying too much nitrogen to a field; at some point the crop yield will decrease as shown in Fig. 1.2. For soil type A, this peaking point is at input level A and for soil type B this input level could be at point B.

By using precision farming with site-specific application, the farmer may in principle be able to use information about the soil type or other site-specific information to make an optimising decision and to improve the distribution of the input.

However, it may also be the case that due to environmental restrictions or other restrictions on access to inputs, the farmer may be able to use only a certain amount of fertilizer as with a quota indicated by the dotted line. At this input level, the yield is higher for soil type A than soil type B.

Assuming that we have only a certain amount of nitrogen as indicated by the quota and dotted line. At this amount, the yield per kilogram of nitrogen is higher for soil type A than for soil type B. If we have a quota of 100 kg of nitrogen and divide it into 50 kg for Soil type A and 50 kg for soil type B then we will gain a higher yield from soil type A. The logical suggestion would then be to add more nitrogen to soil type A and less to soil type B because the yield is higher at soil type A. However, at the point of the quota (and just below and after this point) the "shapes" of the two curves are exactly the same. This means that if we take some of the nitrogen from soil B and give an extra amount to soil type A, then indeed we get more yield on soil type A, but also less yield on soil type B since we took nitrogen from this area. In fact, since the slopes of the two curves are exactly the same the yield loss from soil type B will be exactly the same as the yield increase at soil type A, meaning that the overall yield from the two fields from making that differentiated application will be exactly the same. Since the slope of the curve is the same for both soil types at that input level, it is therefore not beneficial to redistribute the quota amount of input because an additional increase in yield by using more inputs on one soil type will be offset equally with less yield on the other soil type.

This simple example illustrates the increasing and decreasing marginal benefits of inputs and is in our view a key management and economic issue that occurs within site-specific application.

Another issue that illustrates the complexity is that the farmer may not even know about the underlying yield response function if he does not have full information about the soils or he does not have sufficient information about how well the field is drained or how much it will rain in the days to come while he is distributing his fertilizer. He may not have full knowledge about the site-specific soil water content at the root zone at the right time. To make a good decision about how much fertilizer to use at a given location at a given time – all this information is needed. For many farmers, this information is not readily available and a precise decision-support system is not on offer. Therefore, the benefits realised from variable-rate fertilizer application have been shown to be modest until now.

In this example, the input was nitrogen, but in principle the farm manager may have to consider many other inputs like lime, pesticides, seeds and water in the same manner. What is the marginal net benefit from distributing inputs in the best possible way? In this example, we just used the soil type (either A or B) as the spatial variable, but as more knowledge has been gained about precision farming more information should be included in the decision-making process.

From a farm economic point of view, nitrogen should therefore be applied at a rate where the farmer's expected payoff is optimized. Optimal application rates will vary across fields with different soil types, but also across space and time because of the variation in crop growing conditions. Obtaining the full value of the economic benefits from site-specific applications requires an accurate indication of the variation in crop status in relation to yield potential within the field (Robertson et al. 2008) as well as an indication of the future weather conditions.

Crop status and crop growth status can be measured by using sensors that can be mounted on tractors, airborne UAVs or from satellite pictures. In all these systems, the spectral reflectance of the crop is made into a vegetation index and used as an indicator of the greenness and amount of crop biomass in the field (Evert et al. 2012).

Recently, it was proposed to adopt UAV mounted sensors to provide farmers with better information about the crop status and to enable site-specific application of fertilizers. This is another solution to existing on-board canopy sensing systems, like the Yara-sensor that is applied in Europe, which provide the possibility of online application. So far, the relatively high costs associated with these PF systems have limited the adoption. It is expected that new and lower cost systems may allow more farmers to take up the precision fertilization technology. The combined integration of crop modelling, UAVs and better decision-support systems may provide farmers with improved applications that include information about the spatial and temporal variation of crops in order to perform site-specific application of fertiliser.

Site-specific application is considered as a future eco-innovative technology by many agronomists. However, its adoption by farmers and in particular on farms with small field sizes is still relatively low. Some of the barriers are the complexity of the technology that consists of loose components, the lack of adequate service providers with 'knowhow', the initial investment costs of the systems compared with the yearly benefits and reliability (in particular) of the satellite based monitoring systems due to cloud cover, but similarly on tractor mounted systems.

Several studies have focused on farmers who already practice some kind of site-specific application or yield mapping and their perceptions on a general level. Factors that have been addressed of concern are, time consumption, accuracy of the system, compatibility with other systems and cost versus return (Pedersen and Pedersen 2002; Pedersen et al. 2003).

By using the latest crop monitoring systems (by combining hyperspectral cameras, UAVs, with crop simulation modelling) and integrating this into a comprehensive and directly deployable service may overcome these barriers.

Recently, the availability of site-specific variable-rate equipment (like sprayers and spreaders with GPS and on-board rate controllers) is increasing. Soil and crop simulation models can quantify yields and N-leaching under different soil, environmental and management conditions (Basso et al. 2011). Models can be useful for tactical management of N fertilizer rate in relation to water availability and radiation based on rainfall amounts). Basso et al. (2011, 2012) has demonstrated the economic and environmental advantages of using site-specific fertilizer applications (different zones within the field) and time (over different years) with the SALUS-model. So far, most of the focus has been on applying N fertilizer aimed at increasing crop yield. However, recently more focus has also been directed towards the environmental impact (nitrate leaching and nitrous oxide emissions) in relation to N fertilization strategies. By using a systems approach in crop and soil models, better management strategies are offered that both minimize the environmental impact and increase farmers' profitability. A number of models (including DAISY, FASSET and SALUS have been applied under a wide range of environmental and soil conditions for different crops (Basso et al. 2007, 2010, 2012; Pedersen 2003; Ritchie 1998; Senthilkumar et al. 2009).

1.3.1 Other Variable Inputs and Benefits

In principle, other inputs like potassium, phosphorus and lime can be applied site-specifically, and a conventional soil analysis that focuses on potassium, phosphorus and pH-values in the soil can be conducted site-specifically on grids and in management zones. These three inputs are rather "stable factors" and will be removed with the crop during harvest according to the crops' requirements. However, these inputs are also considered to have a relatively low economic impact. Lime is a low cost input that is applied every 5 years depending on the soil conditions and pH value, and potassium and phosphorus are usually applied in much smaller amounts compared with nitrogen. With lime application, – a low pH value means that the soil has a high acidity. In cases with low pH values, lime is added in order to balance the pH-value.

Studies on variable-rate lime application in the USA have shown that annual returns could increase by more than 20€ ha^{-1} based on simulation models for soybean and corn (Bongiovanni and Lowenberg-DeBoer 2000). A study by Wang et al. (2003) also indicated additional returns to variable rate lime application in combination with nitrogen application.

Site-specific control of pesticides are practices that have received increasing attention. A number of studies have investigated the economics of site-specific weed management (Swinton 2005; Franco et al. 2017). It was initially considered to have a large economic potential in many cropping systems because weeds are expected to be located in patches on the field (Leiva et al. 1997; Daberkow 1997; Audsley 1993; Gerhards et al. 1999; Christensen et al. 1997, 2014). However, since automated detection of weeds still needs improvements in terms of detection and low cost mapping, manual and visual weed detection is often the only practical solution at present. Timmermann et al. (2003) indicate that cost savings could range between 20 and 40 € ha^{-1} with site specific weed management in different arable crops. These costs savings are related to cost savings of herbicides, however, with GNSS it may also enable the farmer to obtain knowledge about his exact location during a specific spraying operation. For instance, it may be convenient or even labour saving to know the location in the field exactly if he suddenly has to end an operation at night or when refilling the sprayer. In that case, it is convenient to use the GNSS location coordinates and return back and continue next day without concerns about how to find the location. A study by Franco et al. (2017) indicated that the potential gains of site-specific herbicide application decrease significantly with increased precision in spraying. Research into insecticides has also gained interest recently. A study with aphids and ladybird beetles in cereals indicated that variable-rate spraying with sensor technology could reduce insecticide use by 13% on average (Dammer and Adamek 2012).

Site-specific seeding and in particular improved distribution of the seed in patterns instead of seeding in rows have also gained interest from researchers in precision farming. Studies have found that a better distribution of seeds can increase yields compared with traditional rows (Heeje 2013b).

Until recently, most remote sensing of crops in Precision Agriculture has been conducted with airoplanes or through satellite imaging to cover large areas in a short time. Recently, the Sentinel satellite images, with a resolution of 10 ×10 m per pixel, have become available to farmers every 5 days free of charge. These satellite images enable farmers to estimate N uptake from maps of Normalized Difference Vegetation Index (NDVI). Major disadvantages with these systems are the lack of flexibility and clouded conditions in many European regions, which makes it difficult to use these remote images. Other systems have been ground based and tractor mounted sensors, however, for these systems to be cost-efficient sensing operations must be carried out with other operations in the field like harvesting, spreading of fertilizers etc.

Recently, the development of UAVs (unmanned eerial vehicles) that can fly underneath the clouds has offered a new and flexible system, which provides images with high spatial resolution (1 pixel <10 cm). A light-weight hyperspectral camera can then be mounted on the UAV to make images to determine biomass index and density and site-specific crop growth. A UAV operator requires less training than with manned airoplanes and investment costs are lower.

So far, most farmers have not been able to process all the available farm information data in an optimal management system in order to make optimal decisions.

As illustrated above with site-specific application, the decision support needed to maximize net benefits is rather complicated and relies on many sources and management of these data that are both spatial and timely.

Big-data handling has become an integral part of precision farming together with the on-going use of crop and soil sensors and yield maps aimed at providing good decision support. However, so far the marginal revenues from site-specific application of nitrogen have been modest.

In parallel to site-specific application of inputs, guidance systems such as light bar systems and automatic guidance systems have been developed. In principle, light bar guidance and automatic guidance are the same except that with automatic guidance the driver does not have to steer after a light bar, but instead the vehicle steers automatically based on an automatic steering algorithm and GNSS signals that go directly to the electric and hydraulic steering actuators. A study by Heeje (2013a) showed that the area for the adoption of automatic guidance systems should be more than about 450 hectares in small grains in order to become profitable.

Auto-guidance is thereby a new way of utilising the GNSS system compared with site-specific application. Auto-guidance systems enable farm machinery to follow driving lines reducing overlaps of the tractor on the field. An auto-guidance system helps farmers to reduce fuel costs, input costs, time, labour costs, soil compaction and increases overall field efficiency as well as operator comfort and work quality. Auto-guidance systems can be used for many field operations such as seeding, tillage, planting, weeding and harvesting (Abidine et al. 2002). A further development of Auto-guidance systems that has proved economically viable on large farms is controlled traffic farming (CTF). The CTF enables farmers both to reduce overlap as with auto guidance and reduce soil compaction and additional fuel consumption on the field (Jensen et al. 2012).

The pathway and **development of new technologies** will often take different directions and speed depending on the complexity of the technology. S. Davies developed a model that characterises two different types of innovations: A and B. The first model is the A group, which illustrates the diffusion pattern for technologies that are fairly simple to use. The learning effects of this simple technology is initially very high but after some time the productivity gains from that technology will be limited implying that the curve falls and stabilises at a given level. The second group B of technologies is fairly complex to use (Fig. 1.3).

Variable-rate fertilizer application can be characterised as a fairly complex technology to use. It requires many systems to be integrated and time to be familiar with the technology and the productivity gains from that technology will take place at a much later stage compared with auto-steering for instance. The concept of variable-rate application is highly technical and requires skills that go beyond technical knowledge. It requires an understanding of the interrelated impact that various data and information have on yields, crop quality and nutrient leaching.

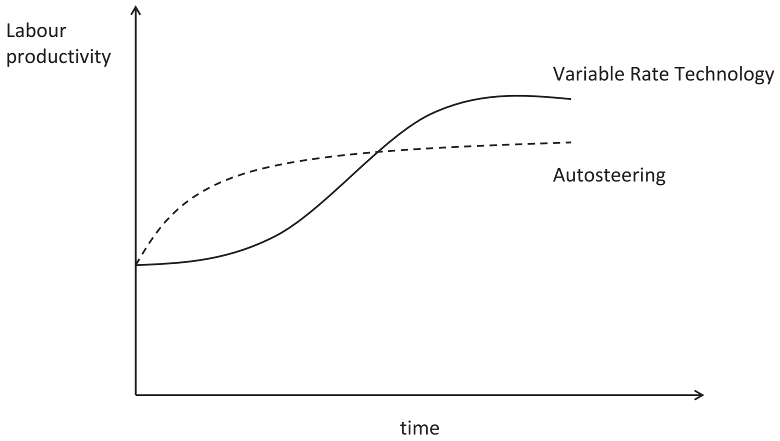

Fig. 1.3 Labour productivity for group A (autosteering systems) and group B Variable rate technology over time (Source: Based on Pedersen 2003; Davies 1979)

The adoption and diffusion of various techniques for practising precision farming depends therefore on the provision of advice, and technical as well as agronomic and biological guidelines.

In addition to the benefits from variable-rate application and reduced overlap and better route planning in the field, precision farming can also be a tool to trace the commodity from the field to the end consumer and thereby it can help to identify the geographical origin of final products in the supermarket. For some consumers, that information may be of value and they might even be willing to pay a premium for that information. In that case, supermarkets and supply companies may have an interest in providing farmers an incentive to use GPS on their farms.

1.4 Adoption of Precision Farming Systems

So far, there have been several surveys on the adoption and perception of site-specific application systems in Europe and North America (Reichardt and Jürgens 2008; Pedersen et al. 2001, 2003; Lawson et al. 2011).

Adoption of precision agriculture technologies is mainly driven by higher expected profits, OECD (2016). Consequently, the technologies that have demonstrated the highest earning potentials disseminate faster. Southern European countries are lagging behind in the adoption of new technologies in agriculture due to relatively small farms sizes (Lawson et al. 2011).

Table 1.2 shows the adoption of PA-technologies in England.

The table shows that positioning systems are the most adopted PA-technology, which is related to the documented significant higher expected profits from this technology. However, variable-rate application, although adopted less by farmers, is

Table 1.2 Farms using PA-technologies, % of farm holdings in England

PA-techologies	2009	2012
GPS	14	22
Soil mapping	14	20
Variable-rate application	13	16
Yield mapping	7	11
Telemetry	1	2

Source: OECD (2016)

still used by a significant proportion of farmers. Clearly, the table shows that positioning systems have had the highest growth rate from 2009 to 2012 relative to variable-rate application, which is most likely to be associated with the latter's mixed economic results.

A European market report from 2012 estimates that GNSS penetration into EU tractors will rise from 7.5% in 2012 to 35% in 2020 and currently about 70–80% of new farm equipment that is sold has some form of PF component inside. In addition, it is expected that average device GNSS/RTK prices will decrease by about 30% from 2012 to 2022, (EU Report 2014).

The United States Department of Agriculture (USDA) Economic Research Service has released a study on the adoption, use and portability of precision agriculture. In the study by Schimmelpfennig (2016), a survey on adoption shows that precision agriculture technologies were used on roughly 30–50% of maize/corn and soybean acres in the United States in the years 2010–2012.

This survey also allowed the examination of production and financial information for a large sample of farms. By focusing on three different technology systems, information mapping, guidance systems and variable-rate technology, the study shows that the use of GPS mapping had an impact on net returns of almost 2%. Guidance systems raise net returns by 1.5%. Variable-rate technology (VRT) raises net returns on maize farms by 1.1%. Yield mapping is mostly to be used on maize/corn and soybean crops although the use of yield maps has increased in other crops like wheat, peanuts and rice, Schimmelpfennig (2016).

A recent farm survey from 2016 from the State of Kansas in the US by Miller et al. (2017) with 348 farms shows that 228 farms (66% of the sample) have adopted auto-guidance systems on their farms. About 47% of the farms use automated section control, but only 17% of the farms use variable rate technology to apply seeds at site-specific rates. Variable-rate fertilizer application was used by 25% of the farmers.

In particular, the adoption of auto-steering systems has increased significantly in the last decade. A study by Lawson et al. (2011) shows a similar trend with high adoption of auto-guidance systems among large farms in Germany and Denmark. Compared with other technologies, the adoption of site-specific weed management has been slow in most countries, and farmers are often reluctant to implement PF technologies because of the high costs of investing in the technology and lack of technical compatibility with existing machinery (Pedersen 2003).

So far, PA have received most attention from countries in North America, Europe and Australia. However, recently more and more attention is coming from Asia and South America. About 90% of the 115.6 million of total farms in India has an area of less than 4 ha in size (Mondal and Basu 2009). A similar pattern with small farms can be observed in many other countries in Asia and Africa.

As investments in GPS systems and PA technologies are quite expensive and the financial burden should be distributed on a significant acreage before the returns from the field can cover the costs. The general perception is, therefore, that PA cannot be applied to small-scale farms in developing countries. To find the right technology for small scale farms to start with is therefore a challenge.

Some low cost technologies could be useful. The chlorophyll meter and leaf colour chart (LCC) are simple and portable tools that can be used for crop N status measurements in rice fields to determine the use of N application in real time (Mondal and Basu 2009).

However, so far most of the PF systems with GPS monitoring, auto-steering and VRT as the main technologies are designed for relatively large-scale farms located in mainly North America, Australia, Europe and South America.

1.5 The Aim and Organisation of this Book

The book is intended for readers who have an interest in precision farming and the economic potential for applying modern technology in arable farming. The book will provide a broad economic and technical insight into the area of advanced farming and cropping systems. In each area, it is the intention to provide the non-specialist with an update of some of the current precision farming technologies and their financial or economic potential among farmers. Each chapter address a different topic starting with an overview of the broad spectre of technologies that are currently available and subsequently followed by specific variable-rate technologies like, VRT fertilizer application, VRT pesticide application, site-specific irrigation management, auto-steering and controlled traffic systems. The following chapters look into new developments of autonomous systems with an example of robotic seeding, farm information management in precision farming and different methods on the adoption of PF. The last chapter focuses on how PF can fulfil the current policy trends on environmental regulations. As precision farming and farm information management have faced tremendous development in recent years and are expected to continue to develop further at high speed together with easier handling of big data sources, it is recommended that this book is updated within a relatively few years.

Chapter 2 of this book gives an overview of the current smart farming technologies that are available among farmers or are about to become available in the near future. Smart farming technologies (SFT) cover a range of different aspects of precision agriculture. This chapter provides an overview of data acquisition technologies, data analysis and evaluation technologies and precision application technologies. Furthermore, the reader can find a technical description of the technologies included in each category accompanied by a taxonomy of all SFT in terms of farming system type, cropping system, availability, level of investment and farmers' motives to adopt them. Finally, the economic impact that each SFT has in comparison to conventional agricultural practices is given.

Chapter 3 provides a first assessment of variable-rate treatment. It considers the potential economic impact of **variable-rate fertilizer application.** This chapter describes a framework for the economic assessment of site-specific fertilizer application and harvest management. It also provides an overview of selected studies and a future perspective of this technology. It concludes that precision farming technologies that aim to identify the economically optimal input rate (e.g. site-specific fertilizer application) often fail to provide considerable economic advantages for the farmer. This phenomenon can be explained by flat payoff functions, which are relevant for many agricultural production processes. Economically more promising technologies from a theoretical point of view are precision farming approaches that enable higher product prices by achieving specific product qualities (e.g. site-specific harvest management).

The purpose of precision farming technologies in relation to herbicide use is to reduce herbicide cost and to reduce environmental impact from spraying, but at the same time to control and maintain an acceptable weed population. Another purpose is to increase the spraying capacity, to reduce the number of sprayer refills, get faster treatment and a larger area per operation, and finally to minimize time-consuming activities like weed detection. Chapter 4 describes the relevance and profitability of four precision herbicide application technologies, two weed detection technologies and a low dose decision-support system (DSS) is analysed.

Chapter 5 focuses on the economics and perspectives of site-specific irrigation management with a focus on automated furrow irrigation, which is a new technology being developed commercially and offered to farmers in Australia. Improvements in water, fertilizer and labour efficiencies are possible with the more precise management of irrigation water, albeit with initial capital and ongoing management costs.

This analysis considers the economics of adopting an improved precision irrigation technology from two different perspectives: economics and environmental.

Chapter 6 provides an analysis of the feasibility of auto-steering systems and controlled traffic farming systems (CTF). In this chapter four different machinery cases were tested in four fields each and the main objective was to compare two different route planning systems under economic criteria apart from the best operational route coverage design criterion. The results show that there are significant reductions in the costs of operation which vary from 9–20%, depending on the specific machinery and field configurations. Such results show the considerable potential of advanced route planning designs and further optimization of farming systems.

Chapter 7 focuses in particular on the profitability of controlled traffic in grass silage production. From a farmer's perspective, the potential profitability of converting to CTF is determined by the existing machinery system and the required investment for a CTF conversion. Moreover, the on-farm profitability potential will be determined by the site-specific conditions in terms of yield response from CTF, opportunities to produce other cash crops and the knowledge and the involvement required in setting up and maintaining the CTF system.

Chapter 8 is looking into a pre-commercial and autonomous systems that have the potential to be implemented in the near future, namely robotic crop cultivation systems. The aim of this chapter is to describe the potential economic benefits from the application of agricultural robots under specific conditions and constraints. Examples given are the potential gross margin for early seeding and re-seeding in sugar beet. With some predefined assumptions with regard to speed, capacity and seed mapping, it was found that both early seeding with a small robot and re-seeding with a robot on a small part of the field could be financially viable solutions in sugar beet.

All the above technical systems require that farmers and advisors are able deploy the technologies in a farm management context. Chapter 9 provides a general description of farm management information systems (FMIS). This chapter presents the state-of-the-art depicting the new functionalities included in evolved FMISs and how they can connect the farm to the external context and stakeholders. Subsequently, the authors delve into the functionality of FMIS to understand how precision agriculture can improve the allocation of costs to the final product by managing PA in a better way.

Although many PA technologies are targeted at large scale farming with an aim to increase farm profitability, PA is also a measure to save on inputs and to maintain a sustainable production. Chapter 10 focuses on how precision farming as a sustainable technology can help to increase yields and reduce environmental impact in crop farming; a case study from Estonia is presented in which PF is one of the technologies among others. The application of different technologies used in crop production was analysed and many previously presented factors from the literature about sustainable intensification were described.

Recently, adoption of PA technologies has been addressed in several national as well as multinational studies. Chapter 11 provides an overview of different adoption studies that have been conducted on precision agriculture. It shows that PA has been shown to affect the performance of farms positively, even though its benefits vary according to the size of farms as well as their location. In light of the promising avenue that precision agriculture opens up, it is essential to understand which factors may facilitate its diffusion and through which processes. This chapter focuses on the models proposed to explain technology adoption. Morever, in this chapter some reflections are presented on how to expand knowledge of precision agriculture along this line of reasoning aimed at integrating personal and social characteristics. The importance of social network patterns and of social support in entrepreneurial initiatives that sustain precision agriculture adoption is also highlighted in this chapter.

Chapter 12 examines the perspectives of precision farming in a broader policy context. Agriculture is faced with contrasting opposing requirements from the broader society. On the one hand, agriculture needs to expand production in order to be able to feed a growing global population. Furthermore, the developing bioeconomy requires agriculture to produce 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 public goods 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 reduces resource use and increases yield. Furthermore, the growing demand for higher value food products in terms of health and quality properties that require traceability and information about production processes and resource use corresponds 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.

1.6 Summary and Main Findings

Precision farming has until now been technology driven in which several novel GPS based farm-technologies have been introduced in the farming society to make decisions about the site-specific application of nutrients and pesticides. The development is both driven by private companies and to some extent public interests. Most of the systems are designed to gather information about site-specific crop status and soil conditions and to make better decisions to increase yield or save inputs.

In the last decades, UAV's, auto-steering, controlled traffic farming and most recently autonomous systems in farming have emerged.

Findings from this book show that several of these new technologies and systems appear to be financially viable to implement among farmers. In particular, auto-steering has turned out to be profitable and has been adopted by many farmers. Moreover, UAVs and free of charge satellite images are expected to provide faster and more reliable images of the field conditions at lower costs. In addition, other specific farm management systems like site-specific irrigation appear to be viable as indicated from studies in Australia. Despite all these developments there is still a lack of adoption among farmers, especially small farms, and the economic benefits from variable rate technology still appear to be inconsequential.

One of the main focus areas is variable-rate nitrogen application, which has so far not provided significant returns to investments which is explained by flat response rate functions. To improve the adoption of variable nitrogen application, companies and researchers should continue the development of scientifically sound decision-support systems based on real-time information, soil monitoring, weather forecasts and the field history. Farmers need clear indications that show yield/profit improvements especially from variable-rate fertilizer technologies. To improve the development of PF the following aspects are important:

- More focus should be put on integrated farm management information systems and integrated decision support that include historic yields, soil texture, weather forecast and real time canopy sensing as well as financial variables.
- Need for more efficient image based autonomous systems to detect pests (weed, insects and fungi) in the field in order to provide reliable and cost efficient solutions to farmers.
- Site-specific fertilizer applications should integrate and manage manure, slurry and mineral fertilizers in an integrated fertilizer plan as well as real time information about crop's status.
- Manufacturers should focus on the development of compatible, reliable and low cost hardware that is easy to implement in existing farming systems.
- Better coordination of experiences and establishment of a common database about PF data among farmers.

Although the economic returns from different precision farming technologies have provided mixed results there are still promising perspectives in the light of the latest developments in UAV's, faster computers, better crop models and the introduction of small low cost cameras and sensing systems. All this combined with fast data processing with timely and accurate decision support is likely to be improved further in years to come. In addition, PF will be an important technology as a means to fulfil the current environmental trends that is a part of the regulation of farms across Europe as well as other countries.

Finally, the growing demand for higher value food products in terms of health and quality properties requiring traceability and information about production processes and resource use corresponds 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.

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