An analysis of precision agriculture in the South African summer grain producing areas

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Mini-dissertation submitted as partial fulfilment of the requirements for the completion of the degree *Master of Business Administration* at the Potchefstroom campus of the North-West University.

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November 2011

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ACKNOWLEDGEMENTS

KEY WORDS

Precision agriculture, precision farming, precision farmers, sustainable farming, crop management, management strategy, information technology, precision agriculture technologies, crop production, production areas, production method, cultivation, variability, management zones, sensors, monitoring, precision agriculture cycle, information, data analysis, decision making, implementation, evaluation, implementation systems, variable rate technology, outputs, inputs, economic advantages, environmental advantages, adoption, farming experience, perceptions, attitudes, precision agriculture group, non-precision agriculture group, total sample, education, marketing strategies.

ABSTRACT

Both globally and locally, agriculture faces ever increasing challenges such as high input costs, strict environmental laws, decrease in land for cultivation and an increase in demand due to the growing global population. Profitability and sustainability requires more effective production systems. Precision agriculture is identified as such a system and is built upon a system approach that aims to restructure the total system of agriculture towards low input, high efficiency and sustainable agriculture.

The aim of this study was to analyse the state of precision agriculture in the summer grain producing areas of South Africa, specifically the North West and Free State provinces. In order to achieve this, a literature study was conducted. During the literature study the term 'precision agriculture' was defined and discussed. The precision agriculture cycle and its components were explained and benefits of precision agriculture were identified. The literature study was concluded with identifying and discussing the most widely used and most beneficial technologies as well as reasons for slow adoption.

Findings from the literature study were used to investigate the state of precision agriculture locally. In order to achieve this, a quantitative approach was used and information was collected by means of an empirical study using a questionnaire. Questionnaires were distributed to farmers using selling agents of an agricultural company that is well represented in the targeted areas. The data was then statistically analysed.

The survey showed that only 52% of summer grain producing farmers in the North West and Free State provinces of South Africa practises precision agriculture as defined in the

literature study. The study also revealed that the majority of precision agriculture farmers are over the age of 40, have more than 16 years of farming experience, are well educated, cultivate more than 1,000 hectares and uses none or little irrigation. The most commonly used precision agriculture technologies were grid soil sampling and yield monitors. The perception among most of the farmers was that precision technologies are not very affordable, not easily available and that it lacks proper testing with regards to efficiency. The group of summer grain-producing farmers that have correctly implemented precision agriculture as per definition stated that the benefits they derived from precision technologies include reduction in input costs, increased outputs and improved management skills. Too high implementation costs and technologies not providing enough benefits were among the main reasons farmers do not implement precision agriculture.

It was concluded that a significant effort and amount of work is needed to increase the use of precision agriculture among summer grain-producing farmers in the targeted areas. A consolidated effort from government, agricultural institutions and agricultural companies will be needed to achieve this goal. Implementing precision agriculture as a system will require education (from primary to tertiary institutions) and improved marketing strategies. Only then will precision technologies be able to help meet the future demands placed on the agriculture sector.

SLEUTELWOORDE

Presisielandbou, presisieboerdery, presisieboere, volhoubare boerdery, gewasbestuur, bestuursstrategie, inligtingstegnologie, presisieboerderytegnologie, gewasproduksie, produksieareas, produksiemetode, verbouing, veranderlikheid, bestuursgebiede, sensors, monitering, presisieboerderysiklus, inligting, data-analise, besluitneming, implementering, evaluering, implementeringsisteme, differensiële tegnologie, uitsette, insette, ekonomiese voordele, omgewingsvoordele, boerdery-ondervinding, persepsies, ingesteldheid, presisieboerderygroep, nie-presisieboerderygroep, totale monster, onderwys, bemarkingstrategie.

OPSOMMING

Internasionale en plaaslike landbou verkeer onder toenemende druk weens hoë insetkostes, streng omgewingswette, afname in beskikbare grond vir bewerking en 'n toenemende vraag a.g.v. die groeiende wêreldbevolking. Winsgewendheid en volhoubaarheid is afhanklik van meer effektiewe produksiestelsels. Presisieboerdery is geïdentifiseer as 'n benadering wat gemik is op die herstrukturering van die totale stelsel van landbou na lae insetkostes, hoë doeltreffendheid en volhoubaarheid.

Die doel van die studie was om die stand van presisieboerdery in die somergraan-produserende gebiede van Suid-Afrika, spesifiek die Noordwes- en Vrystaatprovinsie, te bepaal. Ten einde dit te bereik, is 'n literatuurstudie gedoen. In die literatuurstudie is die term "presisieboerdery" gedefinieer en bespreek. Die presisieboerderysiklus en sy komponente is ondersoek en die voordele van presisieboerdery is geïdentifiseer. Die literatuurstudie is afgesluit met die identifisering en bespreking van die mees gebruikte en voordelige tegnologieë sowel as die redes vir nie-implementering.

Bevindinge uit die literatuurstudie is gebruik om die plaaslike stand van presisieboerdery te bepaal. 'n Kwantitatiewe benadering is gevolg en die inligting is ingesamel d.m.v. 'n empiriese studie met behulp van vraelyste. Verkoopsagente van 'n landbouonderneming wat goed verteenwoordig is in die geteikende gebiede, is gebruik om die vraelyste onder boere te versprei. Die data is statisties ontleed.

Die data het getoon dat slegs 52% van die somergraan-boere in die Noordwes en Vrystaat provinsies van Suid-Afrika presisieboerdery, soos gedefinieer in die literatuurstudie, beoefen

Die meerderheid van presisieboere was ouer as 40 jaar, het meer as 16 jaar boerdery-ondervinding, is goed gekwalifiseer en bewerk meer as 1,000 hektaar met min of geen besproeiing daarop. Die mees algemeen gebruikte presisieboerderytegnologieë was ruit-grondmonsterneming en opbrengsmonitors. Die persepsie onder die meerderheid van die boere was dat die presisietegnologieë nie baie bekostigbaar, geredelik beskikbaar of behoorlik getoets is met betrekking tot die doeltreffendheid nie. Die groep somergraan-produserende boere wat presisieboerdery volgens die definisie geïmplementeer het, het genoem dat hulle verskeie voordele soos verlaging in insetkostes, verhoogde uitsette en verbeterde bestuursvaardighede ondervind a.g.v. die gebruik van presisietegnologieë. Te hoë implementering koste en tegnologie wat nie genoeg voordele bied, was een van die vernaamste redes vir nie-implementering onder die boere.

Die studie het tot die gevolgtrekking gekom dat daar 'n betekenisvolle poging en hoeveelheid werk benodig word om die gebruik van presisieboerdery onder somer graan-produserende boere in die geteikende gebiede te verbeter. 'n Gesamentlike poging van die regering, landbou-instellings en landbou maatskappye sal nodig wees om hierdie doel te bereik. Implementering van presisieboerdery as 'n stelsel benodig onderrig (van primêre tot tersiêre instellings) en beter bemarkingstrategieë. Slegs dan sal presisietegnologieë bydra tot die toekoms van landbou en die eise wat daarmee gepaard gaan.

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LIST OF ABBREVIATIONS

Ca	Calcium
Cu	Copper
Fe	Iron
GIS	Geographic Information Systems
GPS	Global Positioning System
K	Potassium
Mg	Magnesium
Mn	Manganese
N	Nitrogen
OM	Organic matter
P	Phosphate
PA	Precision Agriculture
pH	power of H (hydrogen)
UFS	University of Free State
UK	United Kingdom
US or USA	United States of America
VRA	Variable Rate Application
VRC	Variable Rate Controlled
VRT	Variability Rate Technology
Zn	Zinc

CHAPTER 1: ORIENTATION AND PROBLEM STATEMENT

1.1 INTRODUCTION

Over the years, technological advances from several industries have contributed significantly to agricultural production systems (Zhang *et al.*, 2002:113). The industrial age provided agriculture with mechanisation and synthetic fertilizers, while the technology age presented genetic engineering and automation. Most recently, the information age added the prospective of integrating technological advances into precision agriculture (Whelan *et al.*, 1997:5).

The aim of precision agriculture (PA), namely monitoring of the spatial and temporal variability of soil and crop factors within a field, has been investigated for centuries. Before the implementation of agricultural mechanisation, very small field areas allowed farmers to manually adapt treatments. However, with increasing field area and more intense mechanisation, it has become progressively more difficult to measure and respond to field variability without revolutionary technology developments (Stafford, 2000:267).

The concept of PA is developed towards a system approach aiming at reorganizing the total system of farming to achieve low inputs, high efficiency and sustainable agriculture (Shibusawa, 1998). This new approach is advanced by the emergence and convergence of several technologies, for example Global Positioning System (GPS), geographic information system (GIS), miniaturized computer components, automatic control, in-field and remote sensing, mobile computing, advanced information processing and telecommunications (Gibbons, 2000).

PA offers environmental, practical and economic benefits. Increased yields, lower input costs and more productive work time will result in higher profits. Also, factors such as farm size, cropping cycle, variation in soil properties and consequently variation in yield affect the economics of farming. Practical and environmental benefits are mainly obtained from decreased operator dependence and reduced input wastage (Knight *et al.*, 2009).

The focus of PA is twofold: (i) developing comprehensive databases as a result of monitoring production variability in both space and time; and (ii) improving the accuracy of the consequent response (Whelan *et al.*, 1997:5). Production variability is affected by several factors, such as crop yield, soil properties, available nutrients, crop canopy volume, biomass,

moisture content and pest conditions (disease, weeds and insects). Measuring these factors employ a wide variety of sensors and instruments, for example field-based electronic sensors, spectro-radiometers, machine vision, airborne multispectral and hyper-spectral remote sensors, satellite imagery, thermal imaging, RFID and machine olfaction systems to name a few.

Currently, the most advanced sensing techniques provide data for crop biomass detection, weed detection, soil properties and nutrients and are very valuable tools for site specific management. In contrast, sensing techniques for disease detection and characterization, as well as crop water status, are based on more complex interaction between plant and sensor. The latter technologies are more difficult to implement on a field scale and also more complex to interpret (Lee *et al.*, 2010:2).

In general, the emergence of new technologies has been the results of "developer push" rather than "user pull". Unfortunately, most of the time insufficient attention is being paid to well-known technology adoption paradigms and as a consequence, the adoption of PA technologies leaves a lot of room for improvement. In addition, a large knowledge gap is often present between developers and users of PA and very little effort is made to bridge this gap. Developers can exert a stronger, positive influence on the rate and breadth of adoption by focusing on the development of protocols and realistic performance criteria, (Lamb *et al.*, 2007:4).

The rate of adoption of PA technologies varies considerably from country to country and even from region to region within countries. In the United Kingdom, a survey revealed that 15% of the farmers use one or more PA technologies (Fountas, 2001). A USA-based study conducted by Daberkow and McBride (2000) concluded that the highest rate of adoption was found among maize and soybean farmers in the Midwest region, while the lowest rate was found along the Southern Seaboard. The adoption rate among specific technologies also varies (Seelan *et al.*, 2003). For example, in USA and Canada the adoption rate of variable-rate fertilizer applications and yield monitors (based on GPS and GIS systems) is greater than 5% compared to only 1-5% in Australia, Brazil, Denmark, United Kingdom and Germany.

In view of the world population overtaking the seven billion mark and expecting to increase by another three billion over the next five decades, world food security is a major concern. Since arable land can only provide limited resources, the pressure on productive land is continually increasing. Based on projections, arable land (per capita) will decline from about

0.23 ha (2000) to about 0.15 ha in 2050. In contrast, the global demand for food is projected to increase by 1.5 to 2 times. This is due to the combined effects of a growing population and increasing demand for a richer diet by those ascending the economic ladder. Of major concern is the increased volatility in the cost of agricultural inputs and the income generated from farm products that contribute to the instability in the farm economy. This situation will rely on the introduction of new technologies to improve crop yield, provide information for better in-field management, reduce chemical and fertilizer costs through more efficient application, provide more accurate farm records, increase profit margin and reduce pollution. In other words, farm with precision to optimize inputs and outputs. Although innovative technology has the potential to alleviate the problem that is faced by future generations, an integrated approach would be central to its success (Seelan *et al.*, 2003).

Agriculture in South Africa is facing similar challenges - increasing input costs, especially with regards to labour getting more expensive, low and fluctuating commodity (grain) prices and a degree of uncertainty because of political interference. The aforementioned factors will necessitate South African farmers to monitor and manage their farming operations more effectively. The implementation of PA techniques to farming operations has the potential to provide solutions to the present challenges and assist farmers to achieve sustainability in the South African Agricultural sector.

1.2 BACKGROUND TO THE STUDY AND PROBLEM STATEMENT

The South African agricultural landscape is rapidly changing. External factors such as conflict in the oil producing countries, variation in the Rand against major currencies and increase in minimum wages are some of the factors that contribute to ever increasing input costs. The problem with labour is twofold – it is not only expensive but skilled workers also becoming increasingly scarce due to young people preferring city life over to that on the countryside. Fluctuating commodity prices, which sometimes fall below the cost of production, have caused many farmers to stop production and sell their land to more successful farmers. Consequently a new dynamic has come into being in South African agriculture with fewer farmers but with bigger commercial operations. Uncertainty is something that most of the farmers are faced with every day. This uncertainty is caused by political interference and proposed new laws that could have a dramatic effect on agriculture in South Africa. Another changing factor is rainfall patterns. The past years have seen an increase in annual rainfall as well as a shift in rainfall seasons.

Considering all of the above, it becomes obvious that the practices of the previous decade cannot ensure sustainability and profitability in the future. Practices that promote better management reduced input costs and increased yield is central to profitable and sustainable farming. Based on the studies used in the literature review, It seems that Precision Agriculture concepts and technologies have the potential to significantly reduce input costs and increase outputs.

1.3 OBJECTIVES OF THE STUDY

The objectives of the study are divided into primary and secondary objectives.

1.3.1 Primary Objectives

The primary objective of this study is to determine the percentage of farmers in the major summer crop producing areas of South Africa that have implemented PA practices and are using PA technologies. In addition, the study will provide a PA farmer profile for the targeted areas with regards to age, experience level, education, size of crops planted, irrigation usage and size and of the cultivated area.

Further the study will investigate PA technologies preferred by and currently used by summer crop-producing farmers in the targeted areas. The PA technologies will also be analysed on the basis of the farmer's perception of the availability, affordability and efficiency of each specific technology. Finally, the targeted farmers' view on the benefits provided by using PA practices and technologies will be analysed and discussed.

1.3.2 Secondary Objectives

To achieve the above-mentioned primary objectives, the following secondary objectives need to be accomplished:

- Defining the term "Precision Agriculture" and evaluating the targeted farmers' perceptions of the term.
- Exploring the various PA technologies used in summer grain producing areas of other countries (for example the USA) as well as PA products from these countries that have been demonstrated to yield reliable results.
- Examining the benefits of PA technologies available in literature.

- Identifying the most common factors that result in slow adoption of PA practices and technologies.

1.4 SCOPE OF THE STUDY

The study will apply Operation Management principles to analyze the use of PA technologies to improve the effectiveness of summer grain production. The aim is to determine the proportion of farmers that use PA technologies and practices to achieve more effective production. In addition, the preferred technologies as well as their result on farming operations will be investigated. This study will only focus on summer grains, i.e. maize (white and yellow), sunflowers and soybeans.

Information with regards to the range of available PA technologies as well as their usage and preference by farmers will be the obtained from relevant literature and internet sources.

The empirical study will focus on farmers operating in the major summer grain producing areas of South Africa, namely the Free State and North West provinces. The population sample will include farmers that are land owners, foremen and managers.

1.5 RESEARCH METHODOLOGY

Both primary and secondary resources will be used to gather information during the study. Primary sources will be used to identify available PA technologies and their usage by means of interviews and correspondence with industry leaders and farmers in the South African sector. Secondary resources will include journal publications, excerpts from text books as well as information obtained from reliable internet sources. The aforementioned resources will be used to provide an accurate definition of PA as well as identify the range of PA technologies and practices globally and evaluate their effectiveness.

The primary information will be collected by means of an empirical study. A quantitative research approach will be followed and the resulting data will provide an objective base to meet the research objectives. Questionnaires will be distributed to the summer grain producing farmers (i.e. farm owners, foremen and farm managers). These questionnaires will be distributed through the agent network of an agricultural company of which the author is an employee. The method will be effective in reaching farmers in the North West and Free State provinces since the agents are in continuous contact with the farming communities of these areas. Questionnaires will also be distributed to farmers by the author

himself. The aim is to collect data from a study population of at least one hundred farmers representing the two provinces.

The questionnaire will consist of two sections. The first section, Section A, will be used to construct a sample profile as well as a PA farmer profile. Section B will evaluate farmers' views of the definition of PA as well as the benefits, availability, efficiency and cost-effectiveness of PA technologies. This section will also be used to identify reasons for not adopting or slow adoption of PA. The data will be statistically analysed and presented.

1.6 LIMITATIONS OF THE STUDY

The most important challenge for the current study will be to get good representation from the population of summer grain-producing farmers in the target areas. According to the South African Department of Agriculture (2010) there are approximately 5 940 summer grain producing farmers in these two target areas. Given the limited time frame and the great distances between farmers and size of the target areas, it will not be possible to gain access to the entire population. The best approach to reach the majority of farmers in the shortest time frame was to make use of the agent network of an agricultural company with good representation within the targeted areas. The biggest risk of this strategy will be that the collection of the majority of data will now be in the hands of a network of agents that does not necessarily put the same value on the outcome of the study.

Most of the data obtained from secondary resources originated from international publications and text books which are not necessarily applicable to the South African context. On the other hand, South African research data for PA is very limited and most of the studies were conducted in the '90s and early 2000 which mean that some of the information derived from these sources can be out dated.

1.7 CHAPTER DIVISION

Chapter 1:   Introduction; Problem statement; Objectives of the study; Scope of The study; Research methodology; Limitations; Chapter division; and Chapter summary.

Chapter 2:   Literature study; Definition of PA; Identification and discussion of PA technologies, practices and the PA cycle and its components; Availability and usage of technologies; Identification of most beneficial technologies from

other leading summer grain-producing areas like the USA; Benefits of PA and the reasons for slow adoption; and Chapter summary.

Chapter 3:   Empirical study and methodology employed.

Chapter 4:   Findings, conclusions and recommendations.

1.8 CHAPTER SUMMARY

Precision Agriculture is built upon a system approach that aims to restructure the total system of agriculture towards low input, high efficiency and sustainable agriculture. This approach is fuelled by the development and union of a number of technologies, including Global Positioning System (GPS), geographic information system (GIS), miniaturized computer components, automatic control, in-field and remote sensing, mobile computing, advanced information processing and telecommunications. PA provides environmental, functional and economic advantages to farmers.

New technologies have mostly been developed through "developer push" rather than "user pull". The direct consequence being insufficient technology adoption models that result in slow adoption of PA technologies by farmers.

Globally, the challenges in agriculture are increasing. High input costs, strict environmental laws and low commodity prices that result in very low profit margins, to name a few. The agricultural sector in South Africa is not excluded from these challenges. To be profitable and sustainable it is necessary to investigate and implement more effective production practices. PA can help reduce inputs and increase outputs.

This study will evaluate the state of PA internationally as well as locally. The range of PA technologies used by summer grain-producing farmers will be identified. An empirical study will be conducted by means of a questionnaire that will be distributed amongst summer grain-producing farmers in the North West and Free State provinces of South Africa. The data obtained from these questionnaires will be statistically analysed in order to determine the portion of farmers that use PA technologies as well as the specific PA technologies most prominent in these areas. Finally, PA technologies will be evaluated with regards to availability, affordability and efficiency.

The study will aim to determine the adoption rate of PA in South Africa as well as factors that have a significant influence on the adoption rate. Possible benefits of PA will be identified and discussed.

The quantitative research data will be collected by means of a third party (agents' network from an agricultural company) of which the author is an employee. This may present some limitations to the study. The population size and distribution over a widespread area together with the short time frame may also provide limitations for this study.

The literature study will be discussed in chapter 2.

CHAPTER 2: LITERATURE STUDY

2.1 INTRODUCTION

Between 1980 and 2010, global agriculture has made tremendous progress in expanding the world's food production capacity. Even though the world population has doubled over this time period, food production has increased even faster with per capita food supplies increasing from less than 2000 calories per person per day in 1962 to more than 2500 calories in 1995. The increase in global food production is the result of better seed varieties, widespread irrigation, and higher fertilizer and pesticide use, commonly referred to as the Green Revolution (Corwin & Lesch, 2005:12).

The prospect of feeding a projected additional 3 billion people over the next 30 years poses more challenges than encountered in the past 30 years. In the short term, global resource experts predict that there will be adequate global food supplies, but the distribution of those supplies to malnourished people will be the most important challenge. In the longer term, however, the obstacles become more alarming, though not insurmountable. Although total yields continue to rise on a global basis, there is a disturbing decline in yield growth with some major crops such as wheat and maize reaching a 'yield plateau'. Feeding the ever increasing world population will require a sustainable agricultural system that can keep up with population growth (Corwin & Lesch, 2005:12).

Unfortunately, agriculture's effort to feed the world population has also resulted in damaging impacts such as loss of natural habitat, misuse of pesticides and fertilizers and soil and water resource degradation. By 1990, poor agricultural practices had contributed to the degradation of 38% of the roughly 1.5 billion hectares of global crop land. And since then the losses have continued at a rate of 5-6 million hectares annually (Corwin & Lesch, 2005:12).

From a global perspective, irrigation makes an essential contribution to the food needs of the world. Although only 15% of the world's farmland is under irrigation, it provides an estimated 35-49% of the total food and fibre supplies. Yet poor management of irrigated crop land has caused 10-15% of all irrigated land to suffer some degree of water logging and salinization. In fact, water logging and salinization alone represent a significant threat to the world's productivity and future production capacity (Corwin & Lesch, 2005:12).

Except for unexpected technological breakthroughs, sustainable agriculture has been identified as the most practical means of meeting the food demands for an ever-increasing population. The concept of sustainable agriculture is based on the delicate balance of maximizing crop productivity and maintaining economic stability while minimizing the utilization of finite natural resources and the detrimental environmental impacts of associated agrichemical pollutants (Corwin & Lesch, 2005:13).

Precision agriculture has been identified as the most promising approach for achieving sustainable agriculture and keeping productivity up with population growth. This chapter will focus on the definitions and current applications of precision agriculture. The precision agriculture cycle and its components will be discussed together with advantages and precision agriculture technologies. Technologies that have been proven most effective, most beneficial as well as most widely used will be highlighted. Finally, perceptions and attitudes towards precision agriculture as well as the adoption rate of the system will be investigated and discussed.

2.2 PRECISION AGRICULTURE DEFINED

Over the years various definitions were given to the term "precision agriculture". Godwin *et al.* (2003:376) defines precision agriculture as "a method of crop management by which areas of land or crop within a field are managed with different levels of inputs in that field". Precision agriculture can also be explained as the techniques that enable the application of variable-rate inputs to crops in order to satisfy the actual needs of parts of field rather than average need of the whole field (Xiang *et al.*, 2007:180). Precision farming is a process where a large field is divided into a finite number of sub-fields, allowing variation of inputs in accordance with collected data (Rusch, 2001:1). Another definition provided by Batte & Arnholt (2002:125) refers to precision agriculture as "an emerging technology with substantial promise to aid both farmers and society by improving production efficiency and or/or environmental stewardship".

To better understand the concept of precision agriculture, certain components of the above definitions must be emphasized and explained in more detail.

2.2.1 Precision agriculture as a process, method and management strategy

All of the above definitions highlight that precision farming is not a once-off implementation but rather an on-going process, method and management strategy. These methods or processes include:

LABORATORY TESTING & DATA

The modern day farmer depends on outside sources for key information (for example soil data). Testing laboratories provide analytical tests for determining nitrogen, phosphorus, potassium and other nutrients present in the soil. It is important for the farmer to select a method that will provide him with samples that will be representative of a specific site. For example, sample point selection can be done by using a sampling grid obtained with a geographic information system (GIS) (Pfister, 1998).

PLANTING – HOW AND WHAT

One of the advantages of current planting equipment is that it enables farmers to plant at variable seed rates. The rate is programmed according to the data available (for example field conditions and soil composition) for a specific site. The selection of the best seed variety for the specific set of conditions is also of critical importance. The biotechnology era has resulted in a wide variety of genetically enhanced cultivars. Farmers need to make informed choices with regards to the potential advantages that can result from choosing varieties that will perform best under his specific conditions (Pfister, 1998).

CROP SCOUTING

During the growing cycle of a specific crop it is of utmost importance to continually observe and document any signs of potential problems in the field. Crop scouts can use remote sensors, global positioning systems and geographical information systems to enable them to capture the relevant data.

VARIABLE RATE CHEMICAL APPLICATION

The development of automated sprayers that use VRT (variable rate technology) and VRA (variable rate application) has become a very important tool in precision agriculture. The practice of whole-field application of chemicals has been replaced by site-specific treatments

with VRA equipped sprayers. Data obtained from crop scouting and analysis of field conditions are used to program these sprayers to deliver the exact amount of a specific chemical according to the field requirement.

YIELD MONITORING

Yield monitoring is one of the most critical aspects of precision agriculture. Traditionally, yield was determined by weighing harvested batches of crops. However, precision agriculture has resulted in methods that provide instantaneous yield monitoring. The modern yield monitor utilizes sensors in the combine that continuously log grain flow during harvesting together with the speed of the combine (Pfister, 1998).

2.2.2 Smaller sub-fields, management zones and site specific zones

Precision agriculture is based on the principle of dividing large fields into smaller sub-fields, also called site-specific fields. The aim is to treat the smallest possible area as a single element. For example, instead of treating a whole field with herbicide due to the presence of a few weed infestations, site specific management will provide treatment only for the required areas. The definition of a site is simply the smallest unit a farmer can manage with the tools available, whether it is a hectare or an individual plant. The treatment of each site is determined by the needs of the specific site, as determined by soil test data, crop scouting reports and monitoring using sensors (Pfister, 1998).

2.2.3 Variability

Large fields are divided into smaller sub-fields, management zones or site-specific zones based on the variability of crop and soil factors within the specific field. According to Zhang *et al.(*2002:114) variability can be either spatial or temporal and as a result six groups are defined:

(1) *Yield variability:* Present and historical data that represent yield distributions.
(2) *Field variability:* Field topography (for example, elevation, slope, aspect and terrace: proximity to field boundary and stream).

(3) *Soil variability:*

- Soil fertility – N, P, Ca, Fe, Mn, Zn and Cu; soil fertility as provided by manure.
- Soil physical properties – texture, density, mechanical strength, moisture content and electrical conductivity.
- Soil chemical properties – pH, organic matter and salinity.
- Water holding capacity, hydraulic conductivity and soil depth.

(4) Crop Variability:

- Crop density
- Crop height
- Crop nutrient stress for N, P, K, Ca, Mg, C, Fe, Mn, Zn and Cu
- Crop water stress
- Crop biophysical properties – leaf area index, intercepted photosynthetically active radiation and biomass
- Crop leaf chlorophyll content
- Crop grain quality

(5) Variability in anomalous factors: For example, weed infestations, nematode infestations, disease infestations, wind and hay damage.

(6) *Management variability:* Examples of management variability include tillage practice, crop hybrid, crop seeding rate, crop rotation, irrigation pattern and fertilizer - and pesticide application.

2.2.4 Use of Technology

Technology development is the driving force behind precision agriculture. Effective and efficient implementation and use of precision agriculture systems requires technology. A brief outline of the available technology as described by Zhang *et al.* (2002:118):

- Sensors: Yield, field, soil, crop and anomaly sensors.
- Controls: Variable rate technology agro-chemical applicators, automatic guidance systems (incorporating global positioning systems), robotic harvesting systems, network systems and remote sensing systems.
- GIS (geographic information systems).

A more in-depth discussion of these technologies will follow under 2.3.

Based on the above-mentioned definitions of precision agriculture, the term can be summarized as a continuous process where data is gathered, analysed and the necessary actions taken to ultimately reduce inputs, increase outputs and conserve the environment. This can only be achieved in combination with technology. The previously mentioned definition of precision agriculture will be used throughout the study.

2.3 THE PRECISION AGRICULTURE CYCLE AND ITS COMPONENTS

Precision agriculture can be explained in terms of a circle or cycle. In this cycle there are several key components or principles that are imperative to the effective and efficient functioning of the cycle. Each of these components is dependent on each other and miss-management of one of these components will eventually influence all the other components and the cycle as a whole. Figure 2.1 illustrates the components of the precision agriculture cycle as described by Grisso *et al*, 2009.

FIGURE 2.1 Schematic representation of the components of the precision agriculture cycle illustrating their interdependence (Grisso *et al.*, 2009).

2.3.1 Components (actions) of precision agriculture cycle

GATHERING OF INFORMATION

The end product of the precision farming cycle is results. These results are not only collected at the end but also throughout the entire cycle. In Figure 1 the yield monitor represents the process of gathering information. The information gathered from the yield monitor is presented in a yield map. The yield map can show the yield across different parts of the field as well as the average yield for the total land harvested. Yield data is one set of information gathered during this phase of the precision agriculture cycle. Companies like Massey Ferguson have also done a lot of work on mapping other data sets as well. The data required for the construction of a value map can be collected automatically (for example, yield monitors) or manually (for example, data from soil sample analysis that is used for soil nutrient status maps). Manual collection of data is generally not worth the effort. However, in the case of soil samples, the standard practice is still manual sampling and subsequent laboratory testing (Rusch, 2001:5).

Rusch (2001:7) states that collection of different data sets in combination with geo-referencing provide valuable information for map construction. Some of the possible sets include:

- Yield (mainly cash crops, but also forage and sugar cane)
- Vigorousness of growth (either by satellite or during plant protection measures)
- Soil type
- Soil nutrient status for variety of macro and micro nutrients
- Disease status of the soil (nematodes etc.)
- Soil resistance to cultivation
- Heat uptake of soil in spring (soil temperature)

The ideal situation is to utilize every trip over a specific field to collect a useful data set, i.e. a value map.

EVALUATION (ANALYSIS) OF INFORMATION

The "information evaluation" component of the precision agriculture cycle is based on in-depth analysis, evaluation and assessment of the data obtained during the previous stage.

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Rucsh (2001:7) shows that using local knowledge as observed over the year can save considerable time. The main aim of the evaluation should be to assess whether the data is accurate and if not, find possible errors in the monitoring system. Generally, a set of 3 yield maps is required to start implementing the system. Without additional, supplementary information, data from at least 3 yield maps will confirm if yield in a particular sub-field is consistent in the long-term (Rusch, 2001).

According to Rusch (2001:8) the process as illustrated in Figure 2.2 needs to be followed for the construction of every value map in order to determine which parts of the map reflects long term trends and which parts have been influenced by seasonal factors like water logging, drought or disease spots. Moore (1998) also suggested that physical soil properties need to be evaluated prior to chemical soil properties due to the finding that physical problems are generally responsible for decreased yield for a particular sub-field.
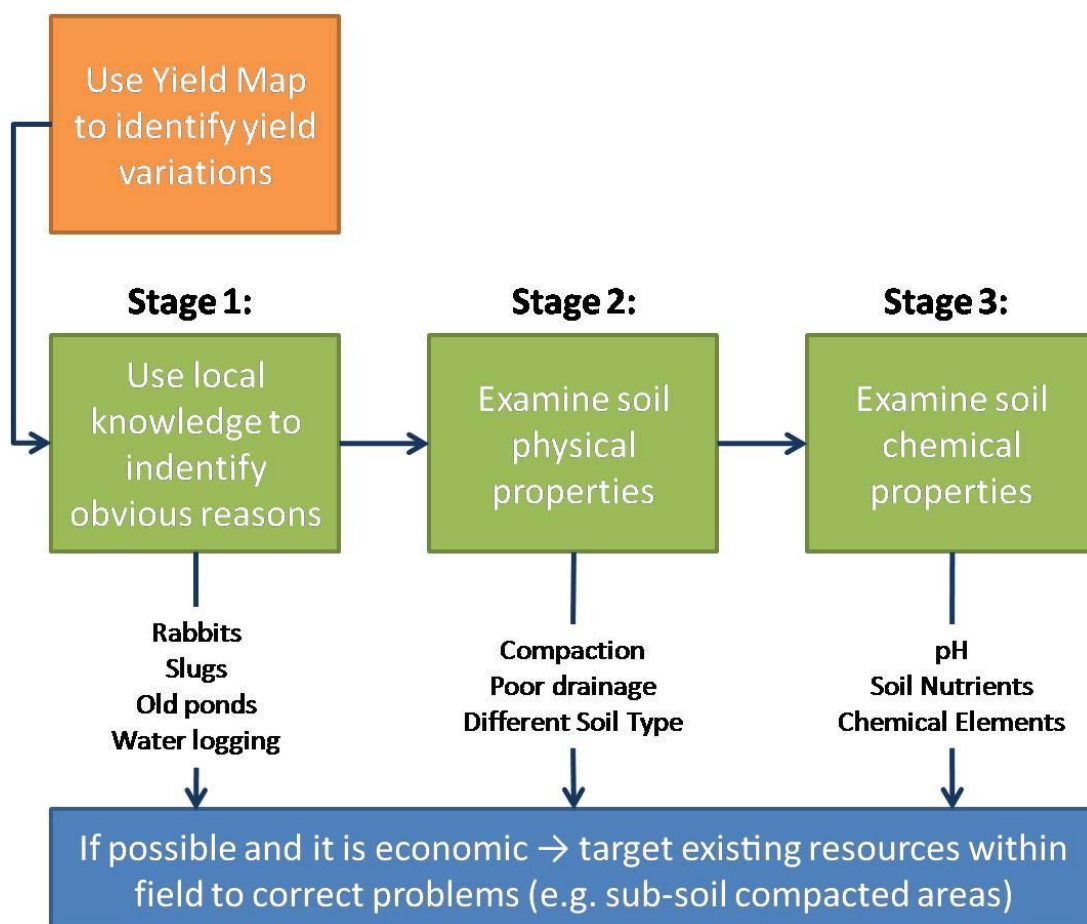

FIGURE 2.2 Strategy to evaluate reasons for yield variations (Rusch, 2001:83).

According to Moore (1998), local knowledge is important when evaluating a map. Local knowledge can be collected from all observations made during a specific growing season.

Moore also states that long-term trends can be established faster when using satellite images to identify the specific parts of the field that indicate long-term trends. This statement is also backed by Bornman (1998). He adds that either satellite or aerial imagery must be used to identify the distribution of growth vigorousness across a field in order to identify areas where high vigorousness resulted in high yield and areas where low vigorousness resulted in low yield. All other combinations of vigorousness and yield will be atypical, and therefore not represent a long-term trend (Rusch, 2001:9).

DECISION-MAKING

Decision-making is an important step in the precision agriculture cycle and is required for developing a precision agriculture strategy. The information gathered is meaningless unless the results are applied to solve problems or to meet farm goals. Bouma (1997:1764) categorize the decisions farmers make in terms of strategic, tactical and operational decisions, all of which are focused on achieving a profitable enterprise. Strategic decisions have a time scope of 10 years or more and concern issues like the selection of a farming system (for example, mixed, organic or integrated). The choice to switch from conventional to precision farming may be considered a strategic decision as well.

Tactical decisions typically involve a period of around 2 to 5 years which also corresponds approximately to the time span of a crop rotation. The selection of a rotation scheme mainly involves agronomic considerations. Decisions regarding best crop for rotation as well as management practice are based upon soil nutrient status, soil water treatment, tillage practices, mineralization of organic matter, and structural stability of the soil.

Operational decisions are taken on a daily basis throughout the entire growing season. These decisions include the selection and timing of management operations such as planting, harvesting, fertilizer application and crop protection measures. The precision agriculture cycle and the information obtained from it is mostly for the operational decision making process.

Due to the amount of decisions, complexity and time constraints required for effective decision making it is usually supported by information technology. This is termed a decision support system. A decision support system enables the farmer to quickly evaluate a multitude of different scenarios based on all the variables influencing his farming operation and highlights the critical steps forward in the farming process. These decision support systems range from entry level to highly advanced systems. An example of an entry-level

decision support system is a software program that comes with a yield monitor. This software enables the farmer to view raw data, determine the field size, and represent the yield in a typical graphic format. The user may also associate certain application rates for certain yields and export these to application equipment.

Since the data presented to the farmer becomes increasingly more complex (for example, tractive effort maps) entry level systems are not able to provide the requirements needed for effective decision making. As soon as more than one value map has to be evaluated at once, these entry-level systems need to be replaced with more advanced systems allowing the user to evaluate more than one value map against a host of varying requirements at once. Though generic systems are commercially available, most of these high-end decision support systems are custom programmed for the purpose (Rusch, 2001:9).

Figure 2.3 illustrates the actions required for the decision making process in order to add value. If used correctly, a decision support system will improve the effectiveness of precision agriculture.

IMPLEMENTATION

The outputs provided by the decision support system will allow the farmer to take specific actions. These actions can include varying the population rate of fields and sub-fields, varying fertilizer application and varying pest control in fields and sub-fields. The limits of a specific treatment can be defined and the crop can then be treated as needed (Rusch, 2001:10).

2.3.2 Components (Technical) of precision agriculture cycle
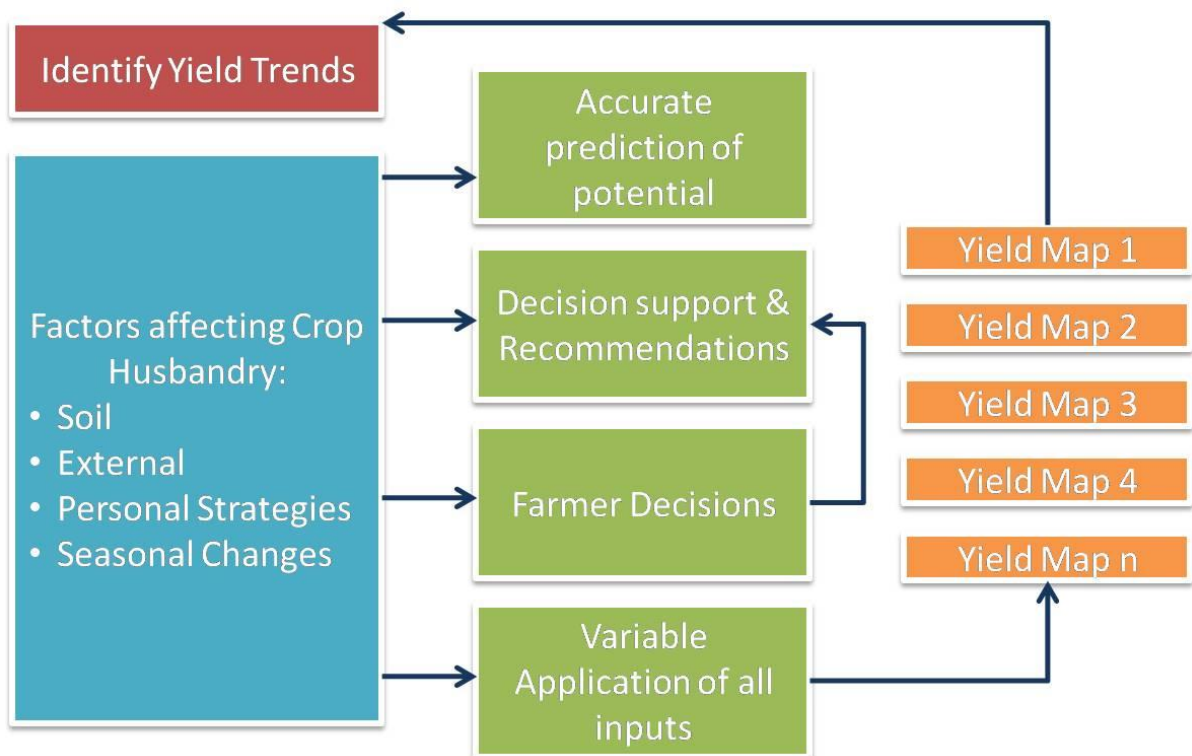
FIGURE 2.3 Flow diagram illustrating the concept of decision support (Moore, 1998).

GATHERING OF INFORMATION

In addition to collecting a large variety of information, it is of critical importance that information is not only accurate but also up-to-date. Engineering innovations have contributed a lot in this area. Currently, the following technologies are available to collect information:

YIELD SENSORS (MONITORS)

Area specific yields in a field can be measured by using a combine mounted sensor or volume meter. Yields are measured using four types of yield sensors, namely, impact -, mass flow -, optical yield - and ray sensors. A GPS receiver mounted on the combine provides the spatial coordinates so that the yield data can be assigned to specific, small areas of a field to create a field map as shown in Figure 2.4. Yield monitors are available for grain, forage and cotton crops (Zang *et al.*, 2002:118).
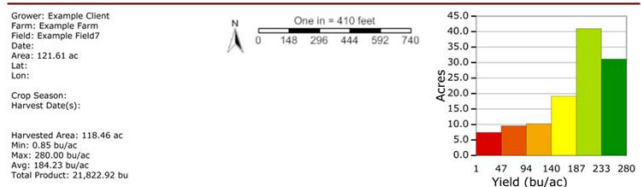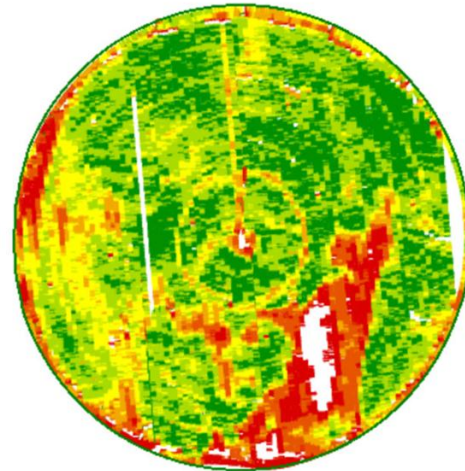
FIGURE 2.4 Ag leader yield sensor and subsequent yield map (Source: Ag Leader).

REMOTE SENSING

Remote sensors are devices that are able to collect data from a distance. This is achieved by light reflectance collected by instruments in airplanes, orbiting satellites or hand-held devices. Figure 2.5 demonstrates the satellite remote sensing process as used in agricultural monitoring processes. Remote-sensed data provide a valuable tool for evaluating crop health. Overhead images can also help detect plant stress related to moisture, nutrients, compaction and crop diseases. Remote sensors are mostly used to reveal in-season variability that affects crop yield. The real-time information provided by these sensors is valuable tools for making management decisions to improve the profitability of the current crop.
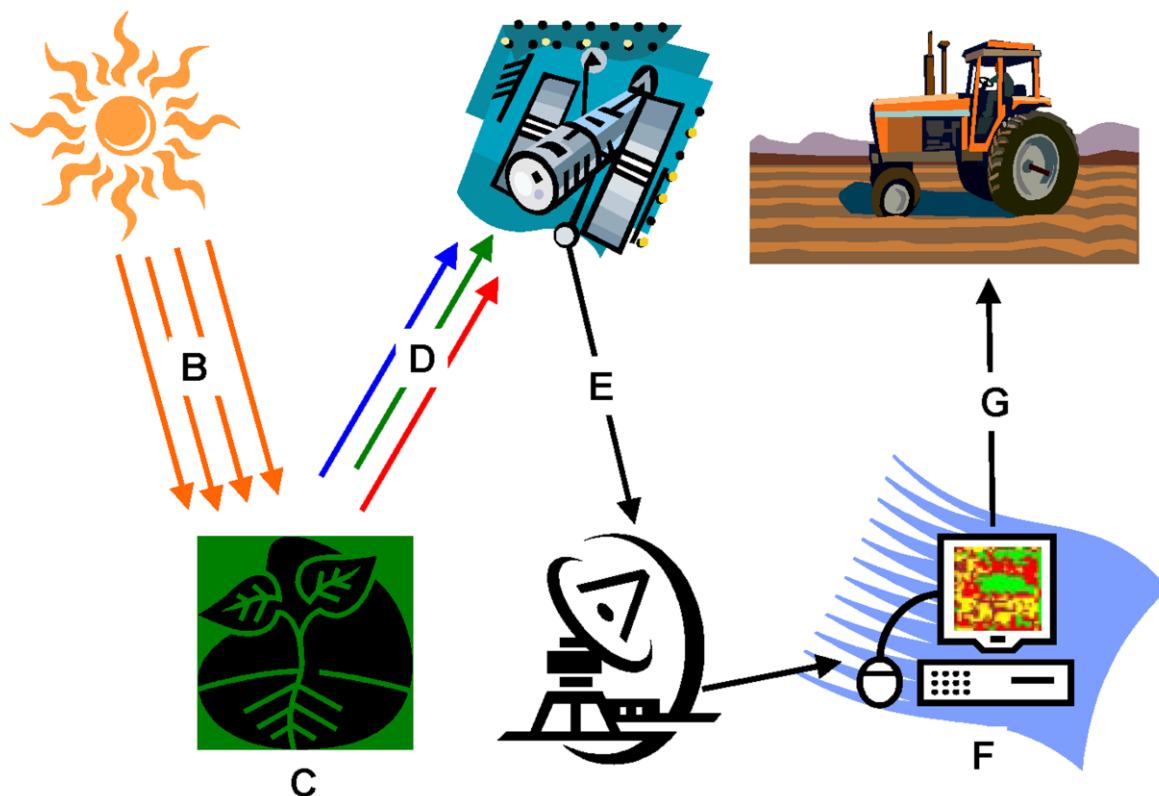
FIGURE 2.5 Illustration of the satellite remote sensing process as applied to agricultural monitoring processes. The sun (A) emits electromagnetic energy (B) to plants (C). A portion of the electromagnetic energy is transmitted through the leaves. The sensor on the satellite detects the reflected energy (D). The data is then transmitted to the ground station (E). The data is analysed (F) and displayed on field maps (G). (Nowatzki *et al.*, 2004)

SOIL SENSORS

Information about the variability of different soil characteristics within a field is essential for the decision making process. Soil testing results in combination with information about the available nutrients forms the foundation for planning fertility programs for different crops (Adamchuck *et al.*, 2004:71). Soil information can be obtained in two ways. The first is by physically obtaining samples throughout fields and analysing these samples at a laboratory. Adamchuck *et al.* (2004:72) points out that the standard test usually include determination of available phosphorus (P), exchangeable potassium (K), calcium (Ca), and lime requirement. Some laboratories may also test for organic matter (OM) content, salinity, nitrate, sulphate, certain micronutrients, and heavy metals. These methods are not only expensive but time consuming.

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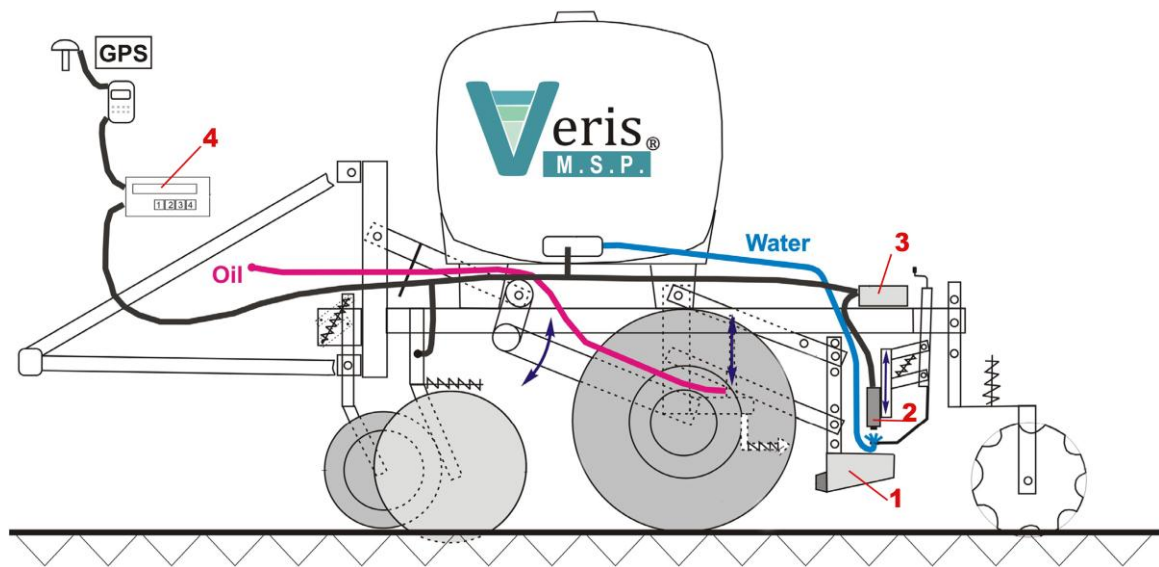
FIGURE 2.6 Schematic representation of a real-time soil sensor used for soil pH mapping. The components indicated (1) to (4) are (1) Soil sampler shoe; (2) pH electrodes; (3) External controller; and (4) User interaction device (Schirrmann *et al.*, 2011:578).

Another method to obtain soil information is through the use of on-the-go soil sensors as illustrated in Figure 2.6. According to Adamchuck *et al.* (2004:72) on-the-go soil sensors can increase the effectiveness of precision agriculture by providing better representative results from the increased density of measurements at a relatively low cost. There is a large variety of design concepts and most of the on-the-go soil sensors involve one of the following measurement methods:

- Electrical and electromagnetic sensors that measure electrical resistivity/conductivity, capacitance or inductance affected by the composition of tested soil.
- Optical and radiometric sensors use electromagnetic waves to detect the level of energy absorbed/reflected by soil particles.
- Mechanical sensors measure forces resulting from a tool inserted into the soil.
- Acoustic sensors quantify the sound produced by a tool interacting with the soil.
- Pneumatic sensors measure the ability to introduce air into the soil.
- Electromechanical sensors use ion-selective membranes that produce a voltage output as a result of the activity of selected ions.

GLOBAL POSITIONING SYSTEM (GPS)

The global positioning system is a network of satellites developed for and managed by the U.S Defence department. The GPS constellation of 24 satellites orbiting the earth, transmit precise satellite time and location information to ground receivers. The ground receiving units are able to receive this location information from several satellites at a time for use in calculating a triangulation fix, thus determining the exact location of the receiver. Global positioning sensors provide continuous position information in real time, while in motion. Having precise location information at any time allows soil and crop measurements to be mapped. GPS receivers, either carried to the field or mounted on implements allow users to return to specific locations to sample or treat those areas.

In addition to location based information, GPS technology also makes satellite-based auto guidance possible. As seen in Figure 2.7, auto-guidance is the guidance of agricultural vehicles using satellite-based positioning equipment.

According to the University of Nebraska (2011) benefits of this technology includes:

- Reduced skips and overlaps
- Lower operator fatigue
- Ability to work in poor visibility conditions
- Minimal setup and service time
- Ease of use
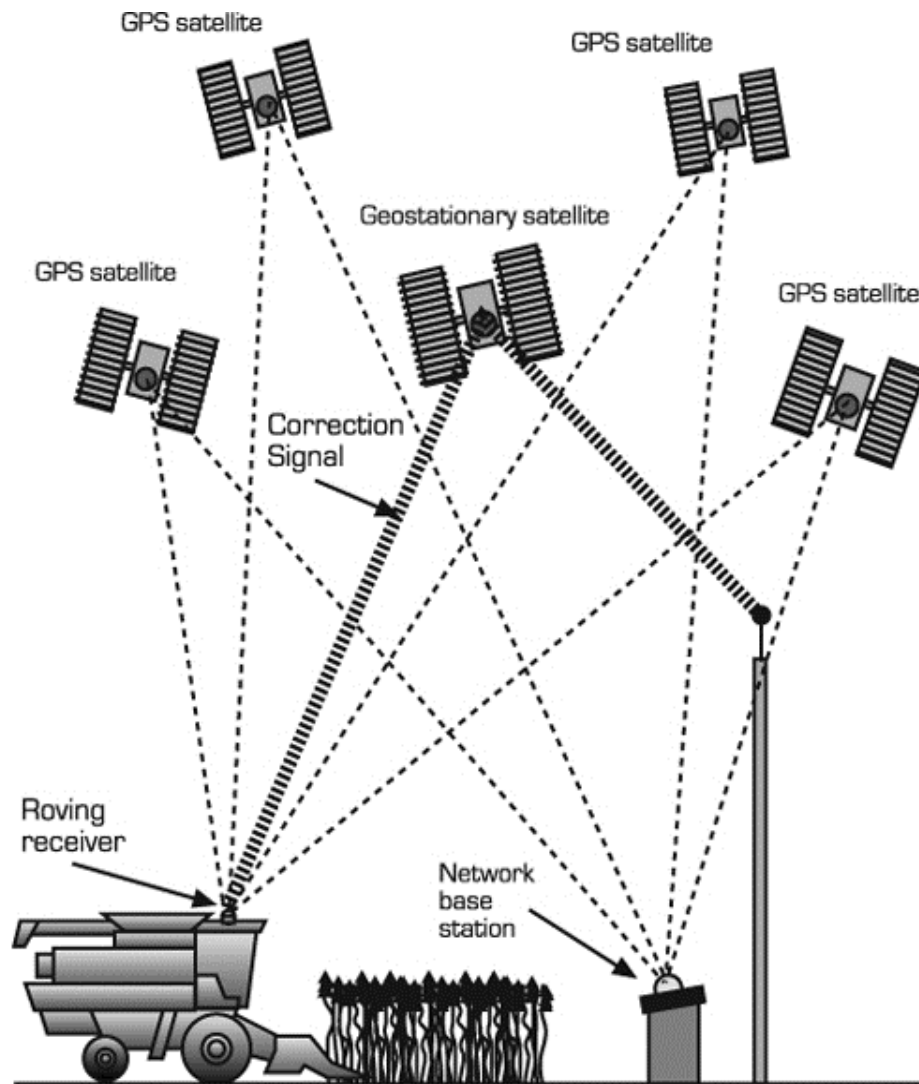
FIGURE 2.7 GPS systems can provide location-specific data that can be used for mapping as well as enable, for example tractors, to be steered by satellite-based auto guidance software (Grisso, 2009).

2.3.3 Evaluation of information and decision making technical components

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographic information systems (GIS) are a combination of computer hardware and software that combine characteristics and location information to produce maps.

Agricultural GIS systems have the ability to store layers of information, such as yields, soil survey maps, remote-sensed data, crop scouting reports and nutrient levels obtained from sensors and convert them into valuable and easily understandable maps that the farmer can use to make decisions.
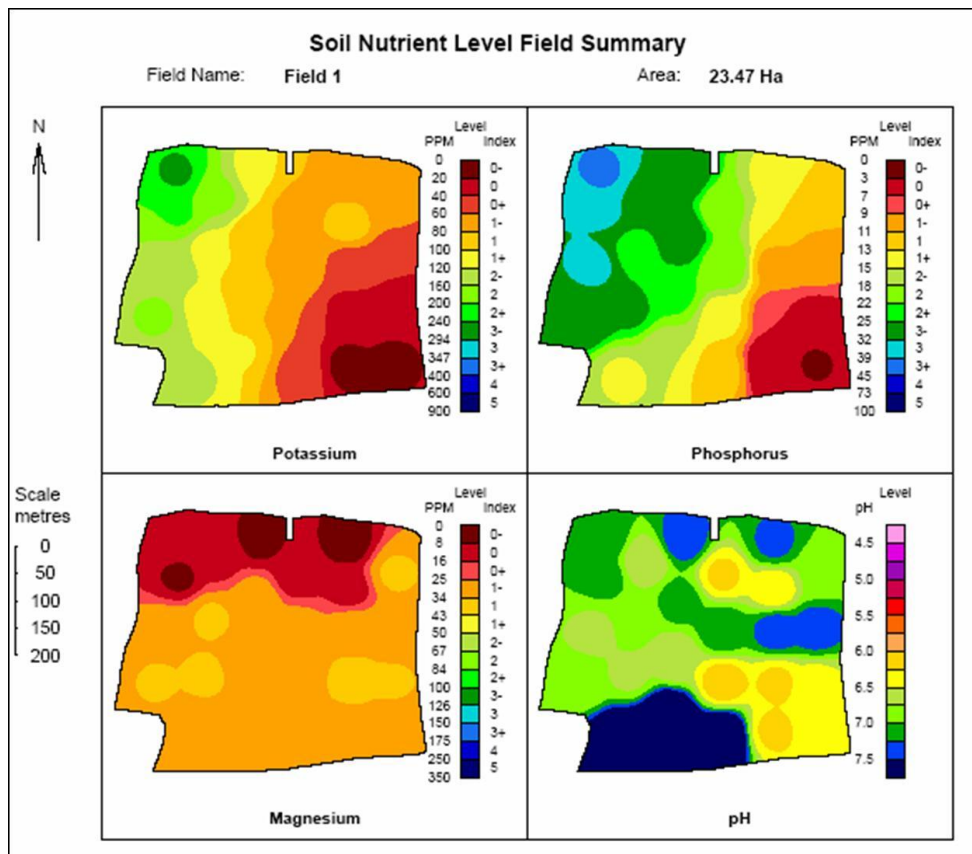
FIGURE 2.8 GIS produced nutrient map showing potassium, phosphorus, magnesium and pH of a specific field (Source: Brett Brothers Limited).

IMPLEMENTATION SYSTEMS

After drawing up an implementation schedule, inputs can be applied according to the potential, which has been determined by the decision support system that uses information such as previous yield maps, personal strategies, and the planned crop for the next season (Rusch, 2001:10). One of the methods that can be used to apply inputs according to GIS-obtained information is called "Variable Rate Technology" (VRT). VRT allows the farmer to apply the exact quantity of inputs required at a specific location in the field. Crop inputs that can be varied in their application include tillage, fertilizer, weed control, insect control, plant variety, plant population and irrigation. Figure 9 shows a fertilizer spreader that utilizes VRT.

A typical VRT system consists out of a computer controller, a GPS receiver and a prescription map obtained from a GIS map database. The computer controller can adjust the equipment application rate of the crop input as previously determined. The computer controller is integrated with the GIS database, which contains the flow rate instructions for the application equipment. A GPS receiver is linked to the computer and the computer controller uses the location coordinates from the GPS unit to find the equipment location on

the map provided by the GIS unit. The computer controller reads the instructions from the GIS system and varies the rate of crop input being applied as the equipment moves across the field. The computer controller will record the actual rates applied at each location in the field and store the information in the GIS system, thereby constructing precise field maps of materials applied.

FIGURE 2.9 A variable rate fertilizer spreader in action (Fulton, 2011).

2.4 ADVANTAGES AND BENEFITS OF PRECISION AGRICULTURE

Precision agriculture not only provides economic and environmental advantages and benefits but also other advantages as shown over the years.

2.4.1 Economic advantages

According to Godwin *et al.* (2003:376) a major economic benefit from precision agriculture is the increased economic margin for crop production which results from both improvements in yield and reduction in inputs. More effective use of inputs results in increased crop yield, increased quality and reduced input costs. Precision Agronomics Australia also adds that precision agriculture technologies result in increased technical efficiency and thereby reducing input costs. A study conducted by the University of the Free State (2005) presented additional economic benefits from precision farming as reduced manpower, guidance saving

costs of making swaths and decreased operator fatigue and as a result enhanced productivity due to automatic steering.

2.4.2 Environmental advantages and benefits

According to Zhang *et al.* (2002:114) the strict environmental legislations enforced in countries like USA, Australia, UK, Denmark and Germany indicate a future trend towards directives that will force farmers to significantly reduce their usage of agro-chemicals. Zhang added that precision agriculture provides the means of precise and targeted application, recording of all field treatments at the meter scale, tracking from operation to operation and transfer of recorded information with the harvested products, all of which would assist in enforcement of the legislations. Godwin *et al.* (2003:376) also supports this statement and adds that the risk of environmental pollution from agro-chemicals applied at levels greater than the optimal can be reduced by implementing precision agriculture practices.

Another environmental benefit of precision agriculture is the reduced erosion. This can be achieved because the interaction between tillage and soil/water erosion can be studied with the availability of topographic data for fields implemented with precision agriculture technologies.

Water is a resource that is in short supply, and unlike oil there is no substitute for its dwindling supply. Spiker (2009) warned that only 2.53% of the total available water on earth is fresh, drinkable water. Also, two-thirds of the water on earth is inaccessible, locked in glaciers and permanent snow. It is essential that water is conserved. Worldwide, irrigation farming is the largest consumer of water, thus focusing on efficient use of water for agricultural purposes is critical. Precision agriculture technologies allow farmers to reduce their consumption of agricultural water and maximize accessible drinking water. Precision Agronomics of Australia also adds reduction of carbon emissions to the list of environmental benefits of precision agriculture.

2.4.3 Other benefits and advantages

Batte & Arnholt (2003:127) found that farmers derive value from the record keeping and documentation functions of precision agriculture. For instance, yield monitors, GPS receivers, and GIS mapping are useful to maintain precise records of the location, hectares planted, and yields of crops and may be a facilitating technology for identity preservation.

Another benefit from precision agriculture is the surety accurate targeting and recording of field applications provide to improve traceability (Godwin *et al.*, 2003:376).

Helm (2005:76) adds that precision agriculture stimulates and benefits management on different levels resulting in reduced risk and increased management capacity. It was also found that precision agriculture assists farmers in identifying problems in areas in their fields previously unknown to them.

Precision Agronomics Australia identified the following added benefits from precision agriculture:

- Increased speed and timeliness of operations
- Improved ease and efficiency of operations
- Work more hours/shifts safely
- Greater flexibility in the use of labour
- Options for commodity tracking/preservation of identity
- Potentially reduced chemical and fertiliser storage and handling which provides a safer working environment
- Spatial recording of operations to avoid litigation
- Spatial recording of operations for insurance claims
- Increased peace of mind/management confidence.

2.5 MOST WIDELY USED AND MOST BENEFICIAL PRECISION TECHNOLOGIES

A study by Batte & Arnold (2003:135) identified the most commonly used precision agriculture technology in the US as yield monitors, GPS receivers, GIS mapping software and geo-referenced grid or zone management soil sampling. The study revealed that the majority of the farmers represented by the study started with the use of a yield monitor. The second largest group of farmers started using precision agriculture technologies by implementing grid or zone soil sampling. Although variable rate application of inputs is considered one of the most important components of precision agriculture, only 50% of the farmers included in the particular study used VRT applications. Also, VRT application of herbicides was used far more than VRT application of seed populations or site-specific variety selection. The economics of the previously mentioned practices were questioned by several groups due to high costs associated with VRT equipment, consulting services as well as soil sampling. Dolan (2007) reported that although VRT fertilizer applications have

increased significantly over the years, GPS guidance technology has seen the most growth in the precision agriculture industry. Figure 10 represents an overview of technology adoption by USA farmers that was done by Winstead *et al.* in 2010.
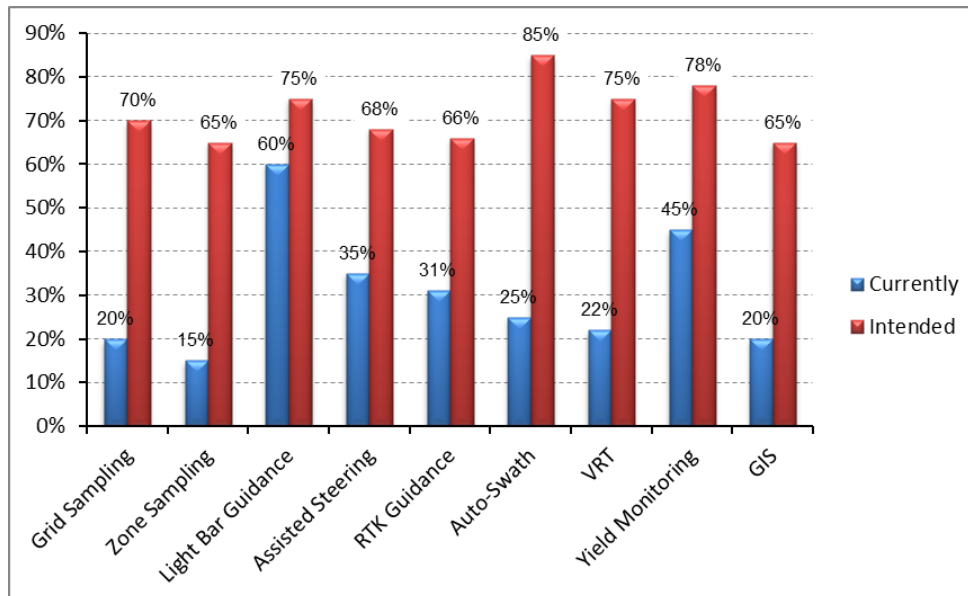
FIGURE 2.10 Percentage adoption of different precision agriculture technologies by farmers in the USA (Winstead *et al.*, 2010).

Griffin *et al.* (2010) found that in some parts of the world variable rate fertilizer application is much more profitable than other parts and therefore it is used more commonly. Their data also revealed that in some areas farmers and agribusinesses pay a lot of attention to yield monitor data and its subsequent analysis while other groups focus on guidance systems as the subset of precision agriculture that significantly influence their profitability. In the US, evidence suggests that an overall reduction in grid and soil sampling has occurred; however, in localized areas precision soil sampling methods are common and are mostly done by a reputable third-party precision agriculture expert (Griffin *et al.*, 2010).

The study by Griffin *et al.* (2010) also showed the same trend as Growing Innovations that GPS-enabled navigation technologies have grown significantly - from 22% in 2005 to 41% in 2009. This may be due to some evidence that suggests that GPS guidance has a return on investment of less than one year. Table 2.1 summarizes the number of yield monitors by country:

TABLE 2.1 Number of yield monitors by country (Griffin *et al.,* 2010)

COUNTRY	ESTIMATED NUMBER	YEAR OF ESTIMATE	YIELD MONITORS PER MILLION HECTARES
USA	30 000	2000	335
Argentina	5000	2009	172
Brazil	500	2009	11
Chile	60	2009	100
Uruguay	150	2009	100
U.K.	400	2000	107
Denmark	400	2000	247
France	50	2000	5
Germany	4250	2003	523
Netherlands	6	2000	27
Sweden	150	2000	119
Belgium	6	2000	17
Spain	5	2003	1
Portugal	4	2003	6
Australia	800	2000	42
South Africa	15	2000	3

A survey by the University of the Free State (UFS) on the status of precision agriculture in South Africa found that precision agriculture is growing fast (Helm, 2005). The following estimates where calculated:

- Yield monitors and mapping: 40 (2001) to more than 600 (2005) farming units with 35% doing just monitoring not mapping.
- VRC (variable rate controlled) application for lime: 16 (2001), 5% done by companies contracting VRC services to farming units to 244 (2005) with 12% farming units doing their own VRC application, with their own converted spreaders.
- Variable rate application of fertilizer: 8 (2001), 87% done by companies contracting VRC services to farming units to 251 (2005) with 15% farming units doing their own VRC application, with their own converted applicators and planters.
- Manual Guidance: 200 (2005) farming units.
- Automatic Guidance: 50 (2005) farming units.

2.6 REASONS FOR SLOW ADOPTION OF PA TECHNOLOGIES

According to Swinton & Lowenberg-DeBoer (2001:557), technology adoption can be examined across space or time. Either way, the pattern of precision agriculture technology

adoption has been uneven. Despite rapid growth of global commerce and the widespread availability of equipment for variable rate applications and yield monitoring, adoption rates appear to differ significantly from one country to another. Based on trends observed in the US, Swinton & Lowenberg-DeBoer (2001:557) suggested that adoption of precision agriculture technology is uneven both geographically and temporally. Interestingly, the uneven adoption trend of precision agriculture technology is totally opposite of the adoption of hybrid maize which has been a rapid and smooth trend since its commercial introduction about 80 years ago. The uneven and slow adoption of precision agriculture technologies is mainly due to four factors:

1. Cost of adoption.
2. Lack of perceived benefit from adoption.
3. Unwillingness to be early adopters (conservatism).
4. Lack of technology delivery mechanisms.

Delivering precision agriculture technologies to farmers requires knowledge and skills that most consulting agencies do not possess and therefore presents a major obstacle. It is even suggested that the conservatism of the consultancy sector seems to create more difficulties than the conservatism of the farmers (Swinton & Lowenberg-DeBoer, 2001:557).

Zang *et al.* (2002:125) identified several barriers that prevent the implementation of precision agriculture technologies:

- Data overflow for farm management. This problem has to be overcome by developing data integration tools, expert systems, and decision support systems.
- Lack of rational procedures and strategies for determining application requirements on a local basis and a parallel lack of scientifically validated evidence for the benefits claimed for the precision agriculture concept.
- Labour- intensive and costly data collection. Development of affordable rapid sensing systems must take place before precision agriculture can be widely practised.
- Lack of technology-transfer channels and personnel. Educational programs involving researchers, industry, extension specialists, and consultants are urgently needed.

2.7 CHAPTER SUMMARY

In this chapter the various concepts relating to precision agriculture were discussed. Firstly, the definition of precision agriculture was investigated. It was found that precision agriculture is an on-going process (cycle) in which data is gathered, analysed and as a result actions are taken to ultimately reduce inputs, increase outputs and conserve the environment. This is accomplished with the use of technology.

The precision agriculture cycle consists of different components that can be classified as actions and technical components. Actions of the precision agriculture cycle includes; information gathering, information evaluation (analysis), decision making and implementation. Monitors and sensors, for example yield monitors, remote sensors, soil sensors and global position systems are some of the technical components available for gathering information. A technical component such as geographic information systems (GIS) is used to produce information maps that can assist with data evaluation and decision making. Variable rate technology is another technical component that is used to apply inputs according to information obtained from geographic information systems. Variable rate technology allows the farmer to apply a specific quantity of crop inputs at a specific location in the field based on the characteristics of that location. Variable rate technology is considered a valuable technical component used for the implementation phase of the precision agriculture cycle.

Advantages and benefits of precision agriculture was investigated and discussed. Advantages and benefits derived from using precision agriculture practices can be classified into two categories, namely; economic benefits and environmental benefits. Other benefits have also been shown over the years. Economic advantages include increase in the economic margin of crop production due to improvements in yield and/or reduction in inputs. More effective use of inputs result in increased crop yield, better quality and reduced input costs. Examples of environmental benefits are reduced environmental pollution from agro-chemicals applied at sub-optimal concentrations, reduced soil erosion and optimized water consumption.

The long term benefits of precision agriculture include reduced risk, increased management capacity, increased speed and time management of operations as well as the ability to improve safety and work capacity.

Several studies identified yield monitors as the precision agriculture technology used most commonly. Second to yield monitors, GIS mapping software and geo referenced grid or zone management sampling are also used fairly common. The use of variable rate technology is more uncommon and has not increased significantly over the years as the previously mentioned technologies. Global positioning guidance systems were identified as the precision agriculture technology that has showed the most growth over the years.

In conclusion, the reasons for the slow adoption rate of precision agriculture are discussed. The four factors that contribute to uneven and slow adoption of precision agriculture include the cost of adoption, a lack of perceived benefit from adoption, unwillingness to be early adopters (conservatism), and the lack of technology delivery mechanism. A major obstacle for delivering precision agriculture technologies to farmers is the level of knowledge and skills required by the consulting agencies and agricultural companies. It seems that the conservative approach of the consultancy sector is responsible for more challenges than that created by the conservatism of the farmers.

CHAPTER 3: EMPERICAL STUDY

3.1 INTRODUCTION

An in-depth literature study on Precision Agriculture (PA) was conducted and presented in Chapter 2. In the literature study, information from various sources was used to give an overview of the definition as well as the interacting components of PA. The benefits of PA, the most widely used PA technologies as well as those perceived to provide the most benefits were discussed. Data from countries such as the USA was used to identify the order of implementation and the reasons for slow adoption of PA technologies.

This chapter will focus on the research methodology used to obtain the research objectives stated in Chapter 1 and present the subsequent results from the survey. Initially, Chapter 3 will focus on the procedure and scope of the quantitative research, followed by a statistical analysis and discussion of the results and finally conclude with a chapter summary.

The results from the survey will be discussed under 2 categories:

- Profile of and results from the total sample. This will include: PA technologies most widely used; farmer's perceptions regarding the most beneficial technologies; farmers' rating of specific technologies in terms of availability, affordability and efficiency. The benefits and potential outputs of precision agriculture identified by the survey as well as the factors for slow and no adoption will be presented. In conclusion, the sample's view of how the term 'precision agriculture' is defined will be discussed.
- Profile of and results from the PA group. The PA group will be extracted from the total sample based on the criteria and definition of PA presented in the literature study. Results from the PA group will be compared to the total sample as well as the non-PA group, i.e. the group that did not implement PA as defined in the literature study.

3.2 THE SCOPE AND PROCEDURE OF THE QUANTITATIVE RESEARCH

The empirical study focused on summer grain producers from the two major summer grain producing areas of South Africa, i.e. the Free State and North West province.

3.2.1 Sample group and size

The study targeted farmers involved in the production of maize, sunflower, soybeans and other summer grains in the Free State and North West province. The group included farm owners, farm managers and foremen. The study covered a broad spectrum of participants from various age groups, academic backgrounds as well as the amount and extent of their farming experience. The full profile of the total sample will be presented and discussed under 3.3.

From the total of 250 questionnaires that was distributed among farmers, only 102 responses were returned. After several follow-ups, the most probable reason for the low response rate (41%) is the fact that the questionnaires were circulated during the harvest season which is a very busy and focussed time for farmers.

According to the Department of Agriculture (2010), there are an estimated number of 5,940 summer grain producing farmers (i.e. the population of the current study) in the Free State and North West provinces. Based on a confidence level and allowable error of 10%, 95 responses were required to validate the study. The 102 responses received were slightly more than the minimum amount required and it can therefore be assumed that the survey results are a good representation of the targeted population's view (Creative Research Systems, 2011).

3.2.2 Survey instrument

The instruments used by researchers to capture the required information can be either qualitative or quantitative. According to Neill (2007) the difference between qualitative and quantitative research is that the first is a subjective approach whereas the second is an objective approach. A quantitative approach uses tools such as surveys and questionnaires to gather information. Data resulting from a quantitative approach are mostly numbers and statistics which are less time consuming to analyse than that from a qualitative approach.

A quantitative approach was used for the current study in order to objectively meet the research objectives. Therefore the strategy included a random purposive sampling approach. The goal was to obtain the maximum number of responses within the available timeframe.

The instrument used in this study was a questionnaire. The questionnaire consisted of 25 questions which included: fill-in questions; selection type questions; as well as Likert scale (3 and 5 point) questions. The questions were formulated from information obtained in the literature study. The questionnaire is included in Annexure A. The strategy used to distribute the

questionnaires to the target group was by means of independent agents of an agricultural company of which the author is an employee. The company has 10 agents distributed throughout the Free State and North West provinces. Each agent received 20 questionnaires to circulate among farmers. The remaining 50 were distributed to the target group by the author himself. This strategy was the most cost effective and efficient since the agents participated free of charge and was distributed throughout the target areas. The agents had a time period of one month to distribute and return the questionnaires.

3.3 FINDINGS FROM TOTAL SAMPLE

The first results that will be discussed are from the total sample. The total sample refers to all the farmers that responded to questionnaires, i.e. farmers that indicated that they use PA as well as farmers that indicated that they do not use PA.

3.3.1 Profile of total sample
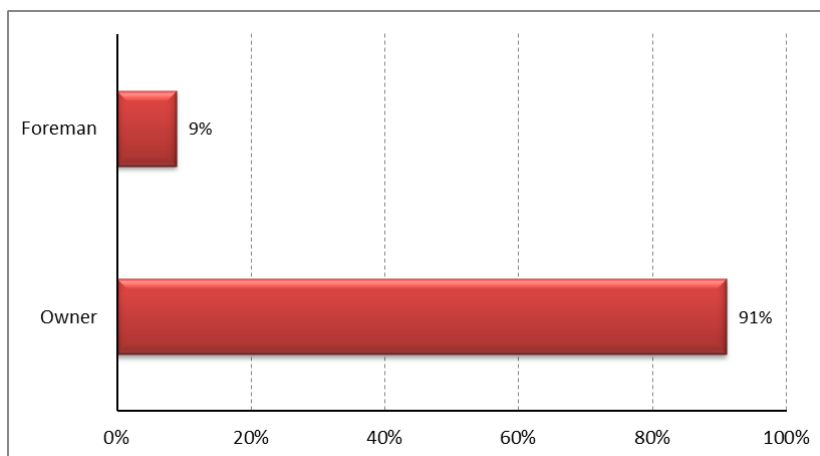
CAPACITY ON FARM

FIGURE 3.1 Respondent group profile: Capacity on farm.

The study targeted farmers that are actively involved in the management of the farm, i.e. farm owners as well as foremen/managers. The results presented in Figure 3.1 indicate that 91% of the respondents are farm owners and only 9% are foreman.
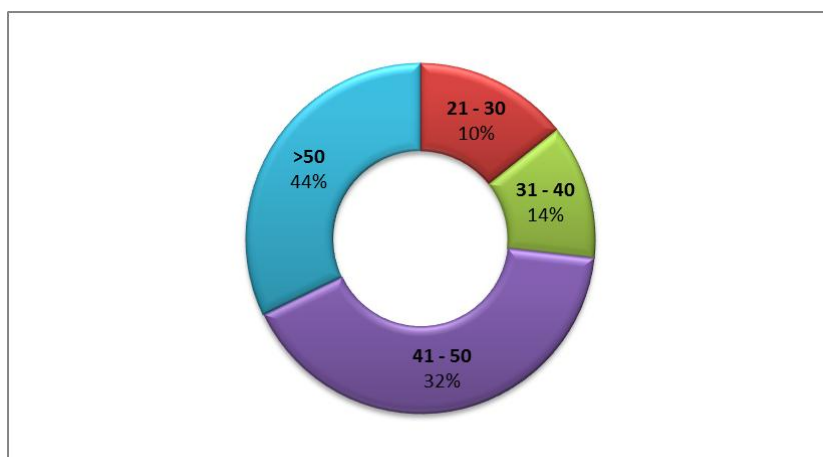
FIGURE 3.2 Respondent group profile: Age groups

Figure 3.2 shows that the majority (76%) of summer grain producing farmers in the targeted provinces are above 41 years of age. This is worrisome because the group of farmers (i.e. age groups 21 to 30 and 31 to 40) that will be responsible for sustaining food production and -security constitutes only 24% of the sample. Since the summer grain producing sector is the biggest agricultural sector in South Africa, it seems that other sectors outside of agriculture are more appealing to the younger generation. The rapidly growing world population together with the decreasing number of producers hold great concerns for the future.

YEARS OF FARMING EXPERIENCE
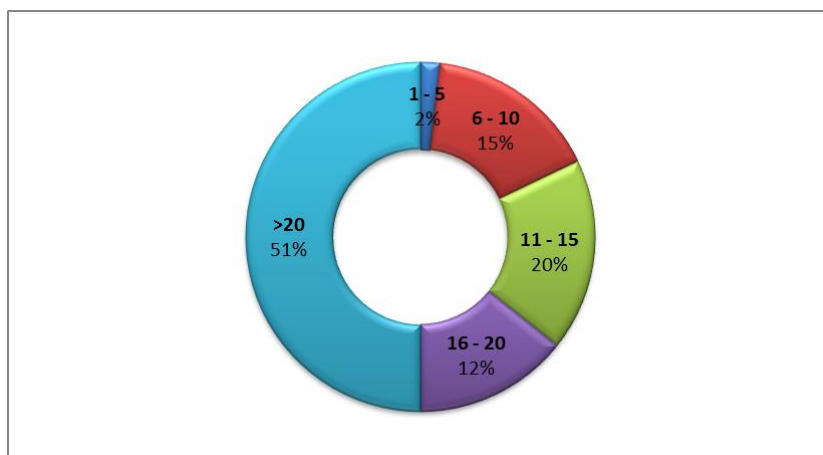
FIGURE 3.3 Respondent group profile: Years of farming experience.

From Figure 3.3 it can be seen that more than half of the sample have more than 20 years of farming experience. This correlates with the fact that 76% of the sample is older than 41 years. 32% of the respondents have between 11 and 20 years' experience. The remaining 17% of

farmers have less than 10 years of farming experience. From these results it can be assumed that the majority of summer grain producing farmers start farming at a young age and that it is an industry with a relatively low people turn-over.

HIGHEST ACADEMIC QUALIFICATION
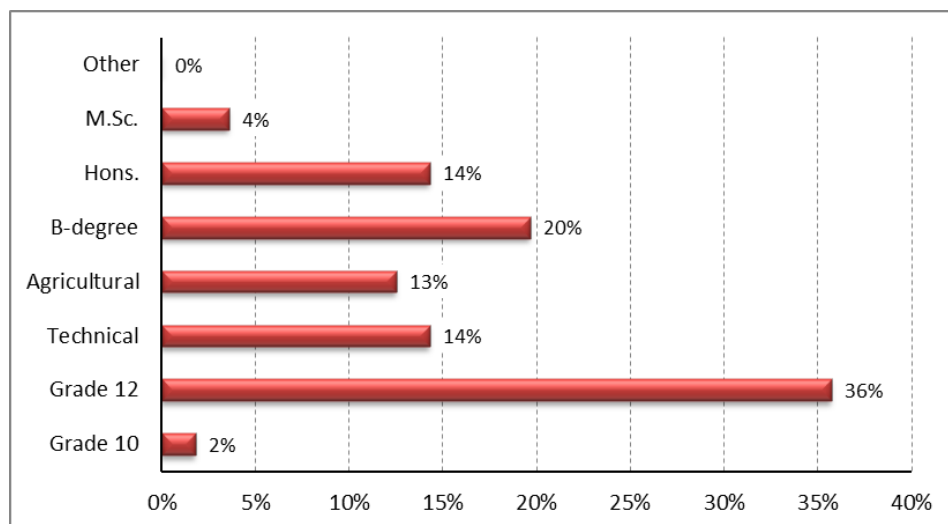
FIGURE 3.4 Respondent group profile: Highest academic qualification.

Figure 3.4 presents the academic background of the sample. The majority of respondents (36%) have a senior certificate (grade 12). From the 38% of respondents that have a tertiary education, 20% obtained a B-degree, 14% an honours degree and 4 % a masters degree. Another 27% of respondents have either a technical (14%) or agricultural (13%) diploma.

AMOUNT OF HECTARES UNDER CULTIVATION
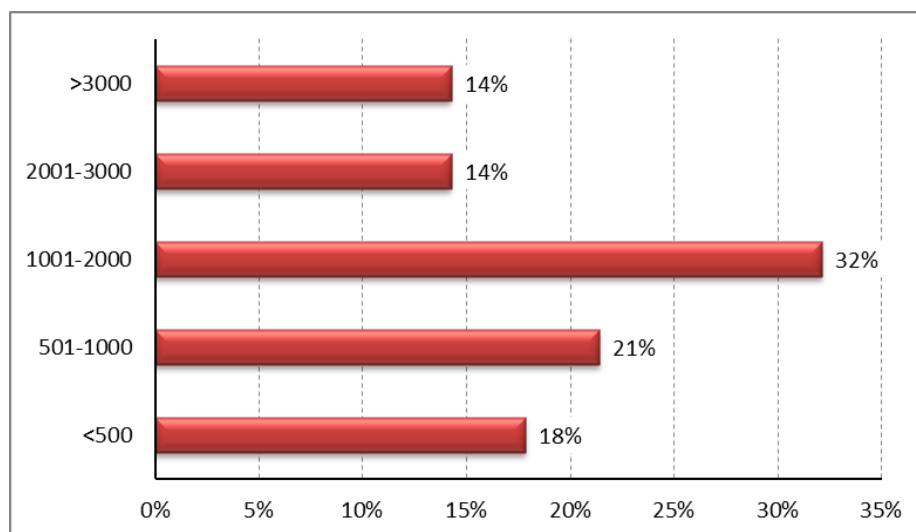
FIGURE 3.5 Respondent group profile: Amount of hectares under cultivation.

Figure 3.5 indicates the area of land (hectares) cultivated by the individual respondents. It can also be referred to as the production capacity of each respondent with regards to summer grain. The majority of respondents (32%) have production areas between a 1001 and 2000 hectares. 28% of the total sample comprises of production areas bigger than 2000 hectares. Included in this group are 14% of farmers that cultivate areas of more than 3000 hectares. Respondents that cultivate "smaller" areas (i.e. below 1000 hectares) contributed 39%. It has been said that rising input costs and lower margins on grain production have caused a decrease in the number farms but an increase in farm size. The results from the current study support this observation by showing that 60% of respondents cultivate areas bigger than 1000 hectares.

TYPE OF CROPS PLANTED
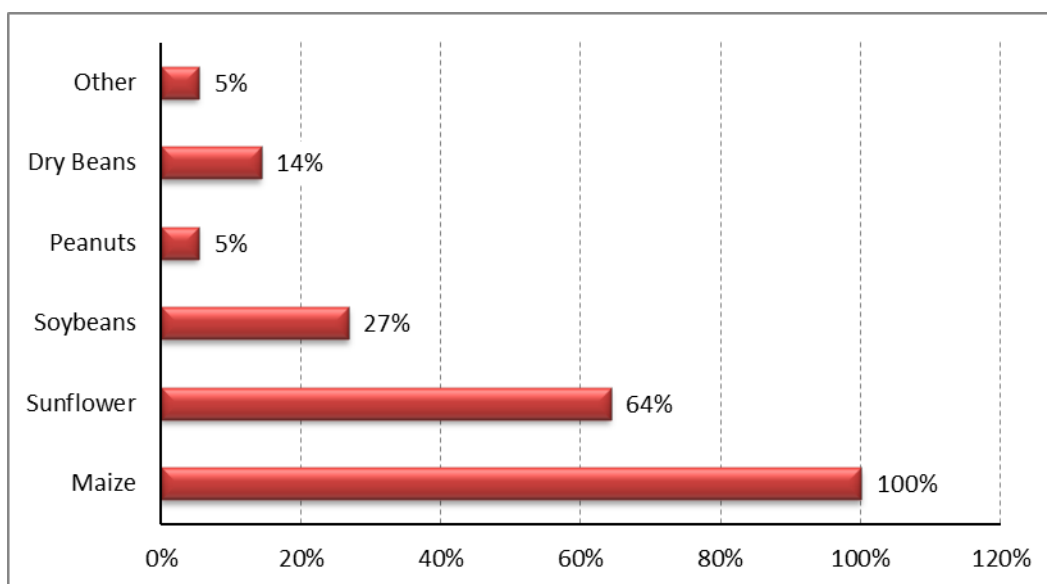
FIGURE 3.6 Respondent group profile: Crops planted.

The study was targeted at summer grain producers, i.e. maize, sunflower, soybeans and other summer grains. The results presented in Figure 3.6 shows the various crops planted by the respondents. It can be seen that all of the respondents are maize producers with 64% co-producing sunflower. Some of the minor crops co-produced by the respondents are soybeans (27%), peanuts (5%), dry beans (14%) and other summer grains (5%). The Free State and North West provinces are the major maize and sunflower producing areas which is in accordance with the data obtained from the study. Soybeans and other bean crops are mostly cultivated in Kwa-Zulu Natal and Mpumalanga which explain their lower representation in the current study.
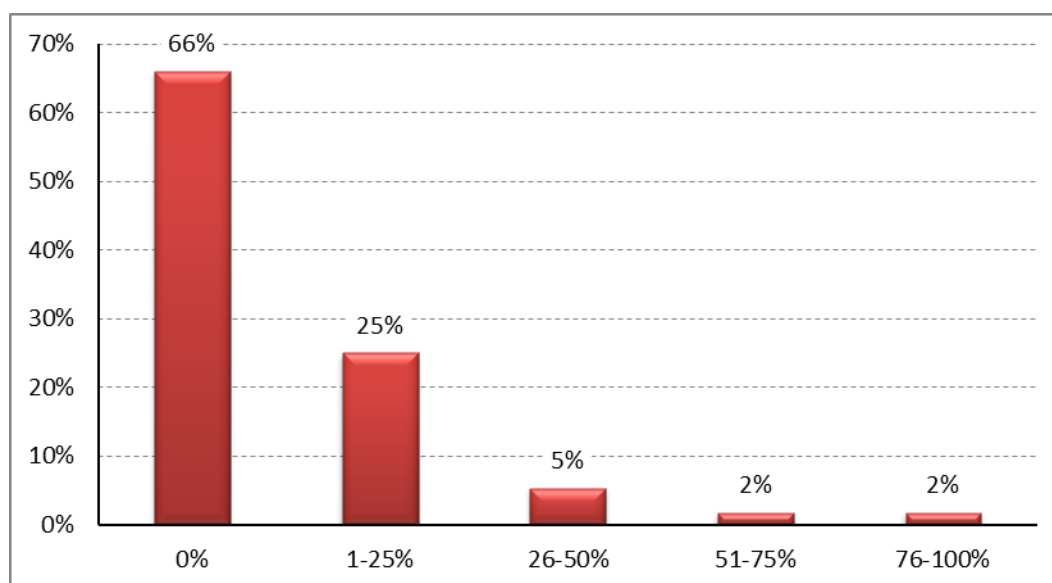
FIGURE 3.7 Respondent group profile: % of crops under irrigation.

Figure 3.7 shows that the majority of the respondents (66%) do not use irrigation. 25% of producers irrigate between 1 and 25% of their crops. A minor portion of the sample (9%) cultivates more than 25% of their crops under irrigation. The Free State and North West provinces do not have a lot of water available for irrigation and the majority of agricultural activities in these provinces are conducted under dry land conditions. Maize has a high drought tolerance and is therefore mainly cultivated under dry land conditions. Maize under irrigation is not uncommon but on smaller, more intensive areas for example seed producers. Sunflowers are not planted under irrigation due to the high disease risk. If the target group included farmers from other provinces or other target crops, the results would have been different.

USERS AND NON- USERS OF PRECISION AGRICULTURE

Figure 3.8 presents the total group's response to the question of whether they do or do not use PA technologies on their farm. The majority of respondents (83%) indicated that they are PA technology users while only 17% indicated otherwise.
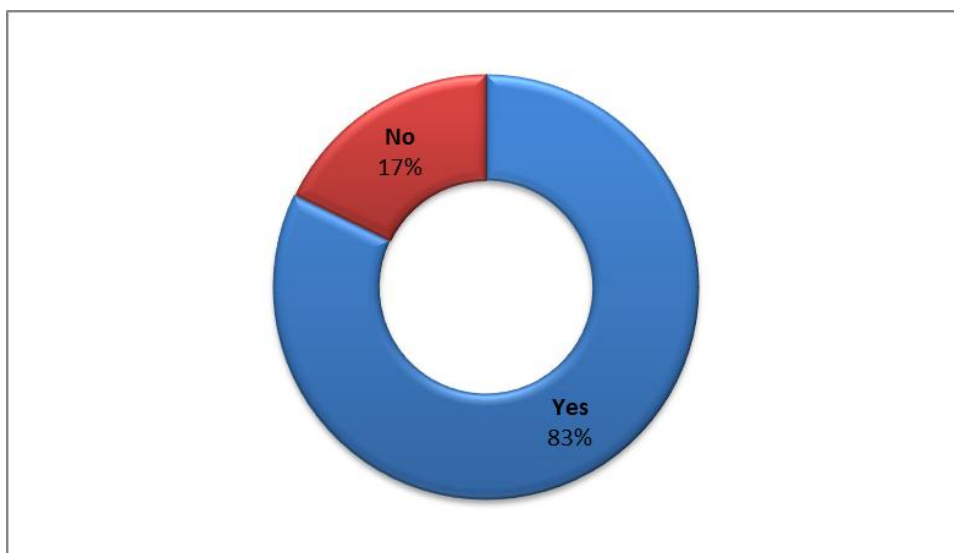
FIGURE 3.8 Respondent group profile: Users and non-users of PA.

3.3.2 Perceptions and attitudes from the total sample

The second part (Section B) of the questionnaire evaluated the respondents' perceptions and attitudes regarding potential outputs (benefits) and reasons for not implementing PA. This section was also used to identify the most widely used PA technologies as well as the technologies first implemented and those implemented and later discontinued. Specific PA technologies were evaluated by the respondents with regards to availability, affordability and effectiveness. Finally, the respondents were asked to select the definition that best describes PA.

MOST WIDELY USED PRECISION AGRICULTURE TECHNOLOGIES
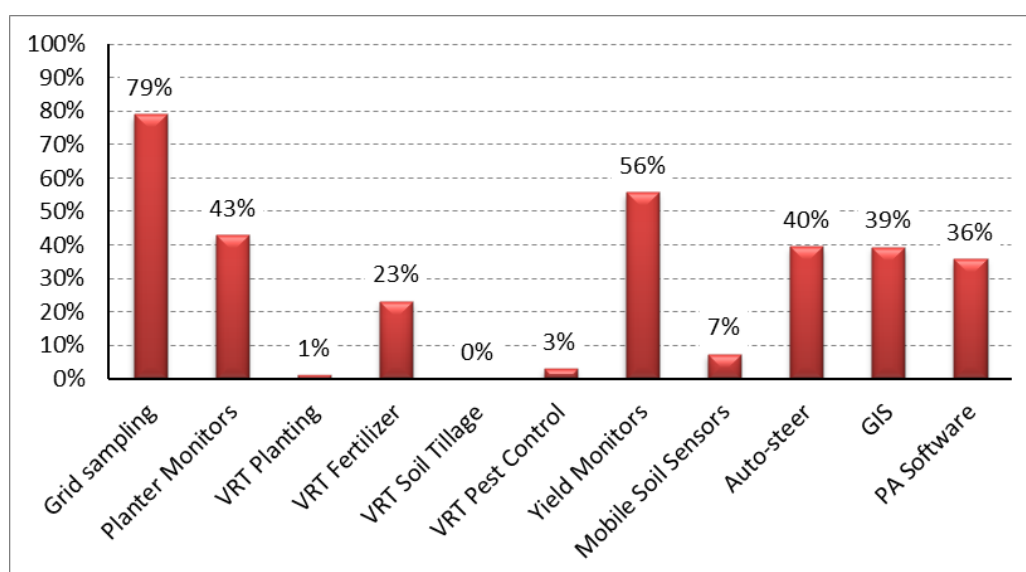
FIGURE 3.9 Respondent group profile: Most widely used PA technologies.

Figure 3.9 shows the % usage of the different PA technologies by the respondent group. The technologies being used by the majority of respondents are grid sampling (79%), yield monitors (56%), planter monitors (43%), auto-steer (40%), GIS systems (39%) and PA software (36%). Technologies not universally used by the sample are mobile soil sensors (7%), VRT pest control (3%) and VRT planting (1%). The results from a US study done by Batte & Arnold (2003) identified the most commonly used PA technologies as yield monitors, GIS systems, GPS and grid sampling. The current data shows a definite trend when compared to the US data from 2003. There may be several explanations for the more prominent usage of the aforementioned technologies, namely, the problems addressed by them are universal and therefore also the benefits accompanied by them. From my personal experience in the agricultural sector, it seems that South African farmers follow the technology trends from the USA very closely.

PRECISION AGRICULTURE TECHNOLOGIES USED AND DISCONTINUED
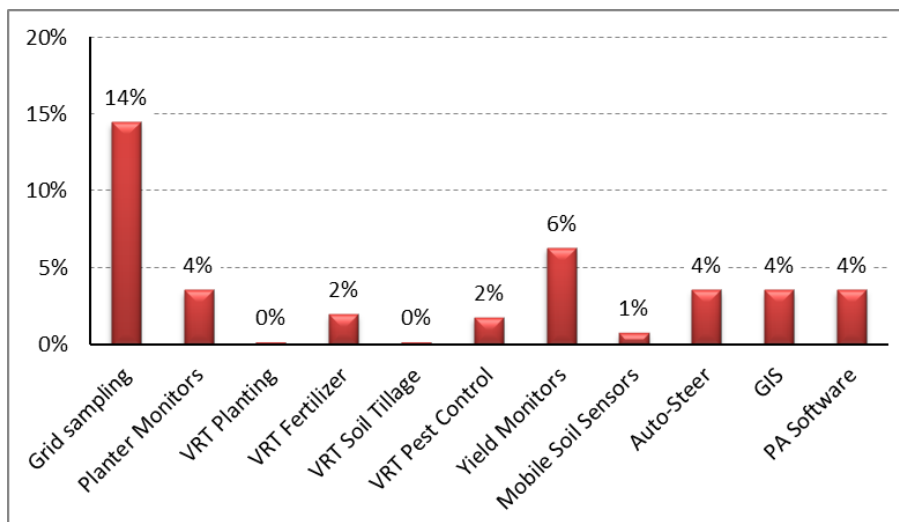
FIGURE 3.10 Respondent group profile: PA technologies used & discontinued.

The results presented in Figure 3.10 indicated that grid soil sampling was the technology most likely to be discontinued. 14% of respondents that used grid soil sampling previously have discontinued it. Although grid soil sampling is the technology most widely used, it is also expensive and therefore not done on an annual basis which can explain the above result. A very small amount of the respondents (4-6%) specified that they discontinued the use of yield monitors, planter monitors, auto-steer, GIS, and PA software. Technologies such as VRT planting, - fertilizer application, - soil tillage and – pest control are not commonly used in South Africa and therefore the % of these technologies discontinued are high relatively to their usage.
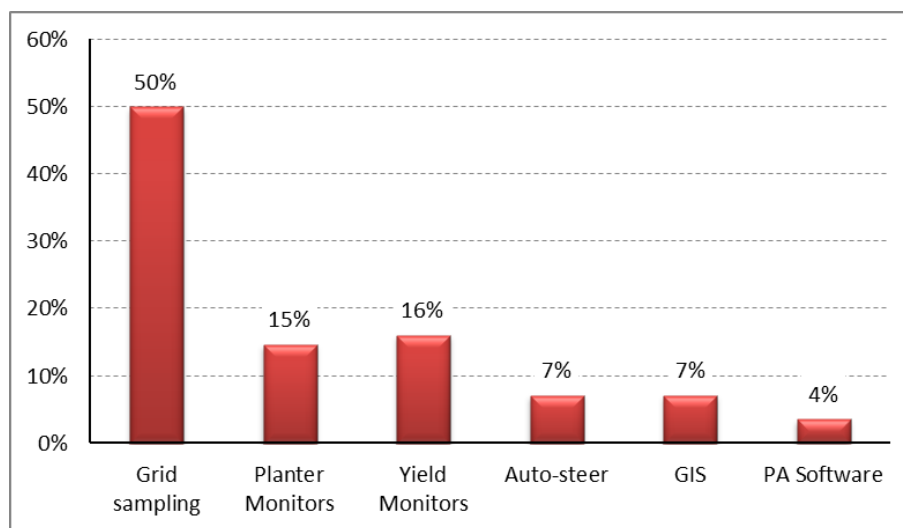
FIGURE 3.11 Respondent group profile: PA technology first implemented.

Figure 3.11 shows that the majority of respondents (50%) first implemented grid soil sampling. The introduction of planter - and yield monitors were also a popular choice among the PA technologies that were first implemented by a significant part of the respondents (i.e. 15 and 16%, respectively). Only a small portion (4-7%) of the sample first introduced technologies such as auto-steer, GIS and PA software. The study done by Batte and Arnold (2003) identified yield monitors as the technology first implemented by the majority of US farmers. The technology first implemented by the second largest group in the aforementioned study was grid soil sampling. The results from the current study correlates with that of the US study. It indicates that grid soil sampling and yield monitors are considered popular technologies when farmers start out with PA.

AVAILABILITY OF PA TECHNOLOGIES

Figure 3.12 presents the respondents evaluation of the availability of the most commonly used PA technologies. The evaluation was done on a scale of 1 to 3: (1) not available; (2) occasionally available; and (3) generally available. It seems that the most popular PA technologies, namely grid sampling, planter – and yield monitors are generally available to the majority of the respondents (57-64%). It is worth mentioning that the majority of PA technologies are imported and not manufactured locally. This might explain the "occasionally available" rating provided by some of the respondents. The availability of imported products may be influenced by fluctuations in the exchange rate, changing import companies, time delays due to logistics, etc.
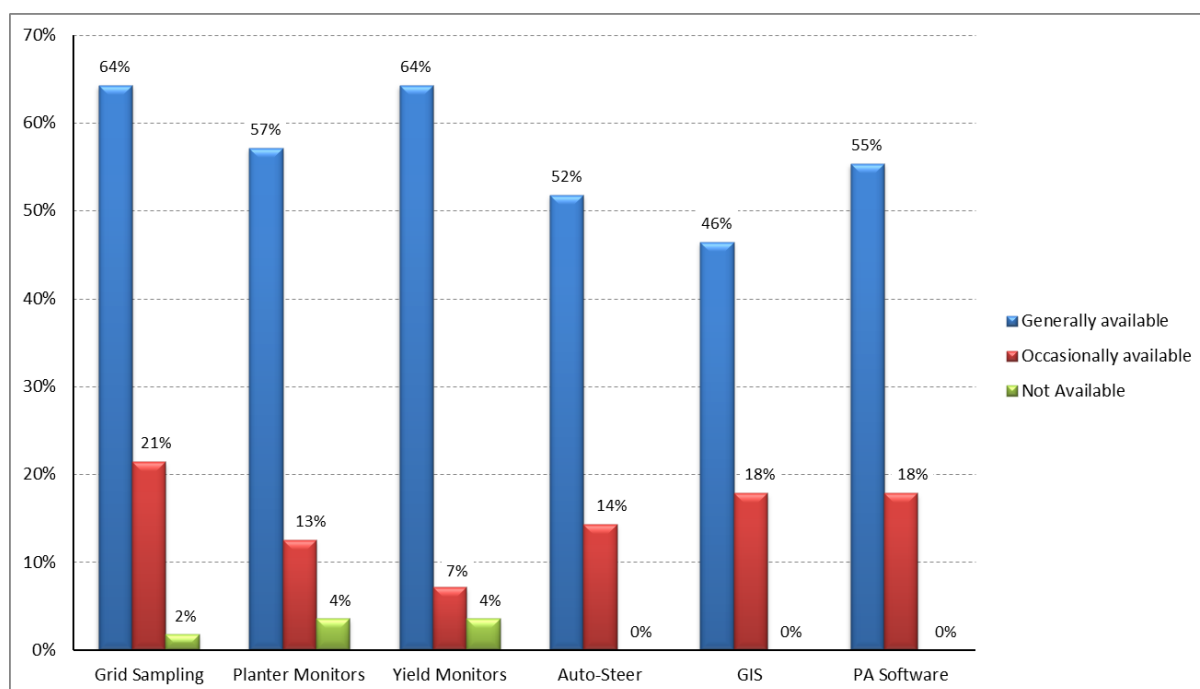
FIGURE 3.12 Respondent group: Availability of PA technology.

Grid sampling and yield monitors are rated by the majority of respondents (64%) as technologies that are generally available. Their availability may explain why they are popular technologies for introducing PA as well as their widespread usage. It might also be the scenario of "supply and demand". The technologies are widely in demand and therefore the suppliers see to their general availability.

Ironically, planter - and yield monitors also have 4% of respondents claiming that these technologies are not available. This contradicts the fact that these technologies are also rated the most widely available. There might be an opportunity for the companies supplying these technologies to improve their distribution channels.

AFFORDABILITY OF PA TECHNOLOGIES

Figure 3.13 shows the respondents evaluation of the affordability of the most commonly used PA technologies. Again, affordability was rated on a scale of 1 to 3: (1) unaffordable; (2) affordable under certain conditions; and (3) very affordable. It is evident from the results that the majority of respondents regard these technologies as only affordable under certain conditions. These conditions may include favourable exchange rates, high commodity prices, etc.
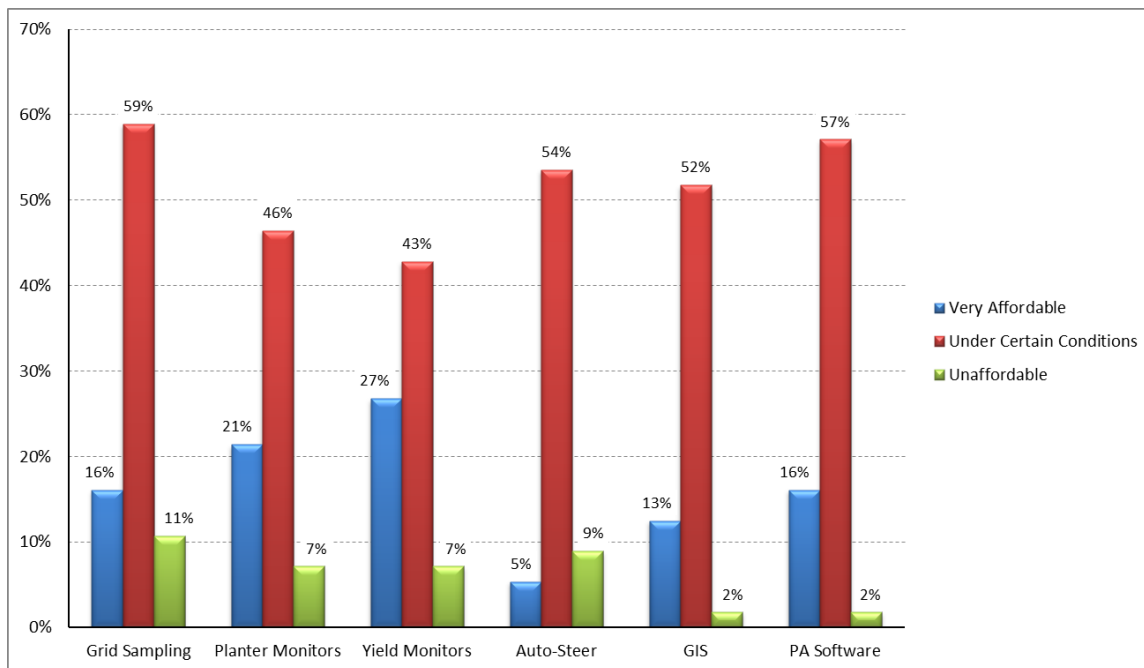
FIGURE 3.13 Respondent group: Affordability of PA technology.

A significant portion of the sample (27%) indicated yield monitors as the most affordable technology. In contrast, grid sampling was rated the most affordable under certain conditions by 59% of the sample as well as most unaffordable by 11% of the respondents.

EFFICIENCY OF PA TECHNOLOGIES
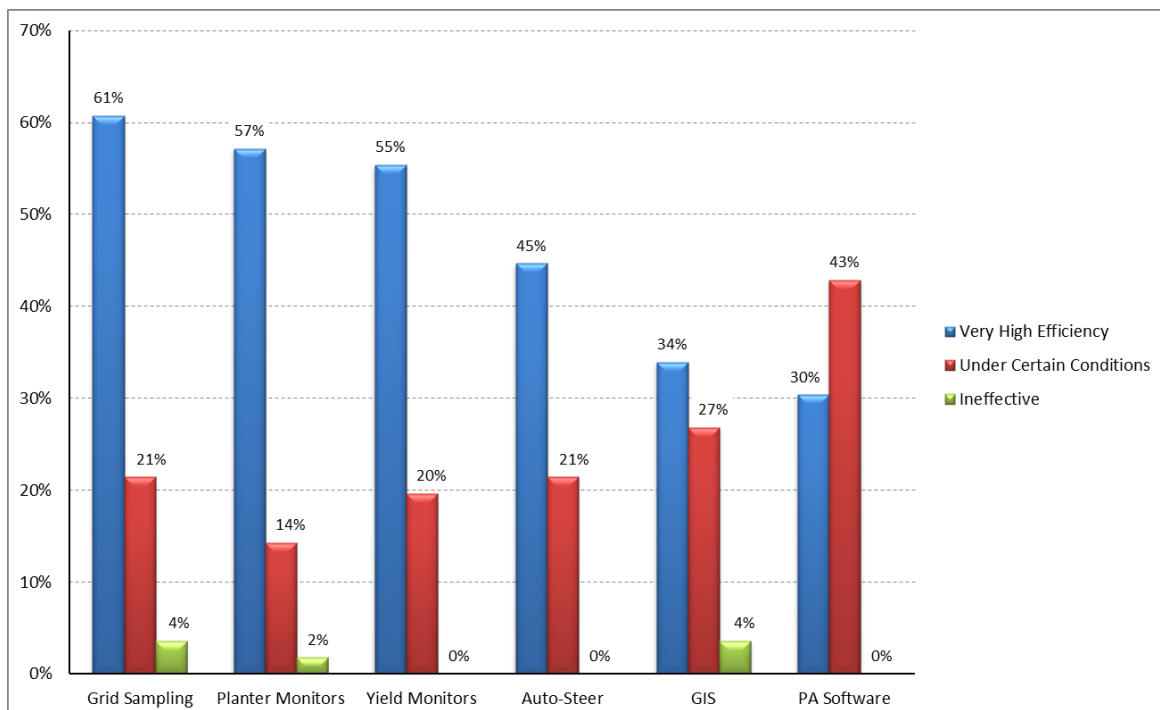
FIGURE 3.14 Respondent group: Efficiency of PA technology.

The respondents' evaluations of the efficiency of the most commonly used PA technologies are presented in Figure 3.14. Efficiency was rated on a scale of 1 to 3: (1) ineffective; (2) effective under certain conditions; and (3) highly efficient. The majority of respondents (61%) rated grid sampling as the most efficient technology. Planter - and yield monitors were also regarded as highly efficient by respectively 57% and 55% of the respondents. The efficiency rating of the aforementioned technologies may explain their widespread usage and popularity as PA technologies first implemented.

PA computer software and GIS were perceived by a large portion of the sample as only effective under certain conditions. Both technologies are software based technologies. Since the majority of respondents are above 40 years of age, their view on software based technologies might be due to this generation not being as computer literate as the younger generation that grew up with computers. A small percentage of respondents (2-4%) regarded planter monitors, grid sampling and GIS as ineffective technologies.

OUTPUTS OF PRECISION AGRICULTURE
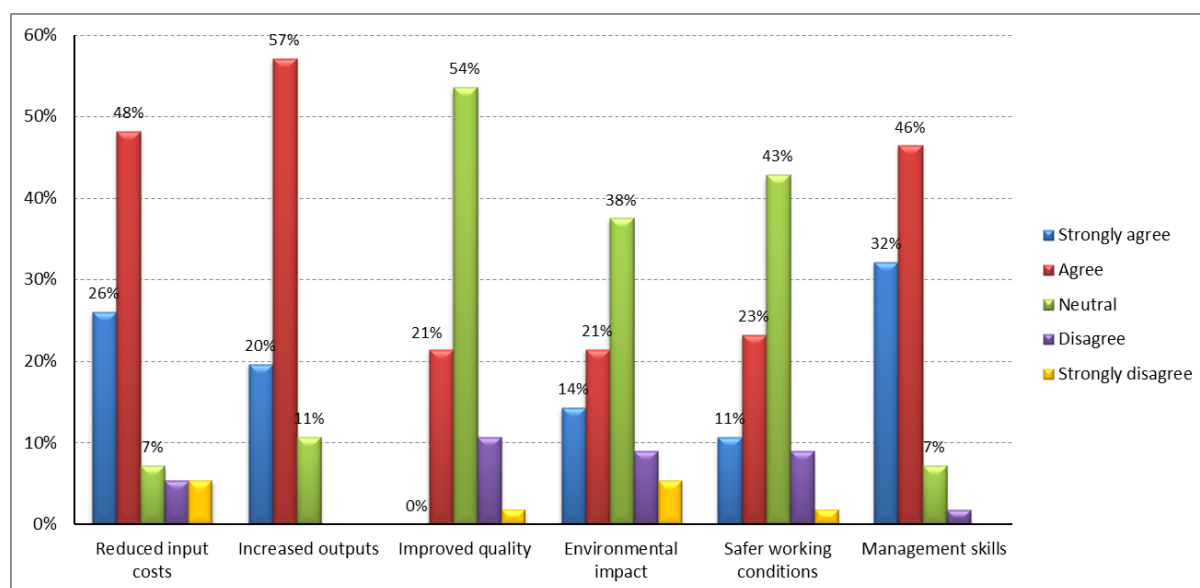
FIGURE 3.15 Respondent group: Outputs of precision agriculture.

PA agriculture became a subject of discussion once the agricultural sector was convinced by the perceived benefits it offers. In the literature study the most common outputs (benefits) were emphasised, namely, reduced input costs, increased outputs (for example better yields), improved quality, positive environmental impact, safer working conditions and improved management skills.

The respondents' evaluations of the benefits of PA are presented in Figure 3.15. It is evident that most of the respondents agreed or strongly agreed that PA reduced their inputs, increased their outputs and improve their management skills. The majority of farmers were not convinced of the other benefits such as improved quality, positive environmental impact and safer working. The farmers view on the aforementioned outputs that neither provided them with positive nor negative results may be due to the complexity of the specific outputs. For example, several factors such as rainfall, disease pressure, etc. can have an effect on quality. On the other hand measuring the effects of a particular technology on the environment or working conditions are more difficult and long-term.

REASONS FOR NOT ADOPTING PRECISION AGRICULTURE
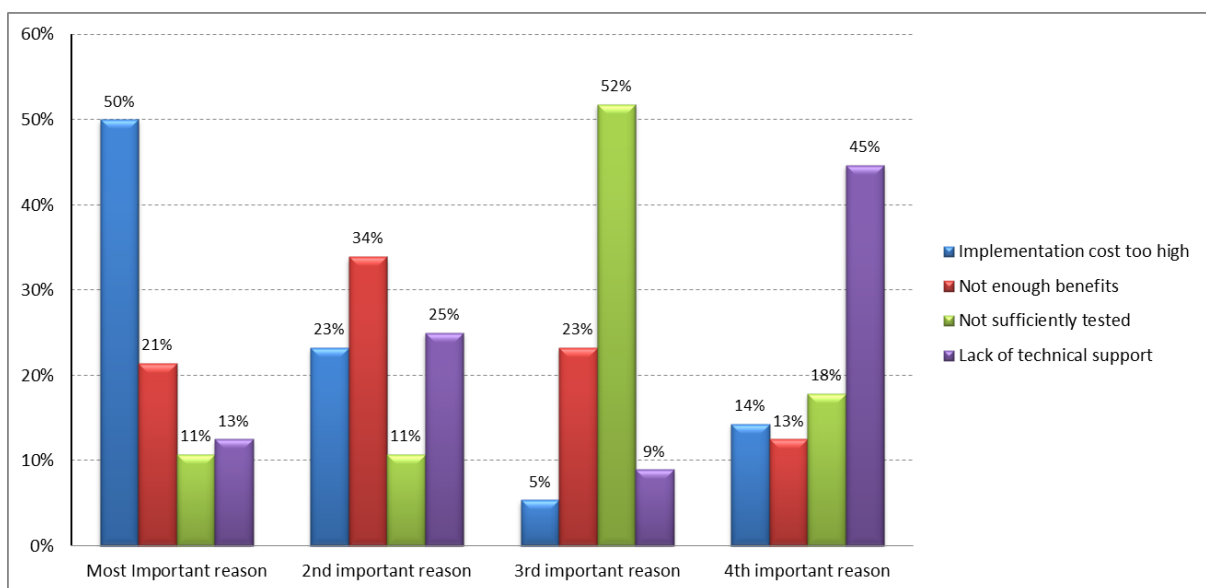
FIGURE 3.16 Respondent group: Reasons for not adopting PA.

Literature provided some of the reasons farmers gave for late or not adopting PA technologies. The reasons included: High implementation cost; not enough benefits; insufficiently tested; and lack of technical support by PA service providers. The results presented in Figure 3.16 indicate the major reasons (in order of importance) respondents provided for not adopting PA technologies. 50% of respondents specified that too high implementation costs were the most important reason for not implementing a specific technology. The fact that most PA technologies available in South Africa are imported explains their high implementation costs. The other reasons provided by the sample, in order of importance, were: Not enough benefits; insufficiently tested; and lack of technical support.
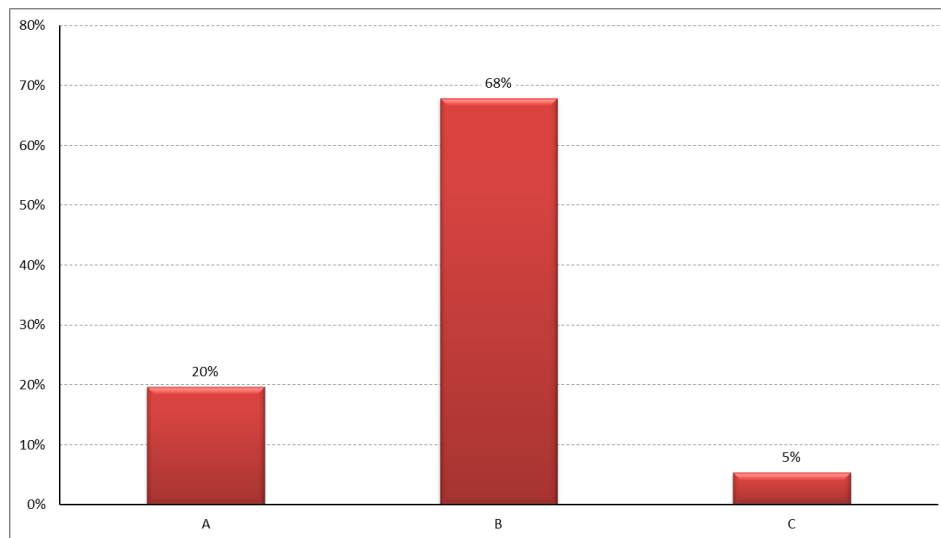
FIGURE 3.17 Respondents group: Definition of PA.

The questionnaire concluded by asking the respondents to select the best definition for PA. The three options provided included the correct definition (B) as discussed in Chapter 2 and two incomplete descriptions (A and C). The textbook definition of PA describes it as a continuous process where data is collected with the aim of reducing input costs and increasing outputs that will result in sustainable farming. Figure 3.17 shows that the majority of respondents (68%) have a good understanding of the definition of PA by selecting the correct definition of PA. Interestingly, a significant portion (20%) of respondents view PA only as use of PA equipment such as GPS, monitors etc. Another 5% of respondents perceived PA as the subdivision of land into smaller, more manageable units. 7% of the sample indicated that they do not use PA and therefore did not complete Section B of the questionnaire.

3.4 PROFILE AND PERCEPTIONS OF THE PA FARMER

The previous section included data from all the respondents that took part in the survey, also those indicated that they do not use PA technologies. In the next section a group was identified and extracted from the total sample namely the PA group. To be taken in account for this group a respondent have to adhere to certain requirements. The literature study conducted in chapter 2 showed that PA is not a once off implementation or the use of one PA technology. It is rather seen as on-going process, method and management strategy. PA is also regarded as a cycle with different components. These components includes the following actions; gathering of information, evaluation and analysis of information and implementation. The three requirements for this group were then that a respondent must use at least one technology in each of the three components of the PA cycle. Technologies used for the gathering of information include; yield

monitors, grid sampling, soil sensors and planter monitors. Technologies for evaluation and analysis of information consist of GIS and PA computer software. The final criteria was that a respondent must use one of the following technologies used for implementation namely, any VRT technology and auto steer. 52% of respondents fulfil these requirements and were included in the PA group. The profile of the PA group will be discussed and compared to the total sample and the finding from section B of the questionnaire will be presented, discussed and compared.

3.4.1 Profile of the PA group

AGE GROUPS
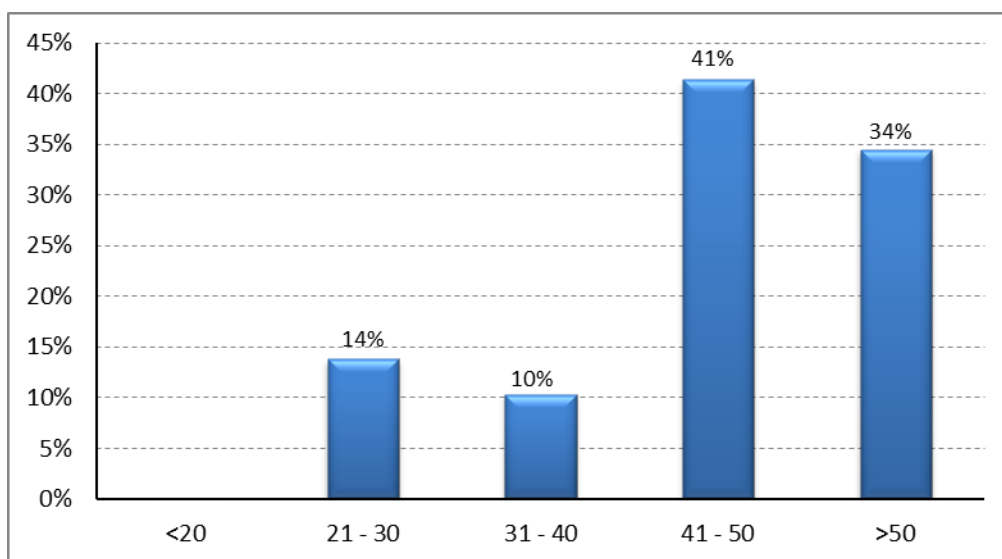
FIGURE 3.18 Profile of PA farmer: Age groups.

Figure 3.18 presents the data from the group extracted from the total sample based on their implementation of PA according to the textbook definition. The majority of farmers (41%) in the PA group are between 41 to 50 years old. PA farmers older than 50 years constituted 35% of the PA group. Thus the majority of farmers (71%) practising PA as per definition are over the age of 40. Only 24% of the farmers from the PA group are younger than 40 years of age.
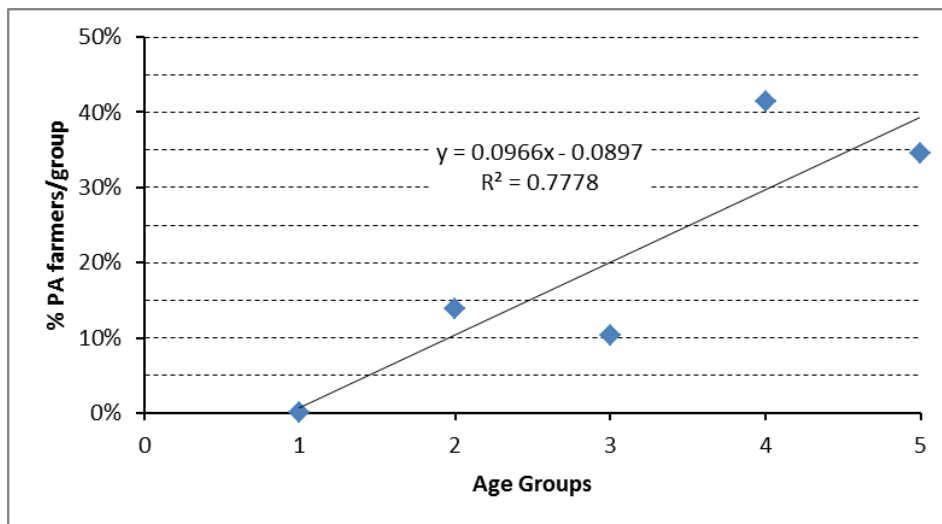
FIGURE 3.19 Age group vs. PA farmer.

Figure 3.19 displays a positive correlation between the age of respondents and PA farmers (as defined by this study). It seems that implementation of PA increases with the farmers' age. Although the majority of respondents were above 40 years of age, the fact that the older farmers are more likely to practise PA might be due to the high implementation costs and the financial position of this group that enables them to practise PA.

FARMING EXPERIENCE
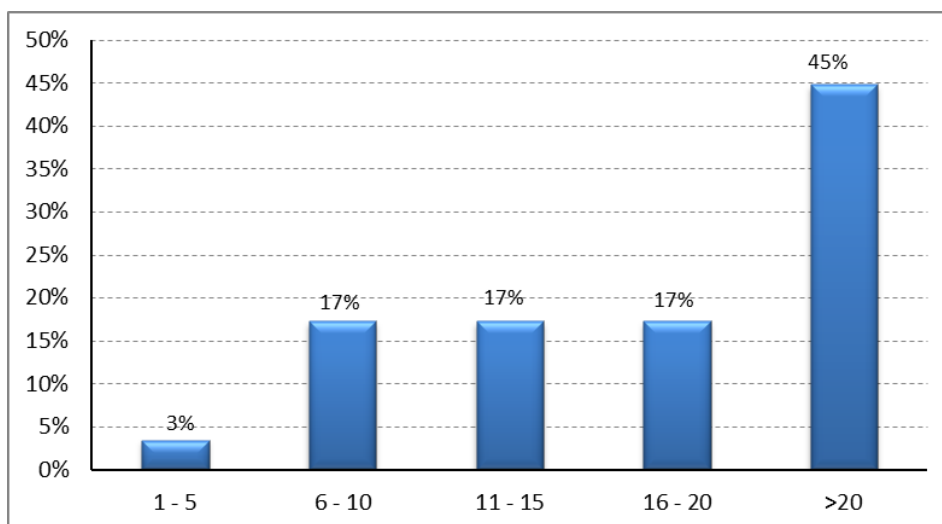
FIGURE 3.20 Profile of PA farmer: Years of farming experience.

The majority of farmers (45%) in the PA group have 20 years or more farming experience. Interestingly the other farming experience groups were equally represented in the PA group with 17% each. It seems that the PA farmer is not only older but also more experienced.
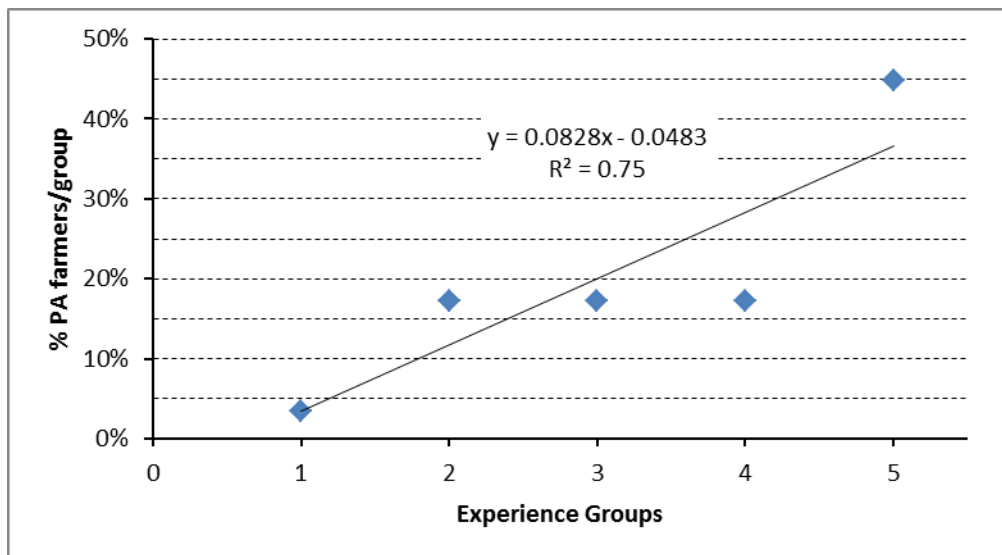
FIGURE 3.21 Farming experience vs. PA farmer.

Figure 3.21 indicates a positive correlation between farming experience and the PA group. It seems that farmers with more farming experience are more likely to engage in PA farming.

ACADEMIC BACKGROUND
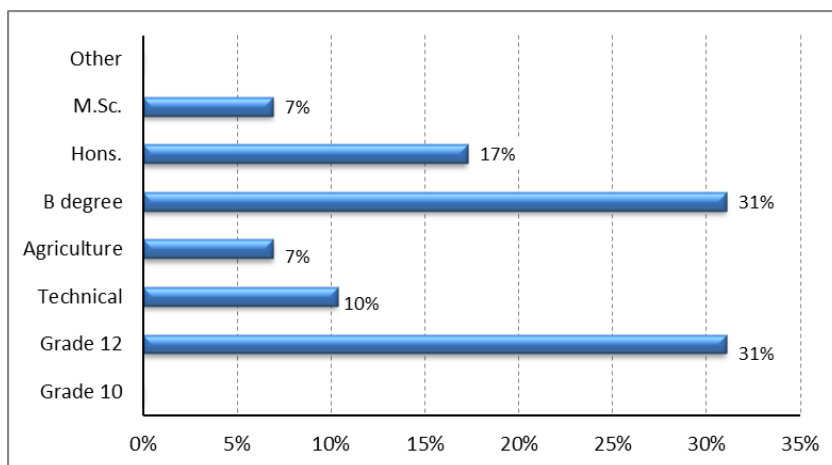
FIGURE 3.22 Profile of PA farmer: Highest academic qualification.

The minimum qualification of the PA group was Grade 12 (senior certificate). The majority of PA farmers had either a senior certificate (31%) or a B-degree (31%). Compared to the total sample, the PA group had 2% less farmers with senior certificates and 11% more farmers with B-degrees. Only 17% of PA group members have technical/agricultural diplomas compared to 27% of the sample. It seems that a tertiary education might have a positive influence on the implementation of PA by farmers.
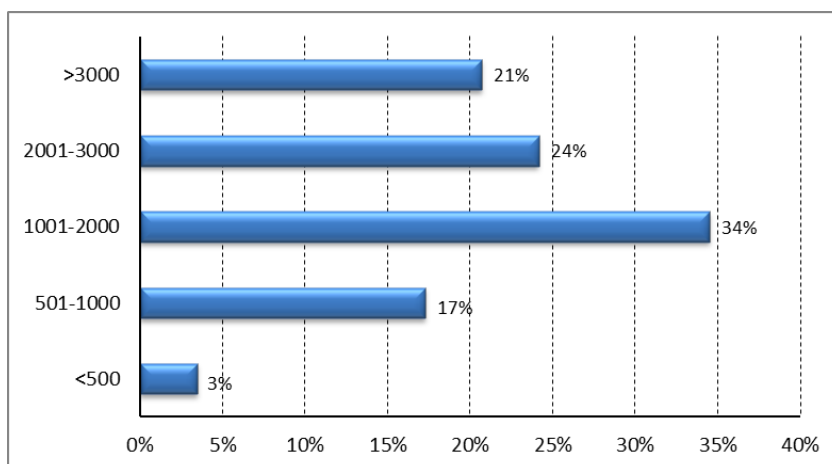
FIGURE 3.23 Profile of PA farmer: Amount of hectares under cultivation.

The majority of farmers in both the total sample (32%) and the PA group (34%) have production areas between 1001 to 2000 hectares. The most significant difference between the total sample and PA group is that the 79% of PA farmers cultivate areas more than 1000 hectares compared to 60% of the total sample. Also, 18% of respondents from the total sample cultivate areas less than 500 ha, whereas only 3% of PA farmers belong to that category. It appears that larger cultivation areas require higher efficiency which is more likely to justify the implementation of PA technologies.
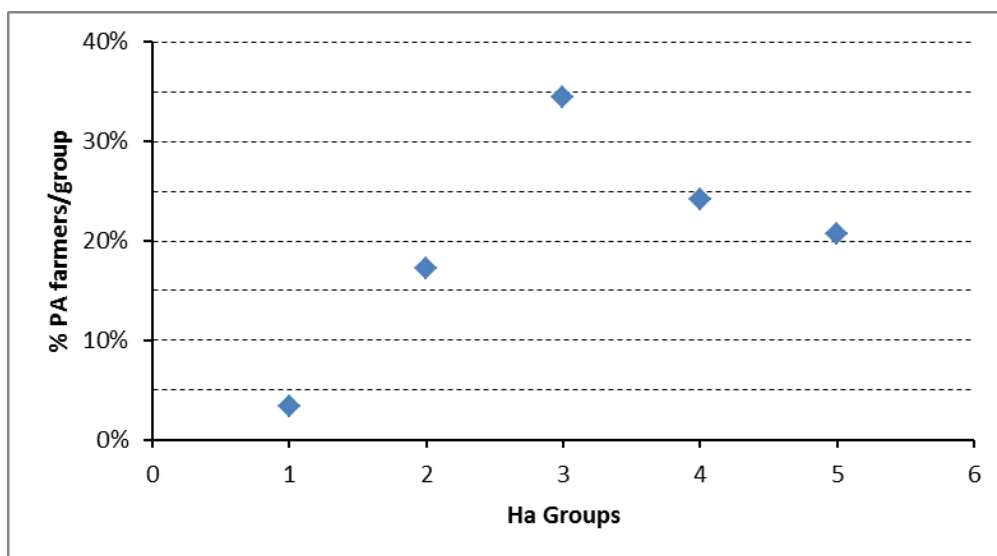
FIGURE 3.24 Amount of hectares vs. PA farmer.

Figure 3.24 presents the correlation between the area under cultivation and the PA farmer. Initially there is a strong positive correlation between increased cultivation area size vs. PA farmer, but only up to 2000 hectares. On cultivation areas bigger than 2000 hectares the plot

52

shows a negative correlation with PA farming. As mentioned earlier the margins on grain production have decreased over the past few years. This might explain the negative correlation. Production on smaller areas require reduced inputs and increased outputs (the benefits from PA) in order to be profitable. On bigger production areas the volume counters the small margins. Farmers who cultivate very large production areas might focus more on quantity than quality.

CROPS UNDER CULTIVATION
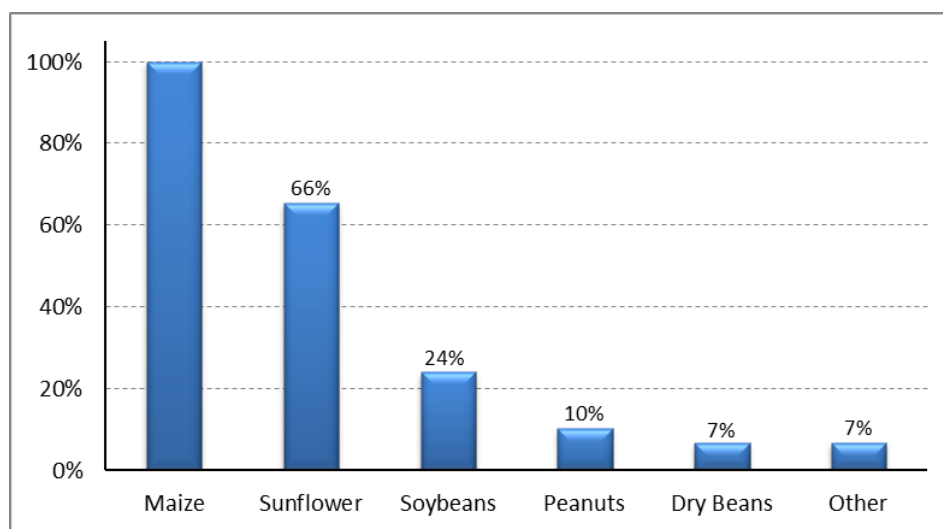
FIGURE 3.25 Profile of PA farmer: Crops planted.

The crops cultivated by the PA group are very similar to that of the total sample. The only significant difference between the two groups is that PA farmers grow twice as much peanuts as the sample (5%). But then again, the sample group produces twice as much dry beans as the PA farmers (7%). There are no obvious correlation between the crops cultivated and the implementation of PA technologies.

IRRIGATION

Figure 3.26 indicates that the majority of PA farmers produce under dry land conditions (55%) or irrigate only 1-25% of their crops (38%). 66% of the total sample cultivate summer crops under dry land conditions and 25% irrigate 1-25% of their crops. The PA group uses slightly more irrigation than the sample group. It might indicate a more diversified farmer.
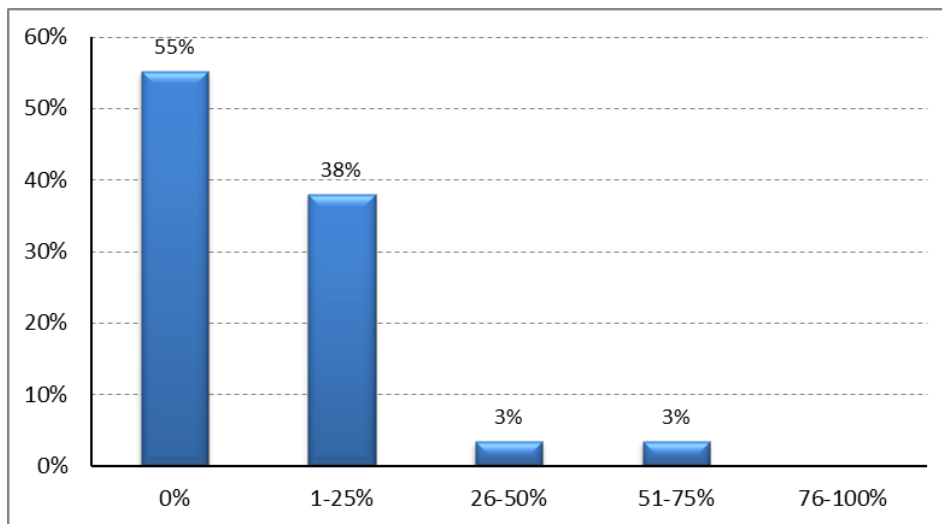
FIGURE 3.26 Profile of PA farmer: % of crops under irrigation.

3.4.2 Perceptions and attitudes of the PA group

The results and evaluations from the extracted PA group are presented and discussed in the following section. These findings will be discussed under the subsequent headings: Most widely used PA technologies; PA technologies used and discontinued; PA technologies first implemented; potential outputs of PA; reasons for not adopting PA technologies; and the perceptions of farmers regarding PA vs. the textbook definition of PA. The results from the PA group will be compared to that of both the total sample and the non-PA group. The total sample represents all the respondents that participated in this survey. The non-PA group consists of the respondents that do not use PA according to the textbook definition as well as respondents that indicated that they do not use PA technologies.

GROUP COMPARISON: MOST WIDELY USED PA TECHNOLOGIES

Figure 3.27 displays the PA technologies most commonly and widely used by the three different groups. Grid soil sampling is used by all the members in the PA group, 77% of the total sample and even 56% of the non-PA group. It appears that grid soil sampling is by far the most widely used PA technology under summer grain producing farmers.

The second most widely used technology in the PA group is yield monitors (72%). This correlates with the results from the US study done by Batte & Arnold (2003). The aforementioned study identified yield monitors and grid sampling as the most popular technologies used by US farmers. In the current study, even a significant amount of non-PA farmers (41%) used yield monitors. In addition, planter monitors is also a technology used by both PA (52%) and non-PA farmers (33%).
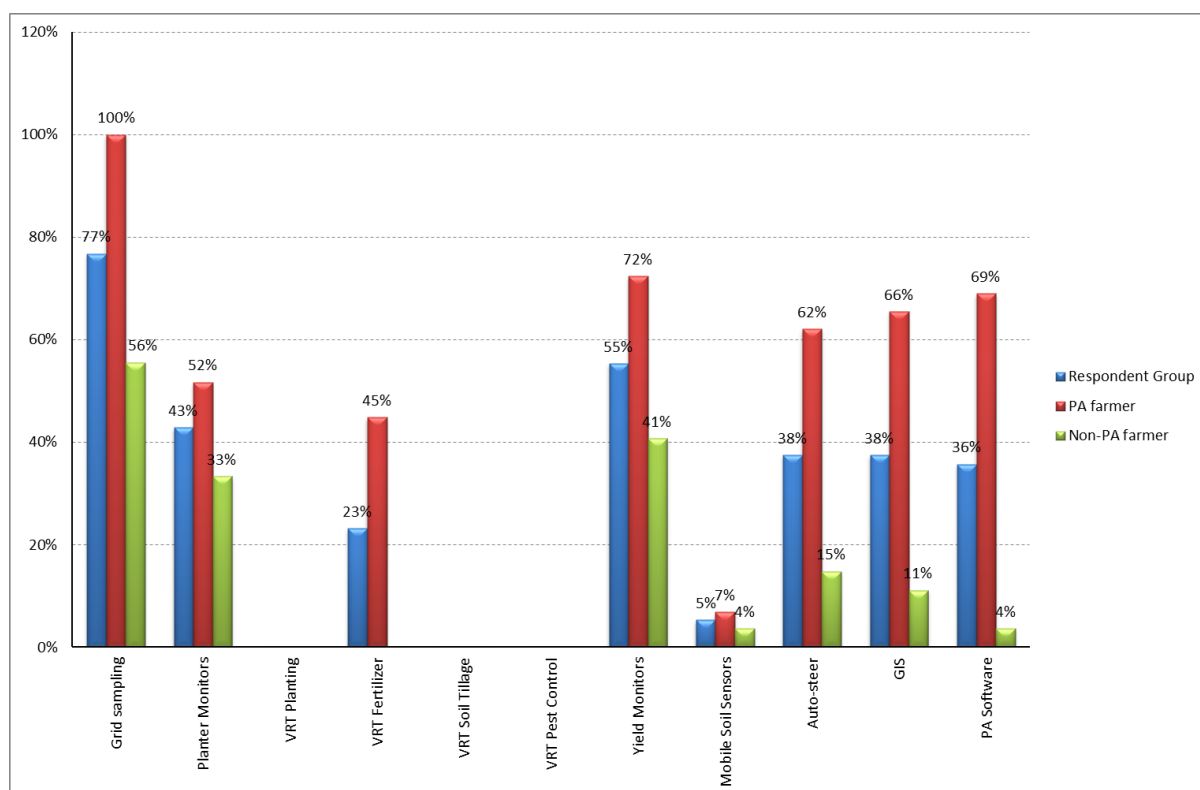
FIGURE 3.27 Most widely used PA technologies.

The most significant difference between the PA and non-PA groups was the use of PA software (69% vs. 4%), GIS mapping (66% vs. 11%) and auto-steer (62% vs.15%). Mobile soil sensors were the technology used by the smallest portion of both the PA and non-PA groups and ranged from 4-7%. VRT fertilizer application is a technology that is only used by PA farmers (45%).

GROUP COMPARISON: TECHNOLOGIES USED AND DISCONTINUED

From the data presented in Figure 3.28 grid soil sampling is identified as the technology used by both PA and non-PA farmers with the highest probability of being discontinued. Again, this may be due to the high costs and seasonality of grid sampling as mentioned in paragraph 3.3.2.2.

Technologies such as planter monitors, yield monitors, auto-steer and GIS mapping have a very low prospect (3%) of being discontinued by PA and non-PA farmers.

Members from the PA group were the only farmers to implement any of the variable rate technologies (VRT). It seems that only variable rate fertilizer application is used with success (Figure 3.27) since all the others were discontinued.
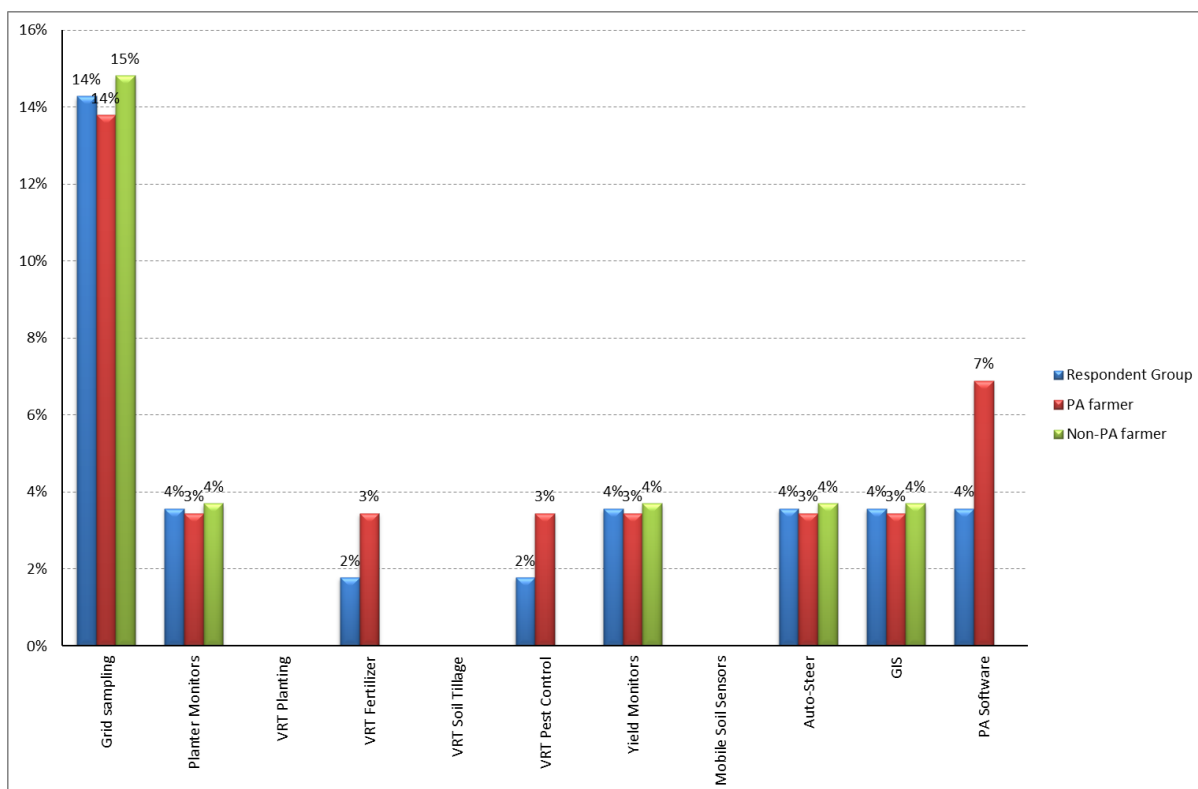
FIGURE 3.28 Technologies used and discontinued.

Figure 3.29 shows that grid soil sampling, yield monitors and planter monitors are the top-ranking technologies among the PA and non-PA group regarding first-to-be-implemented. Grid sampling scored a very prominent first place with both PA (62%) and non-PA (41%) members. Yield monitors were slightly more popular among the PA group (21% vs. 11% non-PA). The results correlates well with that obtained by Batte & Arnold (2003) where grid sampling and yield monitors were identified as the most popular technologies to be implemented first. However, it also showed that yield monitors were in most cases implemented before grid sampling.

A small percentage of the PA group (7%) also listed PA software, GIS mapping and auto-steer as their first choice of technology with regards to the implementation of PA. 7% of the non-PA group was in agreement with them on the GIS mapping and auto-steer technology. In contrast, the non-PA group did not consider PA software as an option for first implementation.
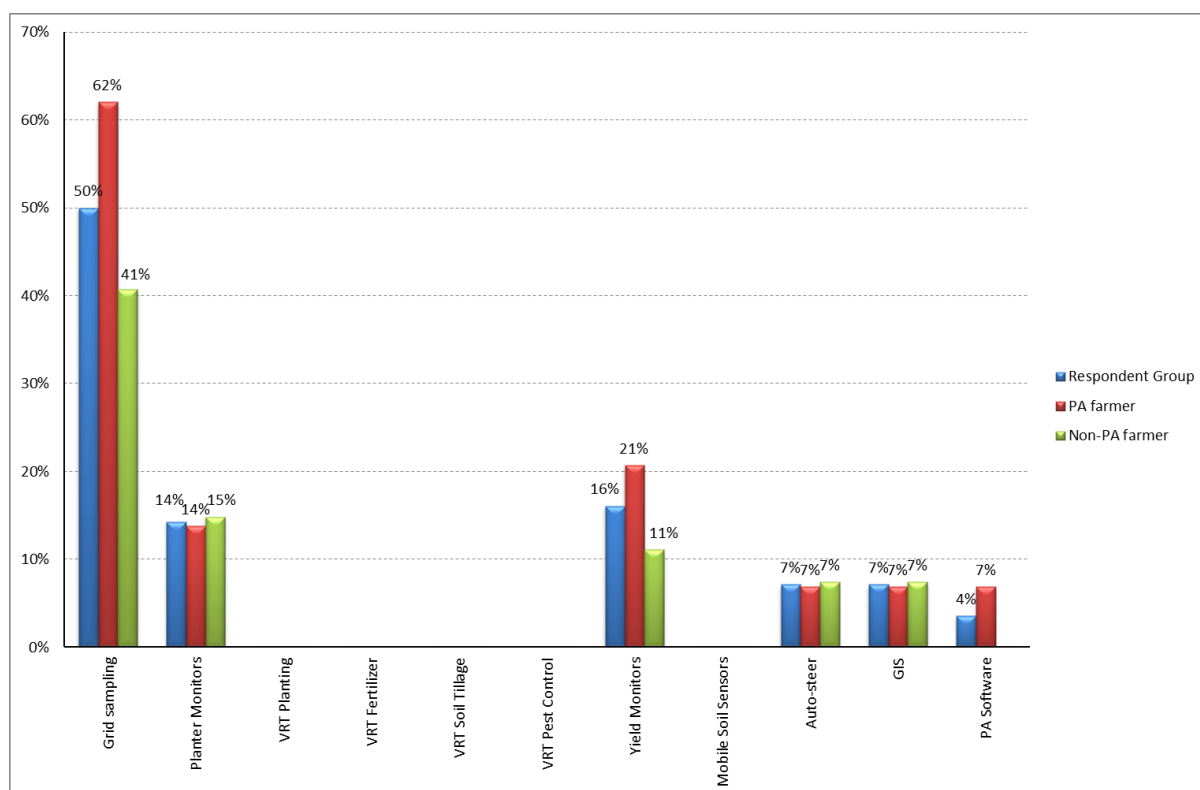
FIGURE 3.29 Technologies first implemented.

Figure 3.30 presents the different groups' evaluations of the potential outputs (benefits) of PA. Both the PA and non-PA group agreed or strongly agreed about the 3 major advantages of PA, namely, improved management skills (PA 97% and non-PA 59%), increased outputs (PA 87% and non-PA 67%) and reduced input costs (PA 83% and non-PA 60%). The responses of the PA and non-PA groups correlated with that previously discussed for the total sample. Also, the PA and non-PA groups were neutral towards whether PA technologies provided a positive environmental impact, safer working conditions and improved quality of grain. As mentioned before, these outputs are more difficult to measure and the effects are mostly seen on the long term. Outputs like reduced input costs and increased outputs are very much the focus of every farmer and any improvement will be noticed immediately.
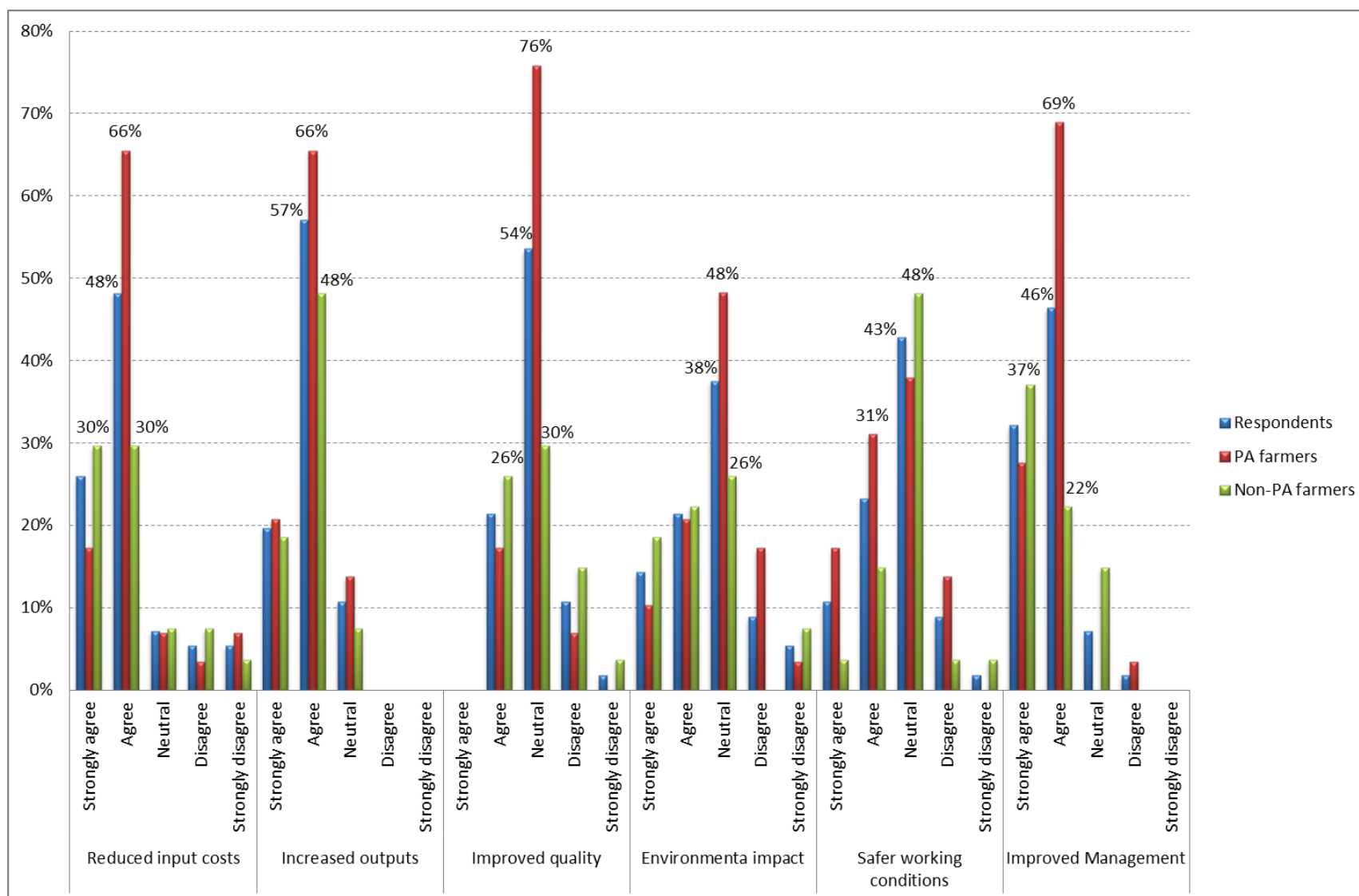
FIGURE 3.30 Potential outputs of precision agriculture.

The respondents were asked to indicate their reasons for not implementing specific PA technologies from most important to least important. The results are displayed in Figure 3.31. The PA group selected high implementation costs and not enough benefits as the two most important reasons for not adopting certain technologies. The non-PA group agreed strongly (59%) that high implementation costs are the major reason for them not implementing PA technologies. When compared to the response of the total sample it seems that implementation cost is a significant hurdle for the implementation of new PA technologies. As mentioned before, most PA technologies are imported and therefore the initial costs are very high. Especially if only a small portion of farmers use it. It is only when a specific technology become established and used by the majority of farmers that the costs are reduced significantly.

The other reasons provided by non-PA farmers for not implementing PA technologies are (in order of importance): Not enough benefits; not sufficiently tested; and lack of technical support. Companies that import/supply PA technologies should first of all focus on the cost of implementing a new technology. If the return on investment is not favourable it will be difficult to get market penetration. Thereafter the benefits provided by a specific technology should be thoroughly evaluated under South African conditions to provide farmers with sufficient data. Although technical support is only the fourth most important reason, it is not to be discarded. It is probably not the most important reason to get customers to adopt a specific technology, but it will be crucial to keep the customer base.
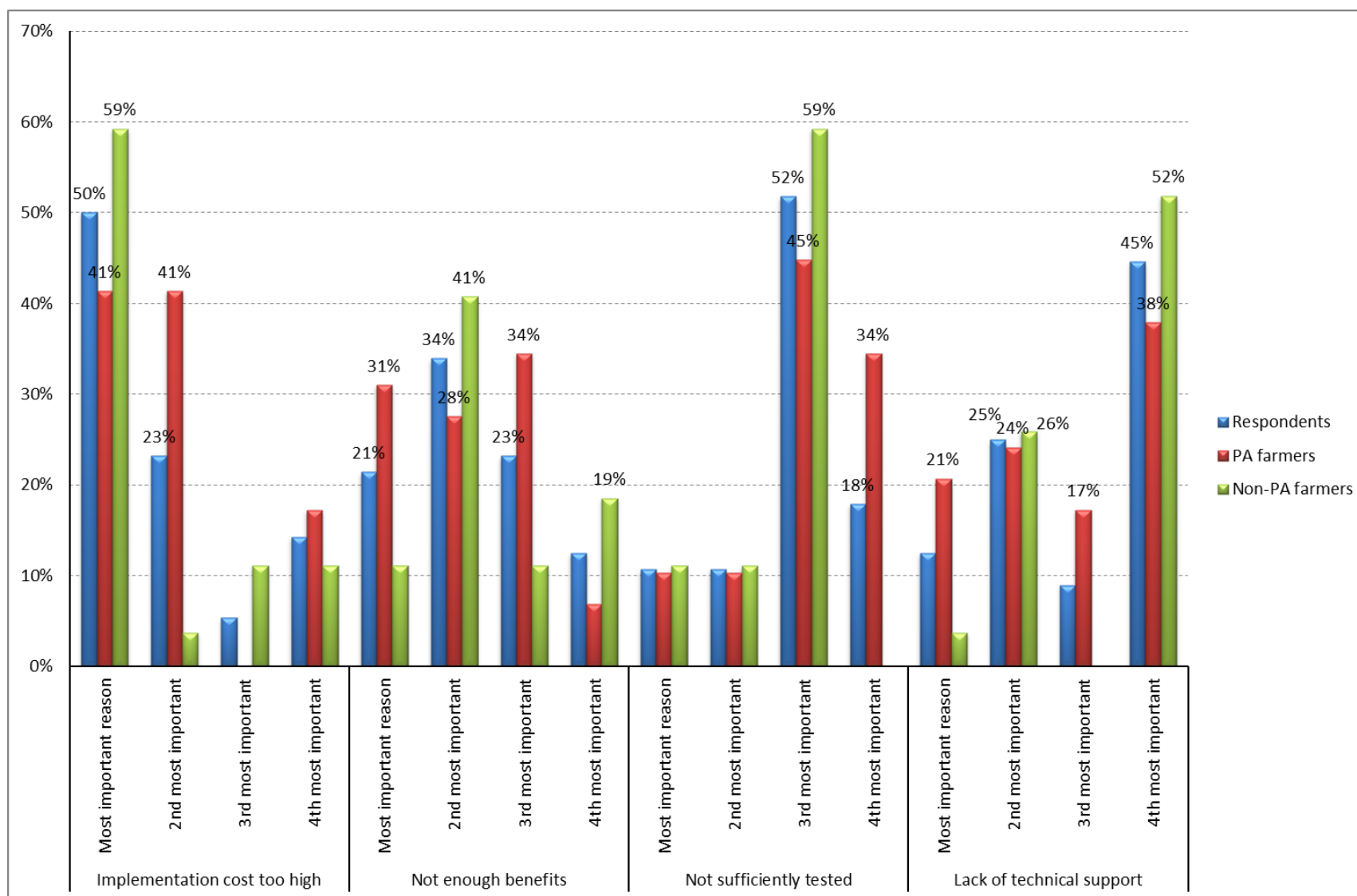
FIGURE 3.31 REASONS FOR NOT IMPLEMENTING SPECIFIC PA TECHNOLOGIES.

FIGURE 3.32 Precision agriculture: Perception vs. definition.

The respondents' perceptions towards PA were evaluated on the basis of 3 criteria. In Section A of the questionnaire they were asked if they practise precision agriculture (PA). In Section B they had to list the PA technologies that they currently use and also select an appropriate definition for PA. 82% of the respondents indicated that they practise PA. This group is presented in Figure 3.32 as the farmer that perceives that he practises PA. However, when evaluating if the technologies they implemented contributed to the full cycle of PA as defined in the literature study, only 52% of the sample matched the criteria and are 'true' PA farmers as per definition. Interestingly, when asked to select the most appropriate definition of PA, only 43% of the true PA farmers had a correct understanding of the term. This indicates that there is still a gap in the understanding of farmers regarding precision agriculture and even farmers that effectively practise it does not necessarily have a complete view of what it entails.

3.5 CHAPTER SUMMARY

In chapter 3 the research methodology was explained and discussed and the results from the survey were presented.

Firstly the scope and procedure of the quantitative research was discussed. The main target group of the survey was farm owners and - managers involved in the production of maize, sunflower, soybeans and other summer grains in the Free State and North West province.

A total of 250 questionnaires were distributed and a response rate of 41% was obtained. The sample size was 102 out of a population of approximately 5940 farmers in the aforementioned areas. Based on a confidence level and allowable error of 10%, 102 responses were slightly more than the minimum amount of 95 needed to validate the study. It can therefore be assumed that the survey results are a good representation of the targeted population's view.

The current survey used a quantitative approach in order to objectively meet the research objectives. The instrument used was a questionnaire (Annexure A) and the aim was to get the maximum number of responses within the available timeframe. The questionnaires were distributed to farmers by selling agents of an agricultural company with good representation in the targeted areas as well as by the author himself.

The data that resulted from Section A from the questionnaire regarding the profile of the sample was presented and discussed. The sample was analysed based on the respondents' capacity on the farm (i.e. land owner or manager), age group, years of farming experience, academic qualification, amount of hectares cultivated, percentage of crops under irrigation and the various crops planted.

The results from Section B of the questionnaire was presented and discussed. The most widely used PA technologies were identified namely grid soil sampling and yield monitors. Next, the PA technologies that were first implemented as well as PA technologies that were discontinued by the sample were documented. These results were compared with that of a similar study from the USA. The respondents' view on the availability, affordability and efficiency of specific PA technologies was determined. Benefits as well as reasons for not adopting/implementing certain PA technologies were evaluated. The majority of respondents indicated that too high implementation costs prevent them from implementing specific PA technologies. Finally the respondents' understanding of PA was evaluated by requesting them to select the best definition of PA. Only 68% of the sample correctly selected the textbook definition of PA as discussed in Chapter 3.

The second part of chapter focussed on the difference between the PA and non-PA groups. Both groups were extracted from the total sample. The PA group was identified based on the textbook definition of PA i.e. PA as a cycle that gather information and implement the results in order to reduce input costs and increase outputs. 52% of the respondents fulfilled the aforementioned requirements. The non-PA group consisted of the respondents that do not use PA (according to the definition) as well as respondents that indicated that they do not

use PA technologies. The profile of both the PA and non-PA farmer were compared with regards to age group, years of farming experience, academic qualification, amount of hectares under cultivation, types of crops produced and the finally the percentage of crops under irrigation. Positive correlations were found between age group, years of farming experience and to an extent the amount of hectares under cultivation vs. PA farming.

The second part of the chapter focussed on the technologies used and not used by the PA group, non-PA group as well as farmers in the USA. The majority of members from the PA group used grid soil sampling and yield monitors. The result correlated with that of the total sample, non-PA group as well as the findings from the US survey. A significant difference between the PA and Non-PA group was that the PA group used much more software based technologies such as GIS mapping and PA software. Both the PA and non-PA group indicated that PA provide benefits such as reduced input costs, increased outputs and improved management skills. High implementation costs were identified as the most important reason for not implementing certain PA technologies.

Finally the sample's perceptions towards PA were evaluated. Although 82% of respondents indicated that they are practising PA, only 52% matched the requirements of the definition and can be referred to as 'true' PA farmers. From the 52% that qualified as PA farmers only 43% had a correct understanding of the term precision agriculture.

The conclusions and recommendations will be discussed in chapter 4.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

4.1 INTRODUCTION

The primary objective of this study was to determine the state of precision agriculture in the summer grain producing regions of South Africa. The definition of PA, the PA cycle and its components, benefits of PA as well as reasons for slow or not adopting PA were researched by means of a literature study (Chapter 2). Chapter 3 presented an overview of the empirical study conducted to achieve the above mentioned objective. Data was collected by means of a questionnaire and the results were used to determine the state op PA in the summer grain producing areas, i.e. the Free State and North West provinces, and construct the profile of a PA farmer.

The focus of Chapter 4 will be an overview from the survey results as well as recommendations for developing PA as a production system among summer grain producing farmers. The recommendations will be discussed out of an educational and marketing perspective. The chapter will conclude with suggestions for further studies, a final conclusion and chapter summary.

4.2 AN OVERVIEW OF THE STATE OF PRECISION AGRICULTURE IN THE SUMMER CROP PRODUCING AREAS OF THE NORHT WEST AND FREE STATE PROVINCES.

The definitions of PA discussed in the literature study (Chapter 2) highlight that PA is not a once-off implementation of specific technologies but rather an on-going process, a method and management strategy. PA can also be explained as a cycle with various components. Components include actions (phases) and technologies. These actions/phases can be divided into three groups: Gathering of information; evaluation/analysis of information; and implementation. Each of these phases involves the use of specific PA technologies. Technologies used to gather information are grid soil sampling, planter monitors, yield monitors and soil sensors. Technologies like GIS mapping and software programs are used to analyse and evaluate the gathered information. The processed data are then used in management decisions that will include the implementation of specific technologies. Implementation technologies are typically VRT planting, VRT fertilizer application, VRT soil tillage, VRT pest control and auto guidance.

When considering the actions that are involved in the PA cycle it is evident that a farmer that only use one or two PA technologies are not in fact practising PA according to the definition. Based on the aforementioned requirements i.e. use technologies that represent all three phases of the PA cycle, the group referred to as the 'PA group' was extracted. Only 52% of the respondents met the requirements of the PA group. Since the survey data was validated on the basis of the minimum amount of responses (95) needed for a confidence level and allowable error of 10%, it can be assumed that the survey results are a good representation of the targeted population's view. Therefore it is 52% of summer grain producing farmers in North West and Free Sate practice PA. The respondents in this group can be classified as PA farmers and their profile will be discussed in the next section.

4.2.1 Profile of PA farmers in the North West/Free State provinces.

AGE

- The majority of PA farmers (76%) in North West/Free State province are older than 41 years.
- 41% of the PA group belongs to the age group of 41 to 50 years.
- Practising PA requires a significant capital input. The older generation of farmers are most probably in a better financial position to finance it.

YEARS OF FARMING EXPERIENCE

- PA farmers in the targeted areas have a significant amount of farming experience.
- The majority of PA farmers (62%) have more than 16 years of farming experience.
- 45% of the group has more than 20 years of farming experience.
- There is a positive correlation between the PA farmer and years of farming experience. It seems that the more experienced farmer is more likely to practise and implement PA.

ACADEMIC QUALIFICATION

- The survey results showed that the group identified as PA farmers are well educated.
- 72% of PA farmers have a tertiary education, either a university degree or a technical/ agricultural diploma.
- More than half of the PA group (55%) in the targeted areas have a university degree.

- PA Farmers produce on large production areas.
- Almost 80% of PA farmers have production areas of more than 1000 hectares. The majority (34%) cultivate areas which range from 1000 to 2000 hectares.
- The survey data indicated a positive correlation between PA and production areas up to 3000 hectares.
- A negative correlation was found between PA and production areas of more than 3000 hectares. It seems that farmers producing on areas of more than 3000 hectares are less focused on PA.
- Production on smaller areas require reduced inputs and increased outputs (the benefits from PA) in order to be profitable. On bigger production areas the volume counters the small margins. Farmers who cultivate very large production areas might focus more on quantity than quality.

TYPES OF CROPS CULTIVATED BY THE PA FARMER

- PA farmers in the Free State and North West provinces are mainly producing maize (100%) and Sunflower (66%).
- Other summer crops, such as soybeans, are on the increase and a significant amount of PA farmers (24%) also produce soybeans.

PRODUCTION AREA UNDER IRRIGATION

- The majority of PA farmers (93%) use no or very little (1-25%) of irrigation.
- Only 6% of PA farmers irrigate between 26 and 75% of their crops.

4.2.2 Farmers' attitudes and perceptions towards precision agriculture.

Section B of the questionnaire evaluated the farmers' attitudes and perceptions towards PA as well as the usage of specific PA technologies. Data was collected and presented under the following headings: Most widely used PA technologies; technologies that were used but later discontinued; farmers' first choice of technologies when implementing PA; outputs of PA; reasons for not implementing PA; and finally the farmers' understanding of the term PA. The results are summarised in the following section.

THE MOST WIDELY USED PA TECHNOLOGIES IN THE SUMMER CROP AREAS OF NORTH WEST AND FREE STATE.

- Grid soil sampling has been identified as the most widely used PA technology by both PA farmers (100%) and the total sample (77%).
- Yield monitors are the second most commonly used technology among PA farmers (72%) and the total sample (55%).
- The most significant difference between PA farmers and the general group are the use of software based technologies such as GIS mapping and PA software programs. PA farmers are more likely to use these technologies.
- Mobile soil sensors are a relatively new technology that has the lowest percentage of users among PA farmers (7%) and the total group (5%).
- From the range of variable rate technologies available, only VRT fertilizer application is currently used in the targeted areas.
- The results from the current study are in accordance with the findings from a similar study done in the USA. Both studies found that grid sampling and yield monitors are the most commonly used PA technologies.

TECHNOLOGIES USED BUT LATER DISCONTINUED

- Grid soil sampling is the technology that has been discontinued in the most cases. 14% of both the total sample and PA farmers have discontinued the use of this technology.
- Grid soil sampling is very expensive and in most cases only done every 2 to 3 years. This may explain the higher than average result.

PA TECHNOLOGIES THAT WAS FIRST IMPLEMENTED.

- The majority of summer crop producing PA farmers (62%) in North West and Free State indicated that grid sampling was the first technology implemented when they started PA.
- The majority of farmers from the total sample were also in agreement with grid sampling being the first technology to be implemented.
- Yield monitors were the second most common technology to be implemented by both groups.
- The results from this study were also in accordance with that from the US where grid soil sampling or yield monitors were the most popular first choices for implementing PA.

POTENTIAL OUTPUTS OF PA

- The most important benefits/outputs of PA as viewed by the total sample and the PA group are: Reduced input costs; increased outputs; and improved management skills.
- Both groups responded neutral towards the statements that PA might improve quality or have a positive environmental impact. Both these outputs are complex (i.e. influenced by several factors such as rain fall, disease pressure etc.) and can only be measured over a longer time period which may explain the farmers' response.

REASONS FOR NOT IMPLEMENTING PA TECHNOLOGIES

- The majority of respondents (including PA and non-PA farmers) specified that too high implementation costs were the most important reason for not implementing a specific technology. The non-PA group was extracted from the sample based on the groups' inability to implement PA as defined in the literature study.
- The fact that most PA technologies available in South Africa are imported explains their high implementation costs.
- The other reasons provided by both PA farmers and non-PA farmers, in order of importance, were: Not enough benefits; insufficiently tested; and lack of technical support.

FARMER'S PERCEPTION TOWARDS PA VERSUS THE TRUE DEFINITION

- 82% of respondents, i.e. summer grain producing farmers of the North West and Free State, indicated that they practise precision agriculture.
- In accordance with the definition of PA as a cycle, only 52% of the group were 'true' PA farmers.
- Interestingly, only 43% of the sample practice PA according to the definition and had a complete understanding of the term precision agriculture.

4.3 RECOMMENDATIONS

This survey showed that 83% of summer grain producing farmers in the North West and Free State provinces use some form of PA and are under the impression that they practice PA. When the textbook definition is considered, only 52% of the group qualify as 'true' PA farmers. It becomes evident that developing PA as a production method amongst farmers

will require a significant amount of education and effective marketing strategies by PA service providers.

4.3.1 Education

The fact that 82% of farmers were under the impression that they practice PA but only 52% do indeed practice PA shows that in general farmers do not have complete understanding of the term PA. In addition, not even all the farmers that were identified as PA farmers (52% of the respondents) had a correct understanding of the definition of PA. Education regarding PA as a production system is top priority. Considering the future demands faced by agriculture and its important role in food production, PA has the potential to contribute significantly to achieving these aims. The government and educational institutions are a vital part of the education system aimed at teaching the principles of PA on all levels – consumers and producers. Society must be informed about the future threats of food scarcity and ways to address the problem. The consolidated strategy to educate all levels of society regarding PA has to include the following educational institutions:

SCHOOLS

PA as a technology and production system has to be incorporated into school curriculums. PA can be introduced at a level as early as Grade 4 in the technology and social sciences learning areas. It is important that everybody, not only those that will be involved in agriculture have knowledge about PA. Agriculture is the second largest industry in the world with regards to the provision of jobs. In countries, like South Africa where agriculture plays a central role in the economy, the probability of learners being directly or indirectly involved in agriculture is very good. It is therefore important that PA must be introduced at an early age as well as progress to the higher grades.

Since PA closely interacts with information technologies it is important that learners obtain sufficient computer skills and have access to the internet. The current survey showed one significant difference between PA and non-PA farmers are the use of software based technologies. Improving learners' computer literacy will have a positive influence in this area.

It is important that PA is also incorporated into the curriculums of higher educational phases (Grade 10-12) of schools. Technology study fields like mechanical technology should equip learners with more in-depth knowledge about PA technologies and practices. This is even more relevant for agricultural schools.

AGRICULTURAL AND TECHNICAL COLLEGES

Colleges should offer students an up to date syllabus on PA technologies and the integration of PA as a production system. Agricultural colleges should provide students not only with the theoretical knowledge of PA but also with opportunities to get practical exposure to PA technologies and the implementation/operation of the PA cycle.

UNIVERSITY

As with many universities in the USA, PA must be integrated into all agricultural study fields at university level. Students must also be motivated and offered opportunities to conduct research in the field of PA. It would be important for the Department of Agriculture as well as the agricultural sector to support research on this level by awarding scholarships for projects in this field.

PRODUCTION LEVEL

The impact of the above mentioned recommendations are long term. For the optimum short term impact it is necessary to educate producers. Agricultural service providers bombard farmers with information on PA technologies. Their aim, in most cases, is not to educate farmers but to sell their products. When considering the survey results it is evident that farmers have an incomplete understanding of the term PA. It is crucial that farmers are educated with respect to the cycle of PA and also that there are technical and financial support to farmers who implement PA. An efficient support system will be able to guide them in every step of the implementation process and avoid costly mistakes. Due to the high implementation costs of PA, it is usually implemented over an extended time period. Farmers need assistance in planning the implementation process as well as measuring the effectiveness of the system components. Agricultural institutions and governing bodies could make a major contribution in this area. It would also be valuable for agricultural companies and service providers to assist in this. Agricultural service providers must not only focus on providing information on their product range but use the opportunity to educate and guide farmers on the complete process of PA.

Farm shows like Nampo and farmers' days are valuable opportunities for sessions to inform and discuss PA. This has been done in the past but the aim was marketing rather than education. The social media can also be an important tool to educate farmers. Websites that focus on educating producers on PA must be established and farmers must be encouraged

to contribute and interact in discussion boards. Social sites like Facebook can also be used to share educational information with farmers and encourage them to share personal experiences and knowledge with other members.

4.3.2 Marketing

Recommendations regarding more effective marketing strategies for PA products and services will be based on Kotler and Armstrong's (2010:36) four P's of marketing, namely product, price, place and promotion.

PRODUCT

PA products are not only pieces of equipment that can be sold and not backed up by product support. After sales service is a very important component of any company operating in agriculture. The current survey indicated a lack of technical support as one of the reasons farmers does not adopt PA. Agricultural companies should provide farmers with sufficient technical support on PA technologies. Well trained employees as well as employing more highly trained technicians are central to this service. Websites and social media as well as call centres and help lines can be used to support farmers on technical issues.

Since the majority of PA products are imported it is critical that products are sufficiently tested under local conditions before marketing these products. The results from the current survey also indicated that products that are not sufficiently tested or not having enough benefits prevent farmers from implementing PA. PA products use highly advanced technologies and incorrect use will cancel all benefits from it. It is therefore important that PA service providers are well trained and equipped to train farmers on the correct use and as a result obtain the maximum benefits from the products. The low efficiency ratings of certain PA technologies that were included in the survey can be due to either insufficient testing of the products under local conditions or insufficient knowledge by the operators that result in suboptimal results.

Agricultural companies must evaluate their PA product ranges with regards to the needs of farmers that produce on smaller as well as those producing on very large areas. The survey indicated that the majority of PA farmers produce on areas between 1000 and 3000 hectares. Entry-level as well as top-end products must be available to accommodate the needs of the smallest to the biggest farmers and a wide range of budgets.

Finally, it is also important that companies do not only focus on the best-selling PA products or the products with the biggest margin but also on quality products that represent the different phases of the PA cycle. Usually products with marketing potential are identified abroad and then brought to South Africa. It would be better for the local industry if the needs of the South African farmers and the local conditions are the primary criteria used for finding the suitable products to develop PA as a production system.

PRICE

The results from the current survey showed that the high implementation cost of PA technologies is the most important reason for not practising PA. Some respondents also stated that PA technologies are only affordable under certain conditions. These conditions may refer to favourable exchange rates, high commodity prices, etc. It is therefore important for companies to consider their pricing strategies. Companies can reduce their margins in order to obtain better market penetration and then focus on after sales service to increase their profits. Companies can also benefit from a more effective value chain, for example use more cost-effective logistics such as shipping containers instead of airfreight. In addition, the cost price of imported goods can be reduced by ordering bigger volumes when the exchange rate is favourable or by using hedging methods to counter a fluctuating exchange rate. Companies that import and sell the same products can combine orders in order to negotiate bigger discounts and share the shipping costs of sea freight.

Since PA technologies are highly advanced, it is seen as a specialist field with only a few companies that run the show. The more companies get involved in the marketing of PA products, the more competitive the market will get and the more likely prices will reduce.

There is sufficient proof from literature that PA provides significant environmental benefits. The government must be aware of these benefits and subsequent subsidy programs must be introduced to reward farmers for implementing PA practises.

Agricultural companies must also focus on quantifying the benefits of PA compared to the cost. This will put farmers' perceptions regarding high implementation costs into perspective.

PLACE

Place refers to marketing channels and the availability of products. The survey indicated that not all technologies are widely available. The technologies that were rated as being the most

widely available were grid soil sampling and yield monitors. The other technologies were only accessible to 50% or less of the respondents. As mentioned before, PA is seen as a specialised field and therefore PA service providers are limited. More companies must explore the opportunities provided by PA technologies and get involved in marketing PA products. Companies currently marketing PA products can improve their networks in order to make it accessible to more farmers. This can be done by appointing independent agents in areas not serviced by these companies. It is however critical that these agents are well trained and sufficiently supported. Another channel that can be explored to increase accessibility is on-line shopping and product catalogues. The success of these channels will depend on how effective the technical information such as installation and operating instructions are communicated and transferred to the farmers. Assistance in the form of a call centre or help line would also be valuable for farmers using these channels.

PROMOTION

Recommendations regarding the promotion or marketing communication will be discussed under the following headings: Advertising; sales promotions; personal selling; public relations; and direct marketing.

ADVERTISING

The most important aspect with regards to advertising PA will be to correctly identify and focus on the target group. The survey indicated that the majority of summer grain-producing farmers are older than 40 years. The characteristics of this specific peer group should be analysed and taken into consideration when an advertising campaign is formulated. For example, the older generation of farmers are generally more conservative and not as receptive to change. Advertising should carefully consider that when constructing the marketing material. Farmers are interested in the benefits of a specific technology or product and advertisers should make that a focus point. It is also important to identify the best channels for a specific target. For example, printed media such as agricultural magazines, specific radio stations or television programs and social gatherings such as farm shows or study group meetings that are preferred by the specific group.

Effective advertising is a continuous process that increases product awareness and not just an in-season marketing plan to sell products. Prominent farmers that have obtained positive

results with PA can be used to advertise products, for example sign boards next to fields indicating what specific products were used.

Companies can use sales promotions to increase the use of PA. As mentioned before, PA is not a once off implementation of a specific PA technology but rather a cycle with several components that include the use of several PA technologies. To effectively market PA as a system, companies should not only focus on individual products but rather on where the products fit into the PA cycle and the long term benefits provided by the whole system. Promotions can focus on purchasing a specific technology and then getting another technology free for a certain trial period. It is also valuable for companies to have demonstration units that they can make available to interested farmers. When exchange rates are favourable and companies save on the cost prices of products, these discounts can be used for sales promotions.

PERSONAL SELLING

This is probably the best marketing channel for agricultural companies. Farmers spent most of their time on the farm and value sales agents that spent time on their farms in order to understand their challenges and farming practises. Companies must have more sales agents in the field introducing and promoting PA to farmers. Because of the economic downturn companies have decreased their staff. The presence on farms can be increased by having more independent sales agents. The most important aspect is that sales agents are well trained and equipped to effectively market the products when visiting farmers.

PUBLIC RELATIONS

PA service providers must implement a public relations strategy in order to improve PA awareness. A dialogue regarding PA must be initiated and maintained by means of media articles that are placed in relevant newspapers and magazines. Articles should address subjects like: The benefits of PA; myths and rumours regarding PA; the PA cycle; and programs for the holistic integration of PA into farming practices. Radio talk shows and television actuality programs can also be used to improve the public image of PA. Informing

farmers on the latest PA technologies, successful practices, and the progress of PA in South African agriculture would be central to the success of this strategy.

DIRECT MARKETING

PA service providers can use direct marketing to increase the use of PA products. The target group for direct marketing should be carefully selected, for example farmers that do not use PA products or younger farmers in a specific area. Tools like information days, direct mail, telephone, e-mail and internet can be used to communicate the necessary information directly to these farmers. Internet, e-mail, social media and cellular communication will be more effective when targeting the younger generation farmers.

4.4 RECOMMENDED FURTHER STUDIES

The dissertation will be concluded by identifying opportunities for future research.

Future research in this field could include: (1) Quantifying implementation costs vs. provided benefits or increased outputs (e.g. increased yield) in monetary values; (2) Analysis of the environmental benefits provided by PA practises in the South African agricultural sector; and (3) Evaluating the state of PA in other agricultural sectors, for example winter crops, horticulture and vegetable production.

4.5 CONCLUSION

The aim of this study was to determine the state of precision agriculture in the summer grain producing areas of the North West and Free State provinces. In order to achieve this, a survey was conducted in the targeted areas. The resulting data was used to determine the percentage of farmers practising PA as well as the profile of PA group. The survey also provided data on the most widely used technologies as well as the availability, affordability and efficiency of the specific technologies. The sample's view regarding benefits from PA and reasons for not adopting PA was determined. In addition, respondents' understanding of the term 'precision agriculture' was evaluated.

The survey results indicated that only 52% of the sample practised PA according to the textbook definition and that a significant effort is needed in order to develop PA as a

production system. The results also highlighted the incomplete understanding of farmers with regards to PA.

PA can assist agriculture to meet the future demands but a collaborative effort is needed from agricultural companies, government as well as agricultural - and education institutions. Educating communities on all levels will help to increase the awareness and the use of PA. Secondly, more effective marketing can also make a positive contribution to the more widespread use of PA.

It can be concluded that the research objectives as set out in paragraph 1.3 were satisfactorily met.

4.6 CHAPTER SUMMARY

This final chapter will summarise the findings of the survey and present the state of PA in the summer grain producing areas of the Free State and North West provinces.

The study found that 52% of farmers in the targeted area do indeed practice PA as defined by literature. The majority of PA farmers are older than 40 years, have extensive farming experience and are well educated. PA farmers in the targeted areas produce mainly maize and sunflower on areas of more than 1000 hectares with no or very little irrigation. The most commonly used PA technologies are grid soil sampling and yield monitors. Grid soil sampling was identified as the technology of choice when implementing PA. PA farmers as well as non-PA farmers regard reduced input costs, increased outputs and improved management skills as the most important benefits of PA. The majority of farmers stated that high implementation cost associated with PA is the most important reason they don't use specific PA technologies. Finally the survey indicated that 82% of respondents considered themselves PA farmers while only 52% of the sample practices PA according to the textbook definition. It was evident that the majority of farmers had an incomplete understanding of the term 'precision agriculture'.

It is evident that a significant effort is needed to promote the usage of PA among farmers. Recommendations were made on how to achieve this. The recommendations were divided into two sections namely, education and marketing. Education was focussed on all levels of society, ranging from schools, colleges, universities to producers. Recommendations regarding an effective marketing strategy for PA were made based on the 4 P's of marketing: Product; price; place; and promotion.

Finally, it was concluded that the research objectives as set out in paragraph 1.3 were achieved. Suggested topics for future research within the field were proposed.

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ANNEXURE A

PRECISION AGRICULTURE QUESTIONAIRE:

SECTION A:

In what capacity are you on the farm?

Farm owner		
Manager		
Other		*Specify:*

Your age?

Number of years in farming?

Academic background?

Standard 8 (Grade 10)		
Senior certificate (Matric)		
Technical diploma		
Agricultural college diploma		
B-degree		
B.Hons. degree		
M.Sc. degree		
Other		*Specify:*

In what field of study have you obtained the before mentioned qualification/s?

Business Administration/Management		
Agriculture		
Science/Technical		
Other		*Specify:*

Number of hectares currently under cultivation?

1 to 500 ha	
501 to 1000 ha	
1001 to 2000 ha	
2001 to 3000 ha	
More than 3000 ha	

Which of the following segments are included on your farm?
Please indicate the largest segment as (1), 2nd largest as (2), etc.

Grain farming	
Stock farming	
Poultry farming	
Dairy farming	
Vegetables	
Other	*Specify:*

Which of the following summer crops do you plant?

Please indicate the largest planting as (1), 2nd largest as (2), etc.

Maize	
Sunflower	
Soybeans	
Peanuts	
Dry beans	
Other	*Specify:*

What % of the before mentioned crops are under irrigation?

0%	
1 to 25%	
26 to 50%	
51 to 75%	
More than 75%	

Are you currently using precision farming practices on your farm?

Yes	
No	

SECTION B

Which of the following technologies are you currently using?

Grid soil sampling	
Planter monitor/s	
Variable rate planting	
Variable rate fertilizer application	
Variable rate soil tillage	
Variable rate pest control	
Yield monitor/s	
On-the-go soil sensors	
Auto-steer	
Geographic information systems (GIS)	
Precision farming computer software (for example Farm Works)	

Which of the following technologies were used in the past but has been discontinued in the mean time?

Grid soil sampling	
Planter monitor/s	
Variable rate planting	
Variable rate fertilizer application	
Variable rate soil tillage	
Variable rate pest control	
Yield monitor/s	
On-the-go soil sensors	
Auto-steer	
Geographic information systems (GIS)	
Precision farming computer software (for example Farm Works)	

In what order have you implemented the following technologies on your farm?
Indicate 1st implemented as (1), 2nd implemented as (2), etc..

Grid soil sampling	
Planter monitor/s	
Variable rate planting	
Variable rate fertilizer application	
Variable rate soil tillage	
Variable rate pest control	
Yield monitor/s	
On-the-go soil sensors	
Auto-steer	
Geographic information systems (GIS)	
Precision farming computer software (for example Farm Works)	

Rate the availability, affordability and effectiveness of the following technologies on a scale of 1 to 3:

(3) Generally available - (2) Occasionally available - (1) Not available

(3) Very affordable - (2) Under certain conditions / circumstances affordable - (1) unaffordable

(3) Very high efficiency - (2) Under certain conditions / circumstances effectively - (1) Total ineffective

Technology	Availability	Affordability	Efficiency
Grid soil sampling			
Planter monitor/s			
Variable rate planting			
Variable rate fertilizer application			
Variable rate soil tillage			
Variable rate pest control			
Yield monitor/s			
On-the-go soil sensors			
Auto-steer			
Geographic information systems (GIS)			
Precision farming computer software			

Rate the following potential outputs of precision farming on a scale of 1 to 5.

(5) Strongly agree - (4) Agree - (3) Neutral - (2) Disagree - (1) Strongly disagree

Decreased my input costs (e.g. labour, fertilizer, pesticides)	
Increased my outputs (e.g. crop yield) is higher	
Improved the quality of grain	
It reduced the negative environmental impact (e.g., less erosion, less water pollution, more efficient water use / savings) on my farm	
The working conditions are safer	
It improved my management skills and provided more peace of mind	

Select the reasons why you do not use the some of the above mentioned precision farming technologies in order from 1 to 4?

Indicate the main reason as (1), 2nd most important reason as (2), etc.

Implementation costs of specific technologies is too high	
Specific technology does not offer enough benefits	
Specific technology have not been tested sufficiently	
Lack of technical support from the technology providers	

Select the <u>best</u> definition of precision farming.

The use of equipment (e.g. planter monitors, GPS, yield monitors) that work more precise.	
Continuous process of monitoring (data collection) with the aim of reducing input costs and increasing outputs that will result in sustainable farming.	
The subdivision of land into smaller, more manageable units.	