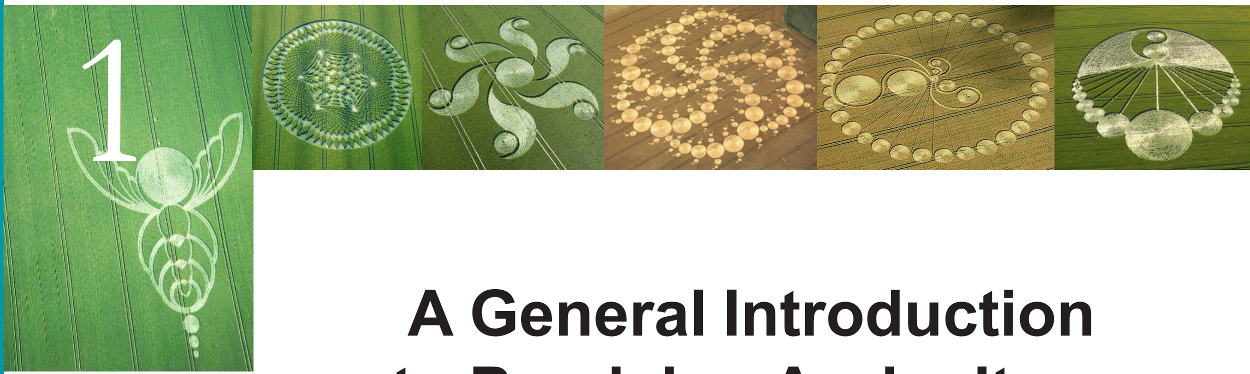
Grains Research & Development Corporation






# A General Introduction to Precision Agriculture

*Precision Agriculture is a now a term used throughout agricultural systems worldwide. But what do we mean by "Precision Agriculture"? This introductory chapter provides a background to the evolution of Precision Agriculture, the principle philosophy and goals of a Precision Agriculture management strategy and some of the steps required to adopt Precision Agriculture in cropping systems. It provides a stepping stone to subsequent chapters in this series that will investigate the theory, technology and methodology behind the adoption of Precision Agriculture, with particularly emphasis on small grains production in Australia.*

## A Brief History

Precision Agriculture (PA) is no longer a new term in global agriculture. Since the first substantial PA workshop was held in Minneapolis in 1992, it has become the subject of numerous conferences worldwide. An Australasian symposium on PA has been held annually from 1997. Its acceptance in the United States of America has been formally recognised by the drafting of a bill on PA by the US Congress in 1997. But where did the term and concept of PA come from?

The impetus for the current concept of Precision Agriculture in cropping systems emerged in the late 1980's with the matching of grid-based sampling of soil chemical properties with newly developed variable-rate application (VRA) equipment for fertilisers. Using a compass and dead-reckoning principles, fertilisers were applied at rates designed to complement changes in soil fertility maps that had been created. Crop yield monitoring technologies were still in the research phase at this stage.

Around 1990, the NAVSTAR Global Positioning System (GPS) became available in a limited capacity for civilian use and the opportunity for rapid and 'accurate' vehicle location and navigation sparked a flurry of activity. Electronic controllers for VRA were built to handle this new positioning information and crop yield monitors began to hit the commercial market. By 1993 the GPS was fully operational and a number of crop yield monitoring systems were allowing the fine-scale monitoring and mapping of yield variation within fields. The linking of yield variability data at this scale with maps of soil nutrient changes across a field marked the true beginning of PA in broadacre cropping.

As yield monitoring systems were improved, it became evident that methods other than grid sampling for collaborative information would need to be developed. In many instances, grid sampling at the intensity required to correctly characterise variability in soil and crop parameters proved cost prohibitive and, by the late 1990's, a "zonal" management approach had become a real option for management. This approach subdivides existing fields into zones of similar crop response and helps account for current limitations in data resolution while trying to maximise the benefits of PA for crop management.

New systems for measuring or inferring soil and crop parameters on a more continuous basis continue to be developed using both proximal (i.e. on ground-based platforms) and remote (i.e. aerial and satellite) platforms. Examples of these are soil ECa measuring instruments, crop reflectance imaging and crop quality sensors.

The success, and potential for further success, observed in the grains industry prompted other farming industries, particularly viticultural and horticultural crops, to adopt precision agriculture. Since the late 1990's more and more research has been carried out in non-grain crops. Also, more emphasis is being placed on the environmental auditing capabilities of PA technology and the potential for product traceability. Advances in Global Navigation Satellite System (GNSS) technology since 1999 have also opened the door for machinery guidance, auto-steering and controlled-traffic farming (CTF). CTF has provided sustainability benefits (such as minimisation of soil compaction), economic benefits (by minimising input overlap and improving timeliness of operations) and social benefits (such as reducing driver fatigue). As a result this form of PA technology has been showing swift adoption rates in the first decade of the 21st century.

## Defining Precision Agriculture

Many definitions of PA exist and many people have different ideas of what PA should encompass. Here two definitions have been selected to illustrate the concept of PA in general but also specifically its application to broadacre cropping industries. The first definition comes from the US House of Representatives (US House of Representatives, 1997).

> *Precision Agriculture:*
>
> *"an integrated information- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment".*

The key to this definition is that it identifies PA as a "whole-farm" management strategy (not just for individual fields) that utilises information technology and that the aim of management is to improve production and minimise environmental impact. It also refers to the farming system which in modern agriculture may include the supply chain from the farm gate to the consumer. This definition also distinguishes between agriculture and agronomy. Whilst the PA philosophy has been expounded primarily in cropping industries it is important to remember that precision agriculture can relate to any agricultural production system. These may involve animal industries, fisheries and forestry and in many cases PA techniques are being implemented without being identified as such. For example, the tailoring of feed requirements to individual milkers depending on the stage of their lactation in a dairy enterprise.

The second definition narrows the PA philosophy of timely management of variation down to its implementation in cropping systems.

*Site-Specific Crop Management (SSCM)*

*" A form of PA whereby decisions on resource application and agronomic practices are improved to better match soil and crop requirements as they vary in the field"*

This definition encompasses the idea that PA is an evolving management strategy. The focus here is on decision making with regard to resource-use and not necessarily the adoption of information technology on farm (although many new technologies will aid improved decision making). The decisions can be in regard to changes across a field at a certain time in the season or changes through a season or seasons. The inference is that better decision making will provide a wide range of benefits (economic, environmental and social) that may or may not be known or measurable at present. From an Australian grains perspective this definition provides a defined goal regardless of a growers current adoption of PA or proposed entry level into PA.

To further expand the concept, SSCM can be considered as the application of information technologies, together with production experience, to:

i) optimise production efficiency
ii) optimise quality
iii) minimise environmental impact
iv) minimise risk

- all at the site-specific level.

This is not a particularly new concept in agriculture with essays on this topic dating from the early 18th century. What is new is the scale at which we are able to implement these aims. Prior to the industrial revolution, agriculture was generally conducted on small fields with farmers often having a detailed knowledge of their production system without actually quantifying the variability. The movement towards mechanical agriculture, and the profit margin squeeze, has resulted in the latter half of the 20th century being dominated by large-scale uniform "average" agricultural practices. The advance of technology in the late 20th and early 21st centuries, has allowed agriculture to move back towards site-specific agriculture whilst retaining the economies of scale associated with 'large' operations.

***Some Misconceptions***

Like many new concepts, PA carries with it some misconceptions.

- PA is often confused with yield mapping. Yield mapping is a tool that is one of the first steps towards implementing a SSCM strategy.
- PA is sometimes misinterpreted as sustainable agriculture. PA is a tool to help make agriculture more sustainable however it is not the total answer. PA aims at maximum production efficiency with minimum environmental impact. Initially it was the potential for improved productivity (and profitability) that drove the development of SSCM as a form of PA. In recent years the potential for this technology as a tool for environmental auditing of production systems has become more obvious. However environmental auditing is not environmental management. The large amount of fine-scale data being collected in a SSCM system can be used for on-farm environmental risk assessment and incorporated into a whole-farm plan to help viability in the long term.
- Finally, machinery guidance and autosteer systems are examples of the successful adoption of new technology on farms. However, these again are tools that help with SSCM. By themselves they are not PA.

## Variability And The Production System

SSCM is dependent on the existence of variability and broadly speaking "variability in production = SSCM opportunity". Having said this, the type, magnitude and distribution pattern of variability is also important. There are generally two types of variability to be considered, spatial or temporal. Spatial variability occurs over a measurable distance, temporal variability occurs over a measurable time period. The difference between the low and high values of a measured property define the magnitude in both types of variability. The distribution pattern maps how variability is changing in either the space or time dimension.

The management implications of these aspects of variability are diverse and fundamentally linked to the production property being measured. However there are a few simple generalisations that are worth keeping in mind. The observed magnitude in the variability should be related a benchmark level below which it would be uneconomical to attempt to manage. It is important to note that the costs used to calculate these benchmarks are presently considered from a short-term economic perspective. If we were able to express environmental benefits in a fiscal sense, then in some instances, areas with a small magnitude of variation in production may be viable for SSCM management.

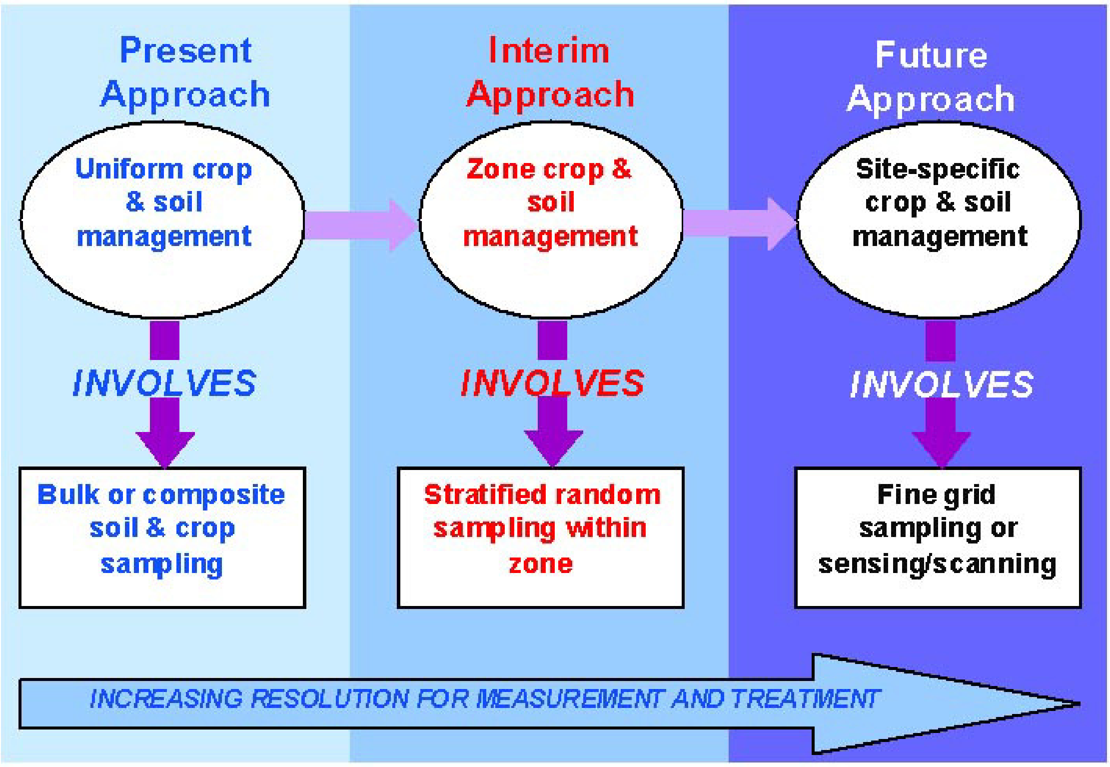



**Figure 1. The evolving timeline of SSCM from a uniform to a totally site-specific approach.**

The distribution pattern of the variability needs to be considered relative to the options for management intervention. In spatial terms, the pattern should be considered in relation to the smallest unit of treatment applicable (e.g. the size and reaction time of VRA fertilser application gear). In temporal terms, the pattern should be considered in terms of the impact on important management stages of the growing season (or the whole season if relevant).

If spatial variability does not exist then a uniform management system is both the cheapest and most effective management strategy. In cropping situations the magnitude of temporal variability may appear much greater than spatial variability. If the impact of temporal variability on production overwhelms the impact of spatial variability then careful consideration needs to be given to whether a uniform or differential management strategy is the optimal risk aversion strategy.

Based on these considerations, SSCM is at present operating on a zonal rather than a completely site-specific basis (Figure 1). As our ability to measure variability improves, the capital cost of VRA technology decreases and the environmental value is factored in, SSCM will begin to approach a truly site-specific management regime.

## Objectives Of SSCM

At the beginning of this introduction SSCM was defined in terms of four main objectives. The success of a SSCM strategy will depend on how each or all of these objectives are met.

### *Optimising Production Efficiency*

In general the aim of SSCM is to optimise returns across a field. Unless a field has a uniform yield potential (and therefore a uniform yield goal), the identification of variability in yield potential may offer possibilities to optimise production quantity at each site or within each "zone" using differential management. The initial emphasis should be on optimising the agronomic response to the manageable input with the most impact on production and costs. In the absence of any clear environmental benefits this will be achieved by differentially applying inputs so that the marginal return = marginal cost at each site or zone in the paddock.

### *Optimising Quality*

In general, production efficiency is measured in terms of a yield (quantity) response, mainly because yield and biomass sensors are the most reliable and commonplace sensors. In the past few years the first attempts to commercialise grain quality sensors have been made and on-the-go grain protein/oil sensors are now commercially available. The ability to site-specifically collect grain quality data will allow growers to consider production efficiency from the perspective of either yield, quality or a yield x quality interaction. Many inputs will impact on quality as well as quantity. In production systems where quality premiums exist this may alter the amount of input required to optimise profitability and agronomic response.

In some product markets, where strong quality premiums/penalties are applied, a uniform approach to quality properties may be optimal. The quality of some agricultural commodities is greatly increased by decreasing the variability in production e.g. winegrapes or malting barley. If quality premiums more than offset yield loss then growers may prefer to vary inputs to achieve uniform production quality (and minimise variability) rather than optimise productivity.

### *Minimising Environmental Impact*

If better management decisions are being made to tailor inputs to meet production needs then by default there must be a decrease in the net loss of any applied input to the environment. This is not to say that there is no actual or potential environmental damage associated with the production system however the risk of environmental damage is reduced.

SSCM, coupled with VRA technology, provides producers with a means to not only quantify the amount and location of any input application but also to record and map applications. This gives producers physical evidence to contest any claims against negligent management or alternatively provide information on 'considerate' practices to gain market advantage. A by-product of improved information collection and flow is a general improvement in the producer's understanding of the production system and the potential implications of different management options.

Apart from avoiding litigation or chasing product segmentation into markets, there is little regulatory incentive for growers to capture and utilise information on the environmental footprint of their production in Australia. Other countries, particularly within the EU, are financially encouraging producers to collect and use this information by linking environmental issues to subsidy payments. Such eco-service payments may well be introduced in Australia.

### *Minimising Risk*

Risk management is a common practice today for most farmers and can be considered from two points of view - income and environmental. In a production system, farmers often practice risk management by erring on the side of extra inputs while the unit cost of a particular input is deemed 'low'. Thus a farmer may put an extra spray on, add extra fertilizer, buy more machinery or hire extra labour to ensure that the produce is produced/harvested/sold on time thereby guaranteeing a return. Generally minimising income risk is seen as more important than minimising environmental risk but SSCM attempts to offer a solution that may allow both positions to be considered in risk management. This improved management strategy will come about through a better understanding of the environment-crop interaction and a more detailed use of emerging and existing information technologies (e.g. short and long term weather predictions and agroeconomic modelling).

The more that is known about a production system the faster a producer can adapt to changes in his own production and in external market forces . For example, accurate mid season yield predictions may give a grower more room to move with forward selling options.

## Practical Implementation Of SSCM

The SSCM cycle is illustrated in Figure 2. Each node in the cycle will form the theme for subsequent chapters in this series, however a short introduction is given here. It is important to remember that SSCM is a continuous management strategy. Initially some form of monitoring and data analysis is needed to form a decision. However it is just as important to continue to monitor and analyse the effect of the decision and feed this information into subsequent management decisions.

### *Geo-referencing*

The truly enabling technology of SSCM in its present form. Global Navigation Satellite Systems (GNSS) (of which the GPS is the most widely used at present) are now common place on many farms. Receivers range in accuracy from 10-20m to 2-3cm, in price from $200 to $60,000, and in application from crop monitoring and yield mapping to autosteer systems. The technology continues to improve and the price of receivers to decrease.

The ability to geo-reference activities gives producers the option to map and visually display farm operations. This provides insights into both production variability as well as inefficiencies in crop production and farm operations. In the past few years more advanced systems have become more common on-farm as growers embrace

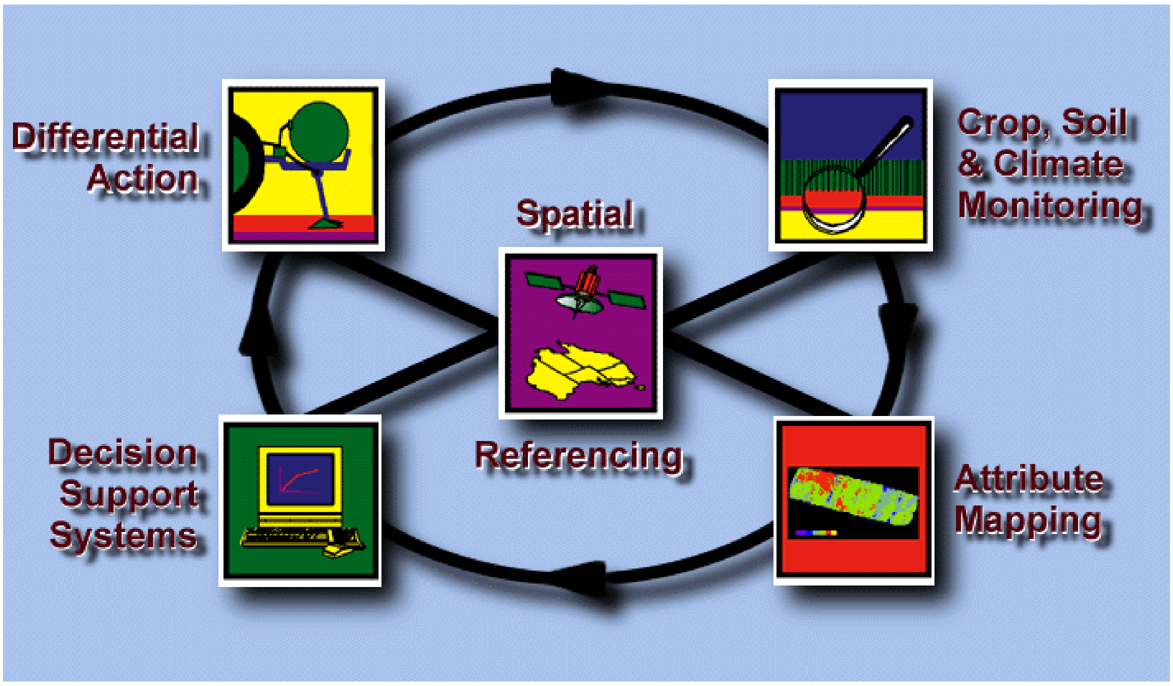



**Figure 2: The SSCM cycle indicating spatial referencing as the enabling technology that drives the other parts of the cycle.**

guidance and autosteer technologies. These permit machinery to drive along repeatable tracks as well as reduce driver fatigue and permit more timeliness of operations.

### *Crop, Soil and Climate Monitoring*

Many sensors and monitors already exist for *in-situ* and on-the-go measurement for a variety of crop, soil and climatic variables. These include yield sensors, biomass and crop response sensors (aerial and space-borne multi- and hyper-spectral cameras), radio or mobile phone networked weather stations, soil apparent electrical conductivity (ECa) sensors and gamma-radiometric soil sensors to name a few. The majority of SSCM research in Australia is currently being directed at identifying how to utilise the output from these sensors to improve production.

The other challenge for SSCM is to adapt *in-situ* sensors and develop new on-the-go sensors. While the commercial potential of these sensors will mean that private industry will be keen to take up the engineering aspects of research and development, research bodies have an important role to play in the development of the science behind the sensors. Market concerns often lead private industry to sell sensors prematurely to ensure market share. This may lead to substandard sensors and a failure to adequately realise the potential of the sensor. Agricultural scientists also need to continue to assess which and how multiple crop and production indicators can be measured.

### *Attribute Mapping*

Crop, soil and climate sensors often produce large, intensive data sets. The observations are usually irregularly spaced and need to 'cleaned' and interpolated onto a surface to permit analysis. For several decades geostatisticians have been researching ways of describing and representing spatial data that accurately represents the raw data. Historically most of this has been done with sparse datasets. The data sets being generated by SSCM technologies have produced new challenges for mapping, but most of these are now well understood within the PA community although answers are generally poorly disseminated through the wider agricultural community.

Software for mapping and displaying data from different sources on a common platform is improving annually. The development of Geographical Information Systems (GIS) specifically for agriculture is allowing this to occur however the adaptation and adoption of this technology for use in SSCM on individual farms is still in its infancy. The main issues still to be resolved are the development of a user friendly advanced data filtering system and the determination of initial and future sampling schemes to ensure that the variability of the system is properly characterised.

### *Decision Support Systems*

Techniques for data presentation and storage, such as Geographical Information Systems (GIS), developed in other industries should be relatively easily applied, with some modification, to agriculture. However Decision Support Systems (DSS) are not so flexible and it is in this area that much research needs to be done. Decision Support Systems use agronomic and environmental data, combined with information on possible management techniques, to determine the optimum management strategy for production. Most commercial DSS are based on 'average' crop response across a field. The majority of engineering companies currently supplying SSCM technology are currently not producing DSS to support the differential use of their equipment in a production system. Therefore the onus is falling on individual industry bodies, and to a lesser extent government agencies, to fill the gap. Initially it may be sufficient to adapt existing agricultural DSS such as WHEATMAN, COTTONLOGIC or APSIM to site-specific situations. In the long run however a DSS that is able to site-specifically model plant-environment interactions in terms of yield and quality will be needed. This will need to be flexible enough to incorporate a variety of sensor-gathered data, accept feedback from other parts of the SSCM cycle and be able to conform to standards such as ISO 9000/14000.

### *Differential Action*

The differential application of inputs using VRA technology is essentially an engineering problem. Due to the commercial potential of VRA technology, much of this engineering development is being driven by the private sector. The main input required for VRA implements is accurate information on required application rates and associated locations or times for the applications. VRA equipment should also record the actual application procedure for quality control. The differential application technology was probably the best developed part of the SSCM cycle in the late 1990's and development of new methods for differential application remains a project of many research and commercial entities around the globe.

Like GPS receivers, VRA equipment is becoming more user friendly, more cost effective and more common especially in broadacre agriculture. The biggest barrier to adoption is the lack of information from a DSS on where, and by how much, inputs should be varied.

## Concluding Remarks

Precision Agriculture is a management philosophy, encompassing the use of advances in information technology in agriculture. In 10-15 years time it is likely (and hoped) that SSCM as a form of PA , with its associated technologies and methodologies, will be simply considered as standard cropping practice. But no matter how technology and methodologies change and adapt overtime, SSCM will still be driven by the central philosophies of improved production efficiency, reduced environmental impact and risk minimisation.

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