# Scoping study to assess the application of precision agriculture for vegetable production

Alexander McBratney
The University of Sydney

Project Number: VG05060

**VG05060**

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the vegetable industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of the vegetable industry.

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ISBN 0 7341 1402 8

Published and distributed by:
Horticultural Australia Ltd
Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399
E-Mail: horticulture@horticulture.com.au

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# HAL PRECISION AGRICULTURE REPORT

# Scoping study to assess the application of precision agriculture for vegetable production

Project: VG05060

(June 2006)

Authors: Taylor *et al.*,

Produced by The Australian Centre for Precision Agriculture,
Faculty of Agriculture Food and Natural Resources,
The University of Sydney.

# Project VG05060

Authors: J.A. Taylor[1], M. Short, D. Rogers, T. Ancev and A.B. McBratney

[1] Australian Centre for Precision Agriculture, FAFNR, McMillan Bld A05, The University of Sydney, NSW, 2006
james.taylor@usyd.edu.au
ph: +61 2 9036 5278
fax: +61 2 9351 3706

**28th June, 2006**

## Synopsis:

Considerable research into the application of emerging agricultural technologies and methodoliges, termed Precision Agriculture (PA), in broadacre and viticulture has been undertaken globally and in Australia over the past decade. There has been little research in this area in the Australian vegetable industry. This report outlines the opportunites for adoption of PA methodologies and technologies from broadacre and viticulture into the Australian vegetable industy. It examines opportunities from a production, environmental and supply chain perspective. A desktop analysis of the likely costs and benefits from adoption in the broccoli industry has been performed. A series of reccommendations are presented for how a cost effective research plan may be implemented for PA in vegetable production.

## Acknowledgements:

This project has been facilitated by HAL in partnership with AUSVEG and has been funded by the Vegetable R&D levy. The Australian Government provides matched funding for all HAL's R&D activities."

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# 1. Executive Summary

This report investigates potential options for adoption and adaptation of precision agriculture technologies and management strategies into the vegetable industry. **Precision Agriculture (PA) is a management philosophy that is based around making better on-farm decisions, generally at finer-scales than current management, using emerging technology and methodologies.**

Over the past 10-15 years there has been a lot of knowledge in PA gained in broadacre and viticulture which can be readily transferred to horticulture. This is particularly true for satellite navigation systems, environment sensing systems, biomass sensors, variable-rate technologies and mapping applications. **Yield and quality sensors are the main technology gaps that need to be filled in vegetable crops.** Decision support systems (DSS) to integrate this information and derive suitable site-specific agronomic decisions have less options for adoption. This is due to differences in agronomy between horticulture and broadacre crops and the general lack of these DSS in broadacre. **The absence of effective DSSs has stalled PA uptake in broadacre production and must be addressed in any horticultural PA research program.**

The successful implementation of a PA management strategy will depend on the amount of variation in a production system. Uniform production systems are best served by uniform management. However where variation exists, in quality or quantity of production, a differential management strategy may be preferable. **For horticulture producers intending to enter PA the first step is to determine if there is sufficient variation to warrant site-specific crop management.**

The economics of PA adoption is generally considered from a production perspective. If a grower is able to recover the cost of investment through improved farm management then adoption will proceed. Very little emphasis and no fiscal value is given to the potential environmental benefits associated with PA. Horticultural production is often located in close proximity to urban areas for ease of market access however this proximity also increases the level of environmental scrutiny that the production systems are under. **PA technologies are able to spatially record farm activities and produce an environmental audit on a production system.** The societal benefit of good farm management should be quantifiable and premiums (or penalties) for good (or bad) environmental management given. Such systems are emerging in Europe and a lesser extent the USA. The horticulture industry has a good opportunity to drive this agenda in the near future. If the industry is not pro-active there remains the possibility of regulators dictating environmental management guidelines to the industry later on.

**Over a given area high-value produce has been shown to have a better opportunity for PA adoption than low-value commodity crops.** A desktop analysis of broccoli in this report confirms this. This is due to the opportunity for adoption being driven mainly by commodity price not input costs. Having said this production systems where input costs (chemical, fertiliser, irrigation etc.) are a large proportion of variable costs also have a good opportunity for PA adoption. These are generally highly mechanised production systems e.g. beetroot, sweetcorn, processing tomatoes. Industries with high labour demands may also have a good opportunity for PA adoption however it appears that the primary concern in these industries is the lowering of labour costs and mechanization. This will provide much greater cost benefits than PA.

Many vegetable crops are vertically integrated, particularly for canned produce. Vertical intergration permits improved information flow in these supply chains. **The ability to provide information on production, especially on sustainable or 'green' production practices, to the consumer may generate price premiums or ensure market access, particularly into European markets.** Information flow is bidirectional and improved communication in the supply chain will also provide growers with correct consumer signals so they can better tailor production to consumer demands. Technologies and methodologies to facilitate bidirectional informatin flow are currently under development. Vegetable and horticulture industries are well placed to take advantage of this and be in the vanguard of research, development and adoption of information technologies in supply chains.

A series of research areas have been proposed in the final section of the report. These are structured along the themes of Production-oriented, Environment-oriented and Supply Chain-oriented PA. The recommendations are designed primarily as an introductory step into PA and to fill some of the missing technology and knowledge gaps in the industry. Without some initial exploratory data it is difficult to formulate a detailed research plan. Appendix 2 provides a template for a more detailed program structure if a major investment in this area is considered.

## 2. A General Introduction to the theory and concepts of Precision Agriculture

The impetus for the current concept of Precision Agriculture (PA) in cropping systems emerged in the late 1980s with the matching of grid-based soil chemical sampling 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 the soil fertility maps that had been created.

**PA began in the grains industry with grid soil sampling**

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 available for 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 1990s, a "zonal" approach had become a real option for management. This approach subdivides existing fields into zones of similar crop response. This helps account for current limitations in data resolution while trying to maximise the benefits of PA for crop management.

The success, and potential for further success, observed in the grains industry prompted other farming industries, particularly cotton and viticulture crops, to adopt precision agriculture. Since the late 1990s 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 2000 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.

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 crop production 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 that 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, including animal industries, fisheries and forestry. In many of these industries 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. This definition provides a defined goal regardless of a growers current adoption of PA or proposed entry level into PA.

**PA is making the right decisions at the right time and place.**

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 however 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.

**Variability equals opportunity.**

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 to 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

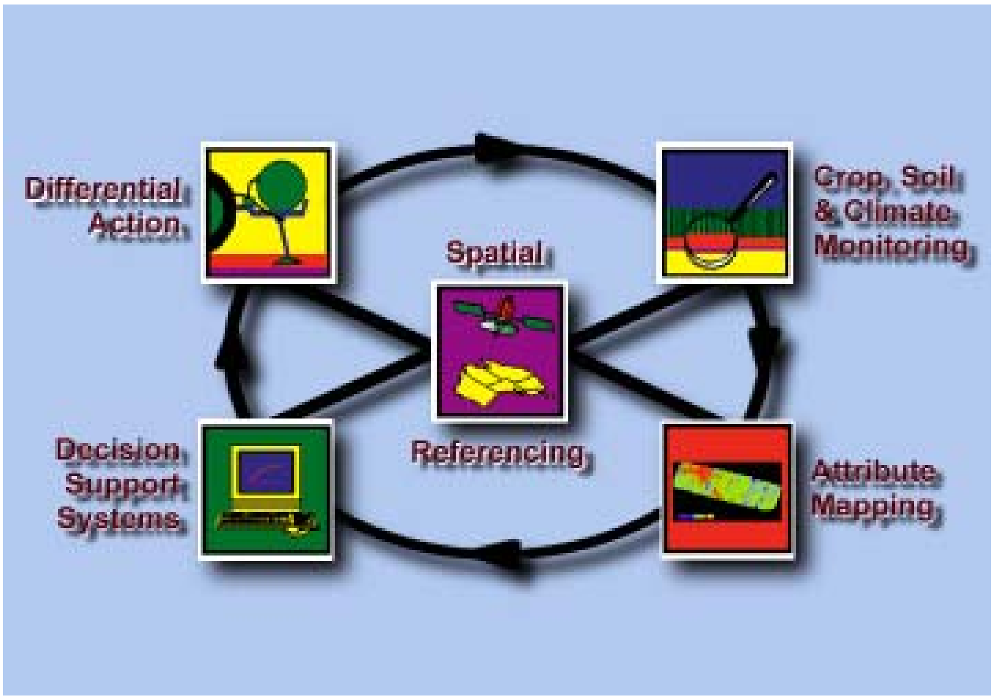


**Figure 2.1:** Diagrammatical representation of the PA cycle highlighting the importance of geo-referencing (GNSS) technology to all aspects of the management cycle (Courtesy of Australian Centre for Precision Agriculture www.usyd.edu.au/su/agric/acpa).

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.

*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 maximising production efficiency while minimising 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.

## 3. Production and Environment Oriented Precision Agriculture

Within cropping systems Precision Agricultural technologies will only be beneficial if there is some level of spatial or temporal variation in crop quality and/or quantity. In situations where crop quality and quantity variation is minimal or nonexistent then current uniform management systems will be optimal. In situations were production variability does exist, which is the norm, the level of crop and environmental variation needs to determined to provide an understanding of where production is varying and if possible what the production determining factors are. By collecting information on the inputs applied to a system and relating this information to crop and environment information, growers can also produce environmental audits of input use efficiency. This serves a two-fold purpose of providing information on the profitability of the production and also the environmental footprint (impact) of production. It is possible that the information on environmental impact may be convertible into a fiscal reward (or penalty) in the near future.

This section provides a brief overview of the technologies and methodologies currently being used to describe and manage variation in production systems. This is followed by a few case studies highlighting applications in horticulture and a discussion on decision support systems that need to be addressed for the technology to be successfully adopted.

### 3.1 Existing Methodologies

**A wide range of technologies already exist for PA.**

In traditional cropping systems, growers managed small areas by hand and developed an intimate knowledge of the production system. The reliance on hand or small-scale implements allowed growers to subjectively adopt differential management practices. With the onset of the mechanical age and the green revolution, production units became much larger, particularly in broadacre systems, and growers lost some of the intimate knowledge they formerly had. The increase in machinery power and size allowed growers to take advantage of economies of scale to improve profitability.

Precision Agriculture accelerated in the early 1990s with the merging of harvester mounted grain yield sensors and global navigation satellite systems (GNSS), in particular the Global Position System (GPS). This permitted the monitoring and mapping of yield within fields. These maps revealed large yield differences within fields that were being uniformly treated. To try to help understand these yield variations various soil and crop sensors were also linked to GPS to map environmental variables. This was done both proximally (i.e. on ground-based platforms) and remotely (i.e. aerial and satellite platforms). The value of the information gained has lead to the development of new sensors, to fill information gaps e.g. soil pH sensors, and a greater application and focus of satellite technology towards agriculture. Sensor development continues today with a large emphasis being put on commercialisation of crop quality sensors (e.g. grain protein).

Merging fine-scale crop, soil and environmental information permitted growers to start experimenting with variable rate application of inputs. Initially the sensor-based data was complemented with ~100 m grid soil surveys, particularly in the USA. However in many countries such intensive sampling was cost prohibitive and, by the late 1990s, a “zonal” management approach became the principal method for management. The zonal management approach subdivides existing fields into zones of similar crop response. Each zone is considered a discrete production unit with a unique management program. This differential management of “fenceless” sub-fields requires variable-rate technology (VRT) to apply inputs. Increasingly this technology is becoming more user friendly and accessible and many on-farm operations can now be variably performed. The approach for constructing management zones using crop (imagery, yield, quality etc.) and environmental (soil $EC_a$, elevation, gamma-radiometrics etc.) data is well understood for Australian conditions (Whelan *et al.*, 2003). Figure 3.1 illustrates this concept.

**PA currently utilises a management zone approach.**

Zone management however is really only an interim step towards a continuous management system (Figure 3.2). While there are some technical limitations to truly site-specific continuous management, there are commercial examples of real-time sensing, decision support and VRT systems, for example, the tractor-mounted Yara N sensor for variable rate N. As the ability to measure variability improves, the capital cost of VRA technology decreases, the environmental value of information is described in a fiscal sense and, most importantly, a better understanding of the decision-making process is achieved, SSCM will begin to approach a truly site-specific management regime.

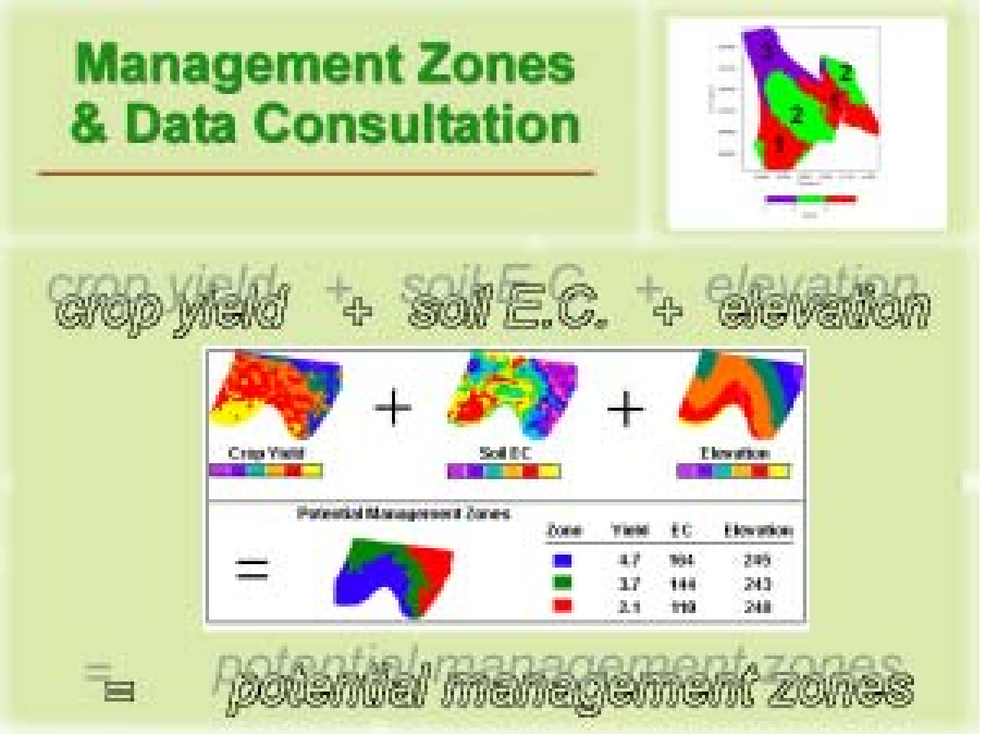


**Figure 3.1:** Diagrammatic representation of deriving potential management zones. (Courtesy of Australian Centre for Precision Agriculture www.usyd.edu.au/su/agric/acpa).

Within each discrete production unit the distribution of crop 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 (such as the size and reaction time of VRA equipment). 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.

## 3.2 Existing Technologies

*Global Navigation Satellite Systems*

**Satellite positioning systems are the pivotal point of PA.**

Global navigation satellite systems (GNSS), of which GPS is the best known, are the crux of precision agriculture. GNSS permits agronomic variables and operations to be mapped and integrated. It also permits returnability to specific locations and precise differential management. The multifaceted uses for GNSS products across society has seen dramatic improvements in the accuracy and cost of GNSS receivers over the past 15 years. Table 3.1 provides an indication of the cost, accuracy and applications of current GPS receivers. When other GNSSs, such as the EU's Galileo system or the Russian Confederation's GLONASS, become active and/or more widely accessible the prices will probably further decrease. The current GPS (and future Galileo/GLONASS systems) already provide sufficient

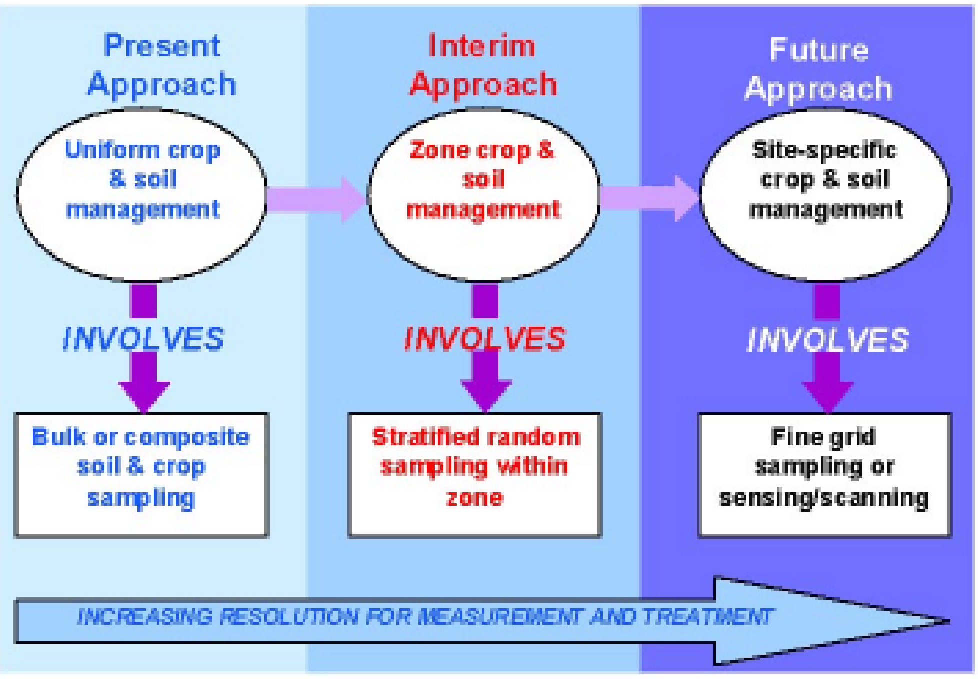


**Figure 3.2:** Continuum from uniform to zonal to continuous management systems. (Courtesy of Australian Centre for Precision Agriculture www.usyd.edu.au/su/agric/acpa).

accuracy for every farm operation. Systems will become cheaper and more fail-safe however the technology is currently ready for adoption.

Stand-alone and differential GPS systems have been available for 10-15 years however GPS use was mainly restricted to crop scouting and yield mapping and uptake was fairly sluggish. Improvements in both guidance (using Differential GPS to help the operator drive predefined paths) and auto-steer (using carrier-phase GPS to automatically drive the vehicle without driver assistance) systems over the past 5 years have seen a much greater adoption of GPS on-farm. The ability to minimise overlap during farm operations, reduce driver fatigue and drive in previously dangerous conditions (such as fog or darkness) has provided tangible financial and social benefits to growers, even with the large initial capital outlay needed for a carrier-phase auto-steer system (~AU$50,000).

**Guidance and auto-steer systems are promoting GPS uptake on-farm.**

The benefits of GPS adoption are outlined in several of the case studies (§ 3.3). Berglund and Buick (2005) also highlighted the benefits of 2 cm accurate autosteer in a lettuce crop. They determined that the cost of adoption was realised after 10 months due to the increased accuracy of laying drip tape and plants and improved yields. Their paper also states that clients received tangible payback from their GPS-based guidance systems, including improved in field productivity, lower farm input usage, reduced operator fatigue and ability to operate machinery longer hours. Controlled traffic also has been shown to improve employee performance and resulted in higher quality work.

*Yield Monitoring*

Load-cell yield sensors for mechanical horticultural harvesters using cross or discharge conveyor belts are commercially available and have been used successfully for several years, particularly in grape and potato production. These yield sensors are designed to be retrofitted to machinery and with some modifications should be adaptable to a wide variety of mechanical harvesters that utilise reasonably level conveyer belts. Load cells are not the only approach used for yield estimation and for broadacre crops there have been a variety of other principles used. Grain yield is usually sensed by measuring the force exerted by the grain on an impact plate. Cotton yield monitors measure the disruption in a light beam by the cotton lint.

Despite their commercial availability the uptake of grape and potato yield monitors has not been high. (However the same can be said of grain and cotton yield monitors). While many large Australian viticulture companies have invested in yield monitoring to a limited extent, in 2003 there was only one current contract harvesting company offering the system as standard for smaller growers in Australia (Smith, 2003). This is expected to change as the larger wine companies put more pressure on contract growers to deliver a more consistent harvest. In Europe, there has been little adoption of grape yield monitoring systems. This can be attributed to the predominance of smaller growers organised into cooperatives and the problems associated with retrofitting the yield monitors to European harvesters with onboard storage capacity. The low adoption rate is in part due to the extra effort needed to run the sensor, a lack of interest in some producers and initial teething problems that have been largely overcome but have produced a stigma. The other reason is the lack of emphasis put

**Table 3.1** - Results of a survey of GPS equipment available from major agriculture suppliers - July 2005

| Manufacture Dealer | Product Name | Visual Guidance (VG) Assisted Guidance (AS) | GPS Signal Correction | GPS accuracy | Unit price excl. GST | Additional costs: Automated Steering Assistance or GPS Subscription |
|---|---|---|---|---|---|---|
| Croplands | Outback S | VG | EDif | Sub-metre (R) | $4,950 | Outback eDrive $8950 |
| | Outback S | VG | Omnistar eDif | 0.30 metres (P) | $6,440 | Outback eDrive $8950 |
| | Outback 360 | VG | EDif | Sub-metre (R) | $4,950 | Outback eDrive $8950 |
| gps_Ag | Eziguide | VG | FreeDiff | Sub-metre (R) | $4,650 | N/A |
| | Eziguide 5100 | VG | Omnistar HP | ±0.10 metres (R) | $11,400 | $2350 subscription$5750<br>Ezisteer$16000 Accutrac |
| | Autofarm | AS | RTK carrier phase GPS (single or dual frequency) | ±0.02 metres (R) | $44,000 (single)<br>$56,000 (dual) | Hydraulic autosteer included in the price |
| KEE Technologies | Zynx X15 | VG | Garmin GPS | Sub 3 metre (R) | $9,000 | |
| | | VG | Triple-X (DGPS) | 0.30 metres (P) | $14,500 | $1900 per annum |
| | | VG | Ominstar HP | ±0.10 metres (R) | $12,000 | $2350 per annum |
| | | AS | RTK | ±0.02 metres (R) | $40,000+ | Prosteer $13000 |
| Case IH | AFS EZ-guide plus lightbar | VG | Ominstar VBS | ±0.25 metres (P) | $14,140 | $1750 per annum for signal<br>Trimble EZ-steer $5750 |
| | | VG | Omnistar HP | ±0.10 metres (R) | $14,890 | |
| | AFS Accuguide | AS | Omnistar HP | ±0.10 metres (R) | $30,000 | Includes steering kit |
| | | AS | RTK | ±0.02metres (R) | $51,700 | |
| AgGuide | RowGuide | VG | Omnistar VBS | Sub-metre (R) | $18,500 | $2100 per annum |
| | | VG | Omnistar HP | ±0.10 metres (R) | $18,500 | $2350 per annum |
| | | VG | RTK (single) | ±0.02 metres (R) | $34,500 | Steering Kit $9500 |
| | | VG | RTK (dual ) | ±0.02 metres (R) | $43,750 | |
| | Feeler Guide | AS | None | ±0.02 metres (R) | $15,000 | Steering Kit includedNeed to purchase RTK GPS |
| | Vision Guide | AS | None | ±0.02 metres (R) | 15,000-20,000 | |
| | Furrow Guide | AS | None | ±0.02 metres (R) | 22,000 | |
| BeeLine | Arro Decimetre | AS | Omnistar HP | ±0.10 metres (R) | $35,000 | $2800 per annum, includes steering kit |
| | | AS | RTK | ±0.02 metres (R) | $45000 | Includes steering kit |
| | Arro Centimetre | AS | RTK | ±0.02 metres (R) | $60,000 | Includes steering kit |
| John Deere | Greenstar | VG | SF2 | ±0.30 metres (P) | $10,700 | AutoTrac steering not included |
| | Parallel Tracking | VG | SF2 | ±0.10 metres (R) | $13,000 | |
| | AutoTrack | AS | SF2 | ±0.02 metres (R) | $29,000-$60,000 | |
| | | AS | Starfire RTK | ±0.02 metres (R) | | |

(R)= repeatable accuracy, (P)= pass-by-pass accuracy on quantity (yield) compared to quality, particularly in viticulture, and the absence of on-the-go quality sensors.

For hand-harvested crops, yield monitoring is more complicated however protocols have been established. These range from simply geo-referencing the location of fruit bins (Scheuller *et al.*, 1999) to more complex systems using bar-codes to identify bays from where fruit was harvested and to track fruit into the packhouse (Gillgren *et al.*, 2003). These protocols still rely on human labour for harvest and merely semi-automate information flow. A lot of effort is being put into developing mechanical harvesting robots in greenhouse conditions (e.g. Hayashi *et al.*, 2005). When these have been successfully developed the more complex problem of robot harvesting in orchards/fields will be undertaken. However despite efforts at the development of a grape harvesting mobile robot to mechanically hand harvest premium grapes (Sabetzadeh *et al.*, 2001) these systems seem a long way off.

**Note: Development of new harvesters is an important issue, particularly for labour savings. Efforts need to be made to either incorporate features in these new harvesters that accommodate existing yield sensors or new yield sensors need to be co-developed with new harvesters.**

*Quality Monitoring*

Yield sensors are only half the story and quality sensors are needed to complete the production (and profitability) picture. This is especially true in high value crops that have strong opportunities for market segmentation and premiums. As a result in-line quality measurement systems in packhouses or storehouses are reasonably advanced and a lot of research has been conducted in measuring various quality attributes. However on-the-go or infield quality sensors are missing in agricultural production in general. On-harvester grain yield monitors have been available for 15 years, however only in the past 3 years have protein sensors been successfully used on-harvester to produce quality maps to complement the yield maps and properly understand the partition of N in the system (Taylor *et al.*, 2005; Long *et al.*, 2002) (foe example Figure 3.4).

**Quality sensors are less developed than yield sensors.**

In viticulture a lot of research and development has been focused on the development of a rapid test for the quality of numerous grape and must properties. This work has primarily focused on the use of spectrometric techniques to develop a desktop-based sensor to replace traditional wet chemistry techniques. In the Australian grains industry, desktop NIR systems are now standard at silos to measure grain quality and, as indicated above, this technology has been successfully transferred onto harvesters.

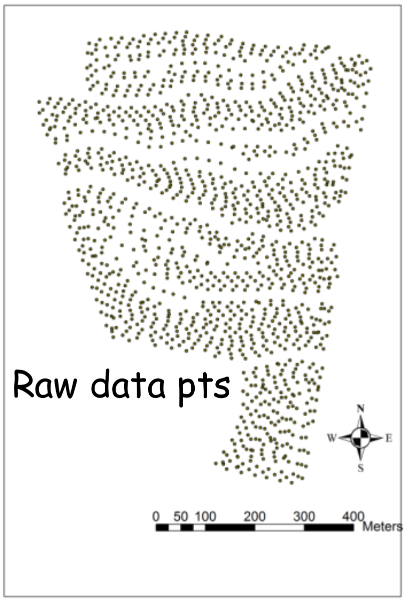
There are two types of quality sensors that are required, an on-harvester sensor, to complement a yield sensor, and a within field scanner to measure quality (and maturity) during the growing season. On-harvester sensors will allow the production of quality maps for various crop properties and also provide data to assess and audit the efficacy of the production system. However the data will have to be analysed retrospectively and applied to future production. The within field scanner may be more useful as it will allow producers to monitor crop development site-specifically and potentially allow differential within-season management to remedy any problems. For horticultural crops (apples and grapes) both types of sensor are under development (Herold *et al.*, 2005, Nazarov *et al.*, 2005). It is possible that these within-field scanners may be readily adapted to other crops that already use (or have the potential to use) in-line NIR in the grading process.

**Quality sensors may be more important than yield sensors in horticulture**

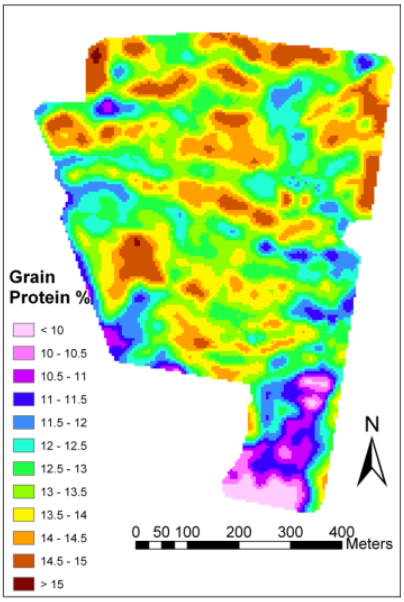
**Figure 3.3:** Example of an NIR 'gun' under development for the analysis of within-fieldgrape quality pre-harvest (Courtesy of Michel Crochon, CEMAGREF, France)

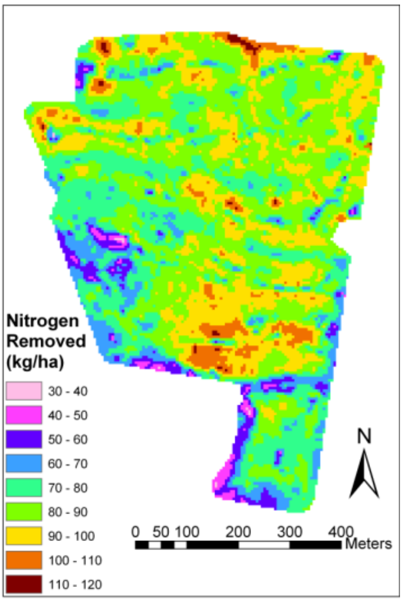
Considerable research has also been done on image and pattern recognition of vegetables and fruits. Crop quality is often multifaceted and these NIR and image sensors may need to be combined to produce a 'total' quality estimate. Since fruit quality is often already measured in the supply chain, there is an opportunity to transfer this information spatially back to the production system (see Fig. 4.1 for an example). This negates the need for the development of a new sensor however some spatial resolution will be lost. This opportunity will be further discussed in the supply chain section. However there are some opportunities available to include new sensors, for example a digital camera has been used to determine carotene content in carrots (Hasimoto *et al.*, 2005) but could also expanded to sense carrot shape and size for grading. Similarly a digital image-processing tool has been developed to assess the quality of the top layer of fruit in bins prior to storage (Vaysse *et al.*, 2005).

Protein Sensor mounted on clean grain elevator



Interpolated protein





Combining yield and protein data provides secondary agronomic data e.g. the amount of N removed site-specifically

**Figure 3.4:** An example of data collected using an on-harvester grain protein sensor. The top left shows the sensor mounted on the clean grain elevator; upper right - a plot of the data points; middle left - an interpolated yields map and lower right - a map of nitrogen removed from the field (calculated from site-specific protein and yield data). (Adapted from Taylor *et al.*, 2005)

*Crop Monitoring*

Growers have used crop monitoring for a variety of reasons including (but not inclusive of):

- counting production units (e.g. trees)
- identifying non productive units
- estimating crop leaf biomass
- quantifying growth rates
- measuring crop N uptake
- predicting crop yield and quality parameters
- identifying disease pressure
- incorporating spatial variability assessment into risk management

Crop monitoring can be done either remotely, from airborne or satellite platforms, or proximally, from vehicle-mounted platforms. Different sensors provide different spectral, spatial and temporal resolutions.

**The right resolution is important for correct use of imagery**

For remote sensing a multi-spectral sensor with a minimum of 4 bands (Blue, Green, Red and Near InfraRed) should be used to produce useful vegetative indices. Some sensors are capable of producing super-spectral (10-60 bands) or hyper-spectral (>60 bands). Super- and hyper-spectral data provides much more information however the cost of acquisition is much greater and to date there has been little research into extracting extra agronomic information out of the data to justify the increased cost. In the future Super- and Hyper-spectral imagery will become more common as costs decrease and the ability of cameras to simultaneously handle large waveband numbers and large pixel numbers (large image sizes) increases.

Spatial resolution refers to the smallest detectable object on the ground (Hall *et al.*, 2002) and in digital remote sensing this equates to the final image pixel size. Image pixel size is a function of the available image-forming pixels in the sensor and the height of the sensor above the ground. The interaction of these two parameters determines the overall area in the image, also referred to as the image footprint. For a given sensor there is a trade-off between spatial resolution and footprint size. The higher the altitude of the sensor the larger the footprint and the coarser the spatial resolution (Verbyla, 1995). Satellite sensors with a fixed elevation provide data at a constant footprint and spatial resolution that varies with the sensor. Aerial platforms are more flexible and can create images with decimetre spatial resolution (Lamb *et al.*, 2001). However they are generally flown to produce ~100 ha footprints at 1-2 m spatial resolution (Hall *et al.*, 2002). Satellite resolution varies from 1 km pixels (e.g. NOAA satellites or METEOSAT) to submetre pixels (e.g. Quickbird). Given the generally small size of horticultural production the choice of satellite sensor will be limited to the higher accuracy sensors (<10 m pixel size) or to airborne sensors.

Temporal resolution refers to the revisit time of the sensor. For satellite sensors the revisit time is determined by their orbital path. Some modern satellites are now able to direct the sensor off-nadir to decrease the revisit time however this usually substantially increases the cost of the data. The presence of cloud/haze may also complicate satellite imagery and decrease the effective temporal resolution. Aerial platforms are generally much more flexible for temporal resolution. They are also less susceptible to cloud interference as they may be able to fly below high cloud layers (Hall *et al.*, 2002).

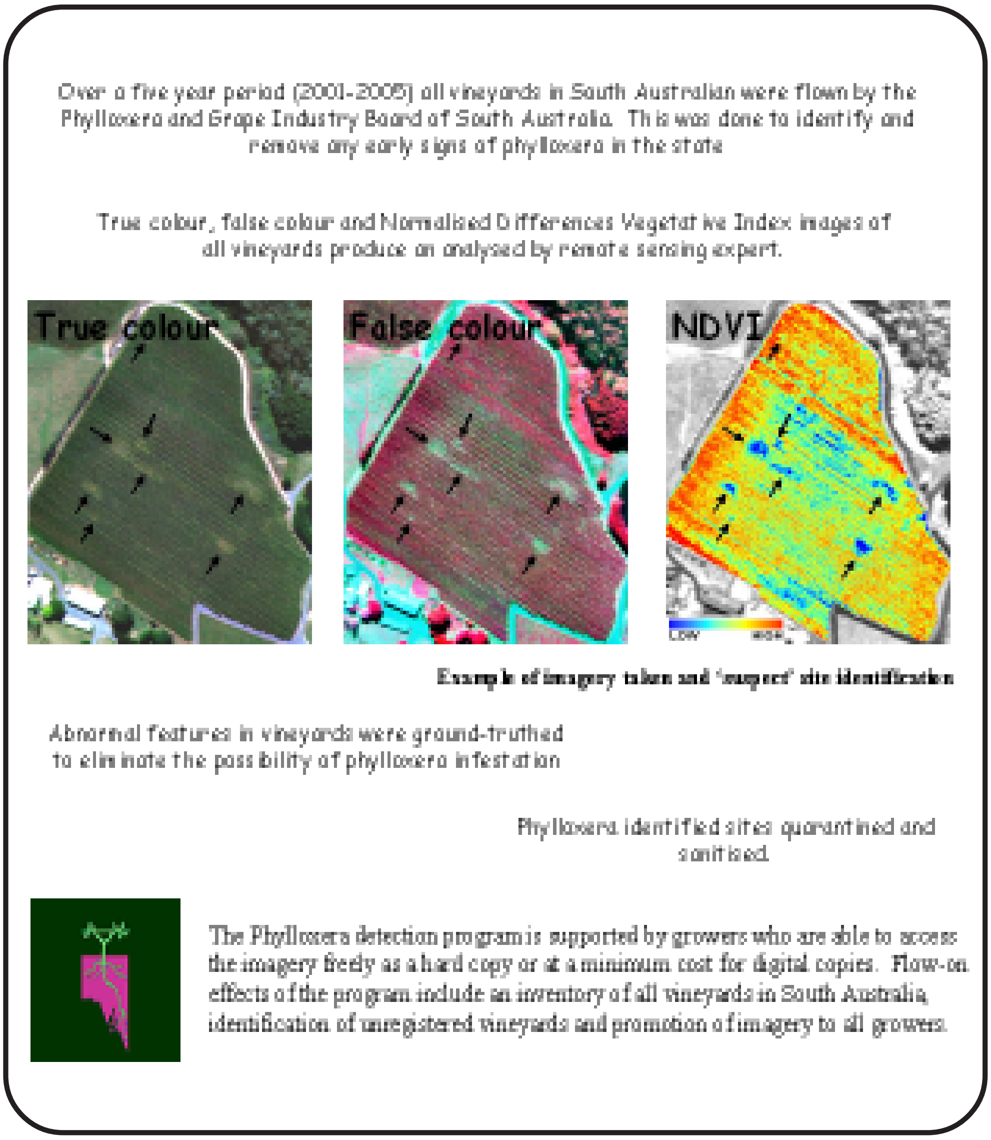
In Australia, remote sensing data has been by far the most sought after horticultural (particularly viticulture) production information. Initial problems with the reliability and usefulness of yield and proximal crop sensors in horticultural crops have led to a greater reliance on remotely sensed imagery. Since the inception of the Cooperative Research Centre for Viticulture's Precision Viticulture program in 1999, the area of viticulture imagery purchased in Australia had grown from ~200 ha (mainly for research) to ~30,000 ha for the 2003 vintage (Dr David Lamb, University of New England, NSW, *pers. comm.*). This represents ~15% of all plantings in Australia. Furthermore, with modern satellite sensors the entire viticulture area has been imaged and archived thus this figure could rapidly increase with the retrospective purchase of images.

**Archived Satellite imagery is available retrospectively**

Similarly, archived imagery will be available for horticultural crops. This provides a rapid and relatively cheap step towards understanding crop variability. Depending

**Table 3.2:** Sensors available for on-the-go survey of vegetative crops (NC indicates that the sensor is non continuous and builds up a paddock image from smaller snapshots overtime rather than in a single image)

| **Sensor** | **Spatial Resolution (m)** | **Applications** | **Cost per Ha** |
|---|---|---|---|
| AirborneMultispectral camera | 2m | Vegetative indices | $3-$4/hadepending on crop |
| Airborne Multispectral camera | 0.5m | Vegetative indices | $20-$35/ha |
| SPOT 5Multispectral satellite | 10m | Vegetative indices, crop biomass, yield predictions | $3.50-$8/ha |
| IkonosMultispectral satellite | 0.8m | Vegetative indices | At least $8/ha |
| QuickbirdMultispectral satellite | 0.6m | Vegetative indices | At least $8/ha |
| Yara N-Sensor | ~40m (NC)Real time | Variably applying nitrogen according to the crop requirements | |
| Crop Circle | ~4m (NC)Real time | Measures plant canopy reflectance day or night with visible and NIR; sense plant canopy biomass on-the-go | |
| Yield sensor | ~10 metreReal time | Real time yield monitoring. Create yield maps with georeferenced data | ~$14,000 to purchase unit~ $1/ha from contractors (grain) |



Over a five year period (2001-2005) all vineyards in South Australian were flown by the Phylloxera and Grape Industry Board of South Australia. This was done to identify and remove any early signs of phylloxera in the state

True colour, false colour and Normalised Differences Vegetative Index images of all vineyards produce an analysed by remote sensing expert.

Example of imagery taken and 'suspect' site identification

Abnormal features in vineyards were ground-truthed to eliminate the possibility of phylloxera infestation

Phylloxera identified sites quarantined and sanitised.

The Phylloxera detection program is supported by growers who are able to access the imagery freely as a hard copy or at a minimum cost for digital copies. Flow-on effects of the program include an inventory of all vineyards in South Australia, identification of unregistered vineyards and promotion of imagery to all growers.

**Figure 3.5:** Example of an industry wide application of remote-sensing technology to combat the threat of disease outbreak in the South Australian viticultural industry. (Adapted from Phylloxera and Grape Industry Board of South Australia - http://www.phylloxera.com.au/)

on the growing characteristics of the crop there may be issues with background noise in the images however previous studies have provided solutions to this problem in viticulture (Dobrowski, et al., 2002).

The ability of NIR sensors, either remotely or proximally mounted, to detect early signs of stress in plants has been used for early identification of disease. Within a production system a digital NIR camera has been able to identify areas of 'blackleaf' infection long before the disease was visually expressed in grapevines (Lang *et al.*, 2000). Further studies in the same area (Silbernagel and Lang, 2002) have shown that the spatial structure of blackleaf expression is temporally unstable and most obvious at the beginning and end of the growing season. The ability to detect early- to mid-season environmental stress will allow growers to better and differentially manage the crop (Sibernagel *et al.*, 2002).

On a catchment/state scale , airborne multi-spectral images have also been used to audit all South Australian vineyards for signs of phylloxera (Fig 3.5). This was done to identify any risk to South Australia's phylloxera free status and protect the industry. In addition, growers were able to obtain cheap imagery of their vineyards and a full audit of the area under vines was completed. It is a requirement in SA to register vineyards and using the aerial imagery several unregistered vineyards were identified.

Aerial imagery has also been used as a tool to assist differential harvesting strategies. The difference observed in canopy growth can be related to grape quality with targeted ground-truthing. Thus the patterns observed in the imagery can be he used to segregate the fruit into different quality grades. This has shown to be potentially very profitable with little capital outlay (Bramley *et al.*, 2005).

Proximal crop sensors are incapable of simultaneously imaging the entire production system and tend to be used to either build images over time or facilitate real-time management. Examples of these sensors are beginning to emerge. In canopy crops digital imaging from the side or underside can be used to determine crop/vine density or porosity (Praat and Irie, 2003; Bruno Tisseyre *et al.*, 1999 and Souchon *et al.,* 2001). In orchards laser sensors have been used to determine the size of trees (Tumbo *et al.*, 2001). In grain crops tractor-mounted sensors (e.g. Yara N sensor) can be used to estimate the site-specific nitrogen requirement of the crop and allow real-time decision making and differential fertiliser application. Tractor-based mapping would be extremely useful as horticultural management frequently requires the traversing of tractors through the crop. By mounting sensors on tractors, information could be gathered with no time-cost and at different stages of crop development.

*Soil and Topography Monitoring*

Understanding the variation in key soil properties, such as moisture holding capacity, fertility, salinity and compaction, often provides an understanding to crop response. Thus soil sensors, in particular apparent soil electrical conductivity ($EC_a$) sensors, are probably the most commonly used proximal sensors in agriculture and viticulture. There are a variety of Soil $EC_a$ sensors available that utilise either electromagnetic induction (EMI) or contact soil resistivity sensors with a direct current (DC). Both approaches give a similar signal that is a function of soil moisture, clay percentage, clay type, the ionic concentration of the soil matrix, bulk density and soil temperature (Dabas *et al.,* 2001). Of these, the first four variables are the most influential on the $EC_a$ measurement. Soil $EC_a$ data is a highly sought after data layer in a production system as it integrates a variety of useful soil properties for crop production. The majority of users rely on this integrated value and there has been little work in trying to decompose the signal to extract site-specific estimations of soil moisture and clay content. Individual estimations of soil properties would be much more useful than the integrated signal.

**Many soil sensors are now available**

Individual estimates of temporally variable soil properties can be achieved without decomposing the $EC_a$ response if a series of temporal measurements are made. Most of the soil properties that make up the $EC_a$ are temporally stable in the short to medium term (e.g. soil texture, clay mineralogy, bulk density, salinity). The most temporally variable attribute is soil moisture. Differences between the $EC_a$ signal at different times can be predominantly attributed to changes in soil moisture. Thus difference maps of $EC_a$ over time can be calibrated to the amount of soil moisture available (Wong *et al.*, 2005). If $EC_a$ data can be collected routinely and cheaply in conjunction with other farm operations, then spatial maps of available soil moisture can produced to assist irrigation management.

Real-time gamma-radiometric and ground-penetrating radar (GPR) sensors are starting to be investigated as potentially useful data layers in agricultural management however these investigations are fairly preliminary at this stage. Gamma-radiometers often provide a very different signal to $EC_a$ sensors as the signal is based on natural gamma emissions from the soil and is generated from the topsoil only.

**Existing soil sensors can be directly applied to horticulture**

An ion selective field effect transistor (ISFET) sensor system to measure pH has been developed and is in the process of being commercialised by Farmscan Ltd. (Perth, WA). A decision support system to determine lime requirement has also been developed to run with the sensor (Viscarra Rossel *et al.,* 2003). The current prototype sampler for this system provides a generic method of sampling and presenting a standard sample of soil. In this situation it may be possible to use other ISFET and ENFET (Enzyme-FET) sensors, e.g. $NO_3^-$, to measure a range of soil chemical properties. Work is also being conducted on the use of NIR to predict soil properties (Shibusawa *et al.*, 2001). The GRDC has recently invested in a project to explore the development of new soil nutrition sensors. There may be an opportunity for collaboration between HAL and GRDC on this issue.

To complete the suite of soil sensors development is progressing on new sensors to measure the physical properties of soil compaction and soil moisture. On-the-go horizontal penetrometers can be set at various depths to give information on soil strength down a profile (Sun *et al.*, 2006) and soil bulk density (Mouazen *et al.*, 2005). This may be beneficial in high quality root crops where soil strength affects growth characteristics. The development of dedicated on-the-go soil moisture sensors is also developing on several fronts (Sun *et al.*, 2006; Thomsen *et al.*, 2005). The need for these invasive sensors to be pulled at various depths through the soil is causing some problems with sensor durability.

Apart from on-the-go sensors, fixed soil moisture sensors are also commonly utilised in vineyards, particularly irrigated vineyards. These often need to be manually scanned or read to access the information however the coupling of sensors to radio frequency identification (RFID) units is being adopted and should facilitate more regular recording and better use of the information. The emergence of Embedded Networked Sensing systems in the past few years has opened up new opportunities in this area and also in microclimate monitoring. Already microclimate sensors are being utilised in ecological applications (Graham, 2004) and the progression to agro-ecological systems is the next step.

When conducting an on-the-go soil survey it is common practice now to also record elevation data from a high resolution (usually carrier-phase) satellite navigation system (e.g. GPS). This permits the generation of a digital elevation model and the

**Table 3.3:** Sensors available for on-the-go survey of soil properties

| **Sensor** | **Depth of Measurement** | **Applications** | **Transects** | **Cost per Ha (for ~100ha)** |
|---|---|---|---|---|
| EMI 38 | 0.75m (horizontal)<br>1.5m (vertical) | EC mapping Soil texture (clay, silt) salinity, CEC, | 10- 20 metres | $7.50-20 |
| EMI 31 | 6 metres | Soil salinityDeep drainageSoil texture | 10- 20 metres | $10-20 |
| Veris 3100 | 0-0.30m (shallow)<br>0-0.90m (deep) | Electrical conductivity (EC) mapping | 10- 20 metres | $10-20 |
| Veris MSP | 0-0.30m (shallow)<br>0-0.90m (deep)<br>pH 12-25 samples per Ha | Combined pH and EC mapping | 10- 20 metres | $15-30 |
| pH & LR Sensor | 0.20 m | Measures pH and determines the lime requirement | 10- 20 metres | $15-30 |
| Elevation | Height measured and georeferenced with GPS every second ~1metre | Digital Elevation Map (DEM) | 10- 20 metres | Data usually gathered simultaneously with other instruments |
| Gamma Radiometer | ~0.45 metres | Soil texture and parent material | 10-20 metres | $20-30 |

derivation of secondary and tertiary terrain attributes such as aspect, slope, curvature and wetness indices.

### *Variable Rate Technology*

A wide variety of variable rate technology (VRT) and controllers are now commercially available for broadacre crops and, with some engineering ingenuity, could be retro-fitted to most horticultural equipment. To date however VRT has not been implemented in horticulture principally due to i) a lack of decision support in deciding how treatments should be varied and ii) relatively healthy profit margins that negate the need to improve production efficiency. As profit margins decrease and the opportunity and support for site-specific management increase then VRT adoption will increase.

Spray equipment linked to multispectral cameras have been developed to identify and selectively spray weeds/plant material at resolutions of <1 cm$^2$ against the soil background (Hanks, 1995). This has permitted a reduction in herbicide use of up to 85% in some instances. While initially developed for fallow broadacre usage these sensors have been adapted for row crops and commercial sprayers are available. Further advances in spray technology are also being made with smart sensors that are able to differentiate between the crop, in this case cauliflower, and weeds (Gorretta *et al.*, 2005). This allows selective spraying along the planted rows as well as down the interrow.

Similarly, tillage operations can be controlled using digital imaging. Robocrop is a tillage systems that uses a digital camera to identify the row where the crop is. An on-board computer systems controls a hydraulic side-shift that moves the position of cultivating tines to avoid the crop. It is intended to be accurate enough to till between 20 cm row spacings without damaging the crop. It offers the chance to control resistant weeds or precisely placed fertiliser after the crop is established without a high-accuracy satellite navigation system.

Over the past 5 years considerable research has gone into the development of variable-rate irrigation (VRI) sprinkler systems (Evans *et al.*, 2000, Sadler *et al.*, 2000, Pocknee *et al.*, 2003). This research has concentrated on overhead- or drop-sprinklers on centre-pivot irrigation systems. These systems use bermad (or asco) valves to shut off the supply of water to the sprinkler head thus are essentially binary systems. Application rates are controlled by turning sprinklers off or varying the speed of the pivot as it ‘walks’ around the field. Sprinkler heads are generally banked along the pivot so that one solenoid will control several sprinkler heads. This is done to minimise the hardware and cost of the system. Trials with this system have been successful (Perry *et al.*, 2002) and commercial systems are available.

Work is also underway on the development of variable rate microsprinkler systems (Coates *et al.*, 2005). The output of each microsprinkler can be programmed in response to the local level of soil moisture determined by soil moisture sensors. Currently there is research underway to develop low cost wireless moisture sensors and actuator networks to control irrigation schedules. Systems like these monitor soil moisture in real-time and determine the optimum time to irrigate. (Torre-Neto *et al.*, 2005). Cheaper sensors will allow more sensors, greater coverage and more site-specific management options. Irrigation auditing systems, such as IRRIMATE™, are available to record the amount of irrigation water applied and help optimise irrigation scheduling.

Apart from measuring soil moisture, irrigation scheduling could also be determined by directly monitoring crop response using infrared thermography. Irrigation could then be applied in response to any stress noticed in the crop however, depending on the crop, irrigation at the onset of water stress may be too late and an understanding of the crop physiology is needed with this approach. Using infrared thermography to measure the difference between crop canopy and ambient temperature has been used to calculate irrigation needs in potato (Viau and Kotchi, 2005).

Even without using these systems to differentially altering input rates, variable rate technology may have an important role to play in environmental auditing of production systems. VRT systems provide the ability to site-specifically record operations within a field. This provides the grower with information on exactly where his input has been placed in the field. In uniform applications it may identify skip rows or doubled rows. For variable rate applications it facilitates on-farm experimental design and application. Perhaps most crucially it provides a physical record of exactly how, where and what farm operations were done. This may be extremely useful in qualifying for quality compliance or environmental management systems or in situations where mismanagement is alleged.

Variable rate applicators are capable of providing a digital output of farm operations thus there is an opportunity to use this output to semi-automate these quality assurance and environmental management schemes with this data. This should lessen the current paperwork associated with compliance but also improved the quality of data being provided.

## 3.3 Existing Applications in the Vegetable Industry

### CASE STUDIES

Growers and industry workers who were identified as outstanding producers and/or early adopters of Precision Agriculture technology were interviewed to gauge their level of understanding, level of adoption and opinion on the use of PA technology. The results of these discussions are presented below.

### *Jeff McSpedden, Sweet Corn producer, Bathurst, NSW*

Jeff has implemented Precision Agriculture technology, in the form of electromagnetic induction (EMI) soil surveys, aerial imagery, and variable-rate irrigation, with the aim of improving the efficiency of input use on-farm. He has a good understanding of Precision Agriculture and believes these technologies will help him better manage his farm.

The EMI soil survey was carried out for an irrigation management plan. The EMI soil survey maps the spatial variation in soil apparent electrical conductivity at a fine spatial scale and was able to identify a clay hardpan at a depth of 30 cm with underlying lighter textured soil. This soil information was combined with real-time moisture measurements to create prescription maps for variable-rate irrigation of the crops. For pivot and linear irrigators there is a commercially available variable rate irrigation System (VRI) system developed by Farmscan Ltd. (Perth, WA). The Canlink 3000 Variable Rate system automatically varies water rates by cycling banks of sprinklers on/off and controlling pivot speed.

Jeff has also purchased aerial imagery. This imagery was collected using a hired plane at a cost of $9 per hectare. Purchasing aerial imagery for large areas instead of individual properties will reduce the cost per ha. This imagery was beneficial for identify different soil and yield zones in the field. Jeff conceded that there are errors of 10-20% in the data in the imagery due to such things as ponded water and cloud cover . However, the information was able to identify areas in the field with yields ranging from 5 to 30 ton/ha and three different soil categories.

The missing link at the moment for sweetcorn production in Jeff's opinion is the development of a yield monitor for sweet corn and he believes that subsequent yield data is crucial for further efficiency gains. Existing impact sensor based yield monitors cannot be used due to the size and shape of the corncob. A yield monitor that incorporates optical sensors may be able to count the cobs and determine the yield using an average cob weight. The combined yield data and EMI data would permit the implementation of variable rate fertigation to achieve further economic and environmental benefits.

Jeff expressed his interest in the use of a pH/Lime requirement instrument. This instrument would be beneficial for applying lime in areas where it is required. Another area where further advancements could be achieved is the mechanisation of the canning line to reduce labour costs.

One of the problems that Jeff has identified with the adoption of PA is his lack of computer knowledge and skills.

### *Wayne Mills, Vin Rowe Farm Machinery, Warrugal, Victoria*

Wayne Mills runs an machinery company that specialises in both the development and importation of farm equipment. He has been involved in the development of a number of mechanical harvesters for the horticulture industry. Wayne has gained a thorough understanding of what Precision Agriculture technologies are available from trips to America and Europe. Through these trips he learnt of the benefits of Precision Agricultural technology for managing inputs depending on soil type.

Wayne believes that most of the mechanical harvesters with rollers or conveyer belts currently marketed can be readily modified and installed with existing load-cell based yield monitors. He believes that the ~$14 000 setup cost would be offset through subsequent management decisions. These management decisions from yield and soil information have the potential to reduce the reduced cost of seed, water and fertiliser on large- scale horticulture operations. He has seen operations in Europe were management zones have reduced the size of production areas, reduced input costs and produce more crops. He believes that producers need to be made aware of the benefits of Precision Agriculture. Wayne believes that inputs are wasted in the horticulture industry and that Precision Agriculture has the potential to manage these horticulture inputs more efficiently.

### *Phillip Beswick from Beswick Holdings, Sisters Creek, Tasmania*

Phillip Beswick is a large horticulture producer from Tasmania. He produces poppies, peas, beans, onions, potatoes, carrots, broccoli, and cauliflowers. He mechanically harvests the onions and potatoes himself while the bean and pea crops are contract grown for McCain and harvested by them. . Phillip has become interested in new information technologies and in particular guidance systems.

Phillip is interested in Autosteer guidance systems (+/-2 cm accuracy) due to the advantages of more accurate row spacings and more accurate spraying. Phillip is looking to replace his current tractors with tractors that incorporate Autosteer guidance systems in the next few years. He believes with the incorporation of guidance systems by tractor manufacturers, including John Deere, that the prices will become more competitive and the system will be paid off as an additional cost of the new tractor. Tractors with Autosteer guidance systems will be the first step for Phillip in a 10-year plan to implement Precision Agriculture technology on his properties that include variable rate technology and yield monitoring. Phillip believes the current cost of Precision Agriculture technology, especially yield monitors, will impede the uptake by companies that have a number of harvesters.

### *Anthony Staatz, Lockyer Valley, Queensland*

Anthony Staatz comes from a family with over 100 years of experience in horticultural production on their 160 ha lettuce farm. Anthony has heard of Precision Agriculture technology but does not believe that it would benefit his property. The farm plan has controlled traffic lines marked out. He has gained an understanding and knowledge of his farm that he knows "where to put a little bit extra." He does not believe that the 2 acres they plant weekly would warrant any additional investment in new technology. If Anthony was adopt new technology it would be through a guidance system. This would complement his existing controlled traffic layout.

### *Steve Muldoon, Simplot Agriculture Manager, Bathurst*

Steve Muldoon oversees the vegetable produce that is contracted to Simplot in the Bathurst region, including sweetcorn production. In 2005 Simplot started using infrared aerial photography of sweetcorn fields. The main aim of this infrared imagery was to identify variation within the crop for management decisions. These images were used to determine yield predictions, water deficiencies and for site directed tissue sampling- for subsequent testing. In the future they would like to use the imagery for developing irrigation plans.

In early 2006 Simplot were trialing a sweetcorn yield monitoring system. This system was developed from a similar method used in the sugar cane industry. The corn is directly off-loaded into a chaser bin with load cells under the basket. The incremental increase in weight is recorded and spatially referenced with a GPS system. The yield information can then be used to create yield maps and identify areas of variation. By identifying these low/high yielding areas and the determinants of yield production, management plans can be implemented.

Steve knows of a number of larger growers that are setup with GPS for precision planting and precision fertilizing however most smaller growers are not and may struggle with the initial capital cost of the technology.

### *Colin Houston, Houston Farms, Cambridge, Tasmania*

Colin Houston runs Houston farms in Tasmania. The farms consist of 1500 hectares of permanent beds and he produces pre-packed salad mixes for large retail chains. Being a supplier for large retail chains requires that his produce meet Quality Assurance standards. The current system is very time consuming due to the amount of paper work that is required. He is on the board for Quality Assurance and has become aware of modern tracing technology. Colin believes that implementing tracing technology will streamline the quality assurance process. He envisions a system that has a microchip incorporated into the crate. GPS will record the location in the field and the crate can then be tracked through processing to market were payment can be recorded. This will make the Quality Assurance scheme more efficient and streamlined.

Colin has recently been making enquires into the installation of Autosteer guidance systems on his tractors due to the lack of skilled operators in his area that are able to drive in a straight line. The most important aspect of the Autosteer system for Colin is the accuracy on his row cropping operation, cost is an issue but he is willing to pay a premium for equipment with higher accuracy.

Colin was not aware of the possibilities available with Variable-rate technology. After outlining the current use of management zones and VRT in grains and cotton, Colin was unsure of the benefit of VRT to his system. On Houston Farms there is a high amount of soil variation that is a challenge to manage. Colin believed that the intensity of his production system would make it difficult to implement variable rate management. However, he believes that the information from the data loggers of what, where, when and how inputs, particularly chemicals, was applied would be of great benefit to enforcing withholding periods and in quality assurance. Colin envisions a system where the harvester, with a GPS-based override, will not be able to operate in a field that has been quarantined.

Another aspect of Precision Agriculture that was discussed was yield monitoring. Currently seasonal yield variations are measured using a process that relies on averages. This process involves weighing produce from an area with a known dimension. He believes that yield monitors would have potential error due to variation in water content between wet/dry lettuce.

### *Tim Watson, Hilston, NSW*

Tim Watson produces ~130 ha of Sweetcorn and ~400 ha of watermelon, pumpkins, cotton and grain in rotations. Tim has been using Autosteer guidance systems for 5 years and he will not run his tractors without it. Tim and his neighbour invested early in the technology and they were able to justify the $120,000 price tag by sharing the technology. There were some issues with a shared systems and Tim purchased his own autosteer guidance system about 18 months ago for $50,000. He has a highly accurate RTK GPS with a base station to provide the accuracy that is required for row cropping. The main advantage Tim has had from investing in autosteer guidance system is the increase in productivity of his tractors, particularly the ability to operated for longer and at night. The advantages in row crops include eliminating guess rows, maintain controlled traffic lines after the field has been ploughed down, laying plastic and drip tape and the planter driver can follow the tracks. Other advantages are that there is less driver fatigue, the tractor driver can concentrate on operations behind them. This improves safety especially during planting when there are people on the planter at the back of the tractor.

Tim has not calculated any economic benefits from using the autosteer guidance system but he knows that he is getting better productivity from his tractors. The depreciation of guidance systems was a surprise. The original autosteer system went from $120,000 to $25,000 (trade-in price) over a period of three years. This was due to the improved technology of the newer systems and the lower price. Tim has also noted that autosteer systems of the same vintage have been sold in the Land with the tractor. Tim recommends that people do their research before investing in autosteer technology. He recommends evaluating different systems look at the user friendliness, ease of use and the capabilities. He stated that some systems are complicated and require a high degree of electronic and computer knowledge.

In relation to other Precision Agriculture technology Tim has trialed yield monitoring. Tim has had a bad experience with yield monitoring his grain 7 years ago due to lost data and other hassles. Tim stated that producers should get everything else right first before attempting variable rate technology. Tim mentioned that he had trialed a crude form of variable rate once using pegs and telling the operator to apply twice as much fertiliser when he got to the pegs. He also mentioned that there was the possibility of linking his enviroscan to his drip irrigation system to improve efficiency.

### *Mark Cable, Harvest Moon*

Harvest Moon produces carrots, broccoli, onions, potatoes, pumpkins, beans, celery, sweetcorn and wheat. The operations are spread over 4000 acres with 50% carried out on their own land and 50% carried out on contracted land. They have travelling overhead irrigation, both centre pivot and lateral.

Mark has had an Autosteer for almost year and bought a second unit a short time later. They invested $50,000 for each autosteer guidance system that has +/-2 cm accuracy. They run the two systems on three tractors including their precision planter and every production operation (such as listing, planting and spraying) is carried out is with the autosteer guidance system. The autosteer system has lead to huge productivity gains both from crops and labour. The main increase in crop production has come from increased production area. They now have more rows per area because overlap has been reduced to almost zero. In the old system with pegs there was up to half a metre overlap. There are also economical benefits of less spray overlap and a reduction in fuel usage. Labour productivity has increased with less fatigue and less stress allowing drivers to work productively for longer hours. The tractors can now carry out any operation 24 hours a day, which was not previously possible.

Mark stated that the technology was user friendly and there was good back up in place for any requirements. He was totally satisfied with the autosteer guidance system and could not think of any disadvantages.

Mark believes that due to the intensive nature of horticulture and the low variation of soil types on his property that variable rate technology is not applicable. Mark said watering events are the main cause of variation in the crop production and he knew the paddocks that weren't yielding. Currently irrigation is scheduled from weather data and from the on farm weather station and soil moisture probes. This data is downloaded on a weekly basis. They do not have yield monitoring technology set up on their mechanical harvesters and are not looking into investing in this technology.

In regards to tracking technology Harvest Moon already use dataloggers to monitor temperature of their produce to market to ensure that the produce is transported correctly. He would want to know what gains could be made through intensive tracking of produce before pursuing more tracking technology.

With the advent of all the new technology Mark is still keen that his employees still take an active role and investigate the crop with their own eyes and knowledge.

### 3.4 Decision Support Systems

From the SSCM definition (page 2), the objective of the information collected is to make better decisions. In Figure 2.1 one of the key steps in the PA cycle is a decision support system (DSS). In many cases the slow adoption of many PA technologies is due to a lack of a DSS to take advantage of the information generated. For any investment into information technology, by HAL or any R&D corporation, a suitable strategy to make the information accessible and useable to growers is paramount. Four examples, highlighting successful and missing applications of DSS are presented to illustrate the importance of DSS.

**Information without a decision is wasted information.**

***Example 1 – Integrated Baby Green Production (courtesy of Bernard Panneton and Michel Broulliard – Agriculture and Agri-Food Canada)***

The production of baby greens in Canada for ready-to-eat salads is a complicated process. Up to 40 different varieties of baby greens are used to create a variety of different recipes that have different desirable packing dates. Within production systems growers attempt to keep varieties contiguous to simplify management. However each variety has a unique growing season length with up to 4 crops per season that often creates a patchwork production system by the end of season. To assist growers a spatial DSS system is being developed to optimise seeding designs to improve efficiency. Initially the DSS uses growth models and climate temperature to predict the optimum seeding date for each variety given a desired harvest date. Using this information a seedbed plan is be generated for the entire season.

A GIS of the production system is created from the seeding plan and stored in on-tractor computers. As farm operations (bed shaping, planting and harvesting) are performed the GIS is automatically updated using on-board sensors (such as actuators to log when the bed shaper and planter are active and a yield sensor). Each day the information from farm equipment is relayed to a base computer. As a result the seeding plan becomes a dynamic farm plan from which updated seeding plans can be generated to account for unexpected changes in production (extreme climate, pests, change in consumer demands etc.). Changes to the seeding (farm management) plan can be transmitted back to farm equipment along with updated daily tasks for each piece of equipment. In this system communication is achieved by mobile phone connections. The process is schematically described in Figure 3.4

This integrated system uses existing knowledge, in the form of known growth models, coupled with information collected during farm management to optimise the logistics of baby green production. Effectively linking technology (tractor sensors, yield sensors, wireless communication) with a decision making process (seedbed plan) and automating the decision-making will make the system accessible and readily

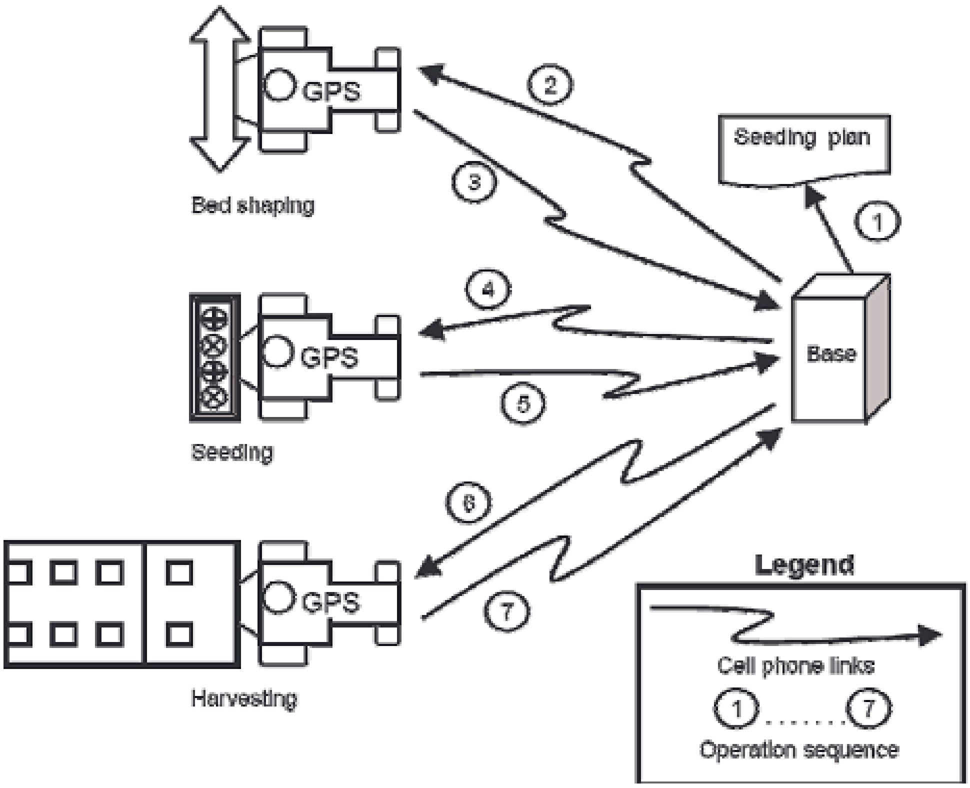


**Figure 3.6:** Schematic of information flow between components of the integrated baby green decision support system (from Panneton and Broulliard, 2005)

adoptable. The system was initially difficult to set up and implement due to the need to write new software applications and integrate it with on-tractor sensors. However experience with infield operation has allowed the system to be simplified and streamlined. Considerable spatial information on farm operations has also been collected but has yet to be analysed for opportunities to further optimise production. The development of the integrated system has also prompted the development of a yield sensor to record the weight and location of packed boxes of baby greens.

### *Example 2 – Variable-Rate Vineyard Spraying*

In vineyards sprayers are a prime example of potential VRT application. The effectiveness of spray applications is a function of canopy size, shape and density (Manktelow and Praat, 2000). The vigour and shape of vine canopies can be ascertained by remote sensing (Dobrowski *et al*., 2002, Hall *et al*., 2003). The potential risk of many diseases, particularly fungal pathogens, is related to the micro-climate of the canopy (Ellis, 1994; Ellis and Erincik, 2002) thus this information should be useful in varying spray pressure and amount through the vineyard to improve the effectiveness of application. The identification of enclosed, potentially humid and still canopies should help identify potential disease hotspots and allow directed risk management spray applications. Figure 3.5 shows the relationship between an aerial image, ground based photos of the canopy and botrytis scores in 2000. This field is susceptible to botrytis infection, particularly in areas with denser canopies. It is currently sprayed uniformly, both in dosage and pressure, with fungicide to protect from *Botrytis cinerea*. The information in Figure 3.7 indicates that the denser

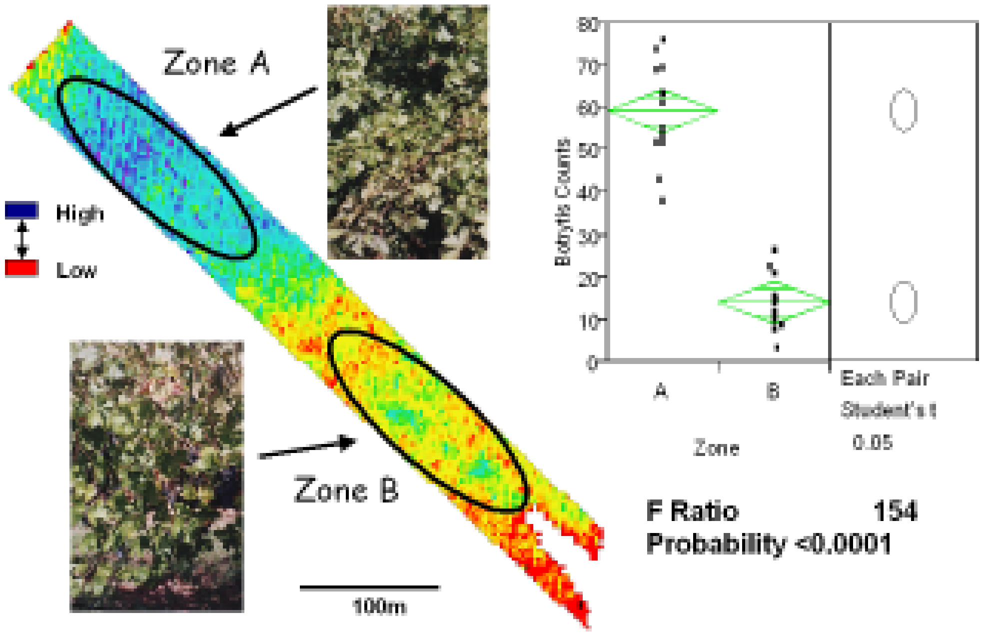


**Figure 3.7:** Normalised Differences Vegetative Index of a block of Cabernet Franc vines near Cowra, NSW and ANOVA of Botrytis cinerea counts within two zones in the block. Photos show the difference in canopy architecture with Zone B having a more open canopy with more exposed fruit. Zone B has a significantly lower incidence of B. cinerea.

canopies do not receive either enough fungicide or the spray pressure is insufficient to penetrate the canopy to provide protection. This appears to be a prime candidate for a decision support system to quantify how the canopy 'vigour' can be used to determine site-specific dosage and applications rates. Certainly there appears to be a strong opportunity to better protect the crop and more effectively utilise fungicide within the vineyard. However a DSS for this does not exist and variable rate spraying in vineyards is almost nonexistent.

A further hindrance to variable rate sprayers, as Manktelow and Praat (2000) observed, is that most current agrochemical labels, thus spray applications, fail to account for differences between sprayer types, canopy structures or the degree of pest/disease risk i.e. again there is a lack of decision support in determining optimal rates of 'average', let alone differential, rates of input.

### *Example 3 – Yara N sensor*

In contrast to spray applications, commercial real-time sensing and variable-rate controllers for nitrogen application in cereal crops are available. The Yara N sensor is an example of one of these proximal sensors that are usually mounted on a tractor and optically senses the reflectance from a crop. It uses some user defined calibrations to determine the appropriate rat of N given the reflectance from the crop. The sensing, decision support process and variable rate control are all done on-the-go as the tractor transverses the field. The process is shown schematically in

Figure 3.8. The system requires local knowledge, thus some local experimentation, to determine the optimum rates of N to be applied to the crop over a range of reflectance values. However the simplicity of this approach allows it to be readily transfer across geographical regions and the system has been used successful across Europe and the U.S.A. Trials are currently underway in Australia to test the N application algorithms and the effectiveness of the system in Australian conditions. As well as the Yara N sensor there are other reflectance sensors also available and under trial in Australia (e.g. Greenseeker and Cropcircle sensors).

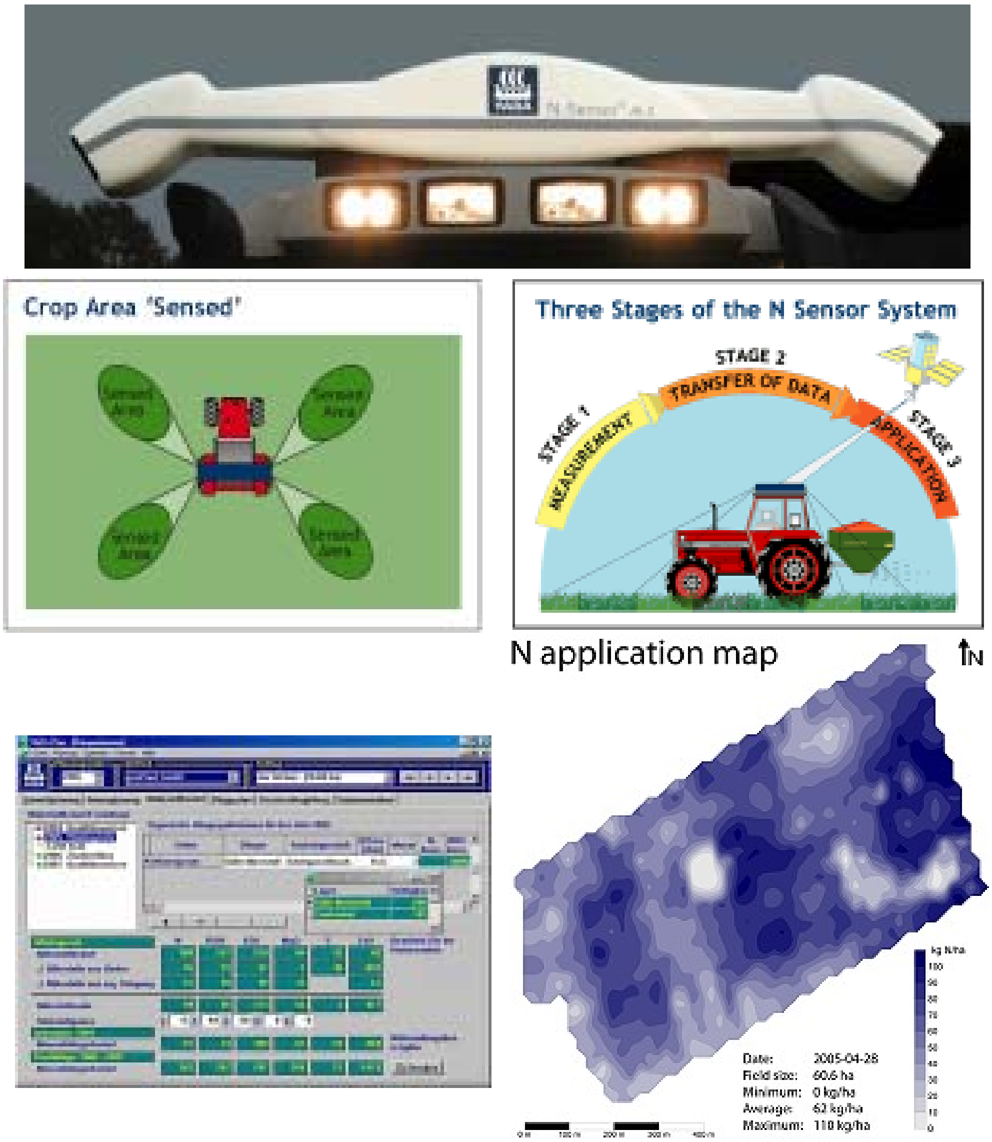


**Figure 3.8:** Components of the Yara N Sensor System. Top - The Yara N ALS Sensor. Middle left schematic of the area being measeured by the sensor. Middle right schematic of the on-the-go process being performed byt the system. Bottom left - Interface for YaraPlan a fertiliser spatial DSS and Bottom right - an example of a variable rate N application map from the Yara N sensor. (Adapted from Yara UK - http://fert.yara.co.uk/en/crop_fertilization/advice_tools_and_services/index.html (lastviewed May 2006))

### *Example 4 - Differential Harvesting in Viticulture*

In viticulture, vegetative indices derived from canopy imagery (either ground-based, aerial or satellite) have been used to identify areas of different 'vigour' within blocks. These 'vigour' zones have been used to form the basis of a differential harvesting strategy. This approach was first recorded in California in 1997 (Johnson *et al.*, 1998) but in recent years has been successfully adopted in South Africa, South America and Australia. The premise of differential harvesting is that canopy reflectance is an integrator of vine health and balance and thus grape quality and maturity. Once the 'zones' have been identified then targeted sampling of fruit quality is undertaken. On the basis of this sampling a harvesting strategy is developed.

Differential harvesting can be achieved by either:

i) picking the block on the same day and segregating the different zones into different bins or

ii) picking the different zones on different days when maturity and quality within each zone is considered optimum are the two approaches currently being used. The second approach will optimise quality from the block but will incur higher harvesting costs that must be offset. It will also increase the risk of adverse climate damage to the later maturing fruit. Two independent reports by Johnson *et al.* (1998) and Bramley *et al.* (2003) report that the differentially harvesting was profitable and easily offset the extra cost of imagery acquisition and analysis and harvesting.

The methods employed by Johnson *et al.* (1998) and Bramley *et al.* (2003) are quite simplistic and only look at relative differences in vegetative indices. There is no set formula to how the 'vigour' zones compare with quality. Over a three-year trial within a single field in South Australia it has been noted that while the vigour zones are stable the highest quality fruit came from different vigour zones in different years (Rob Bramley, CSIRO, Adelaide, *pers. comm.*) However this approach has been adopted by several large wine companies in Australia and the USA and it is now common practice in many vineyards to attempt to segregate blocks prior to harvest (Carothers, 2000 and Smith, 2003). Results from this commercial utilisation are rarely reported and concerns have been raised in Chile where segregation of blocks into harvest zones using NDVI has produced mixed results over a variety of blocks (Ortega and Esser, 2003). Ortega and Esser (2003) observe that harvest segregation using imagery is best suited to blocks containing strongly contrasting soil. In areas with low soil variation statistical differences in grape quality are not observed although yield differences generally are.

Differential harvesting is essentially a reactionary process to account for variability that within season management has caused or fail to minimise. None of the reported studies have attempted to quantify the vegetative index-wine quality relationship. It is likely that this relationship will be highly variety- and site- specific however for proactive management, rather than reactive management, using imagery a better understanding of this interaction is needed.

*Existing Vegetable DSS*

**DSS are underdeveloped in agriculture.**

Information on existing decision support systems was difficult to find, even after consultation with State IDOs. This seems to be an area where more research is required. The only DSS systems identified were based on IPM or disease management e.g. TomCast, which is used to predict disease risk and thus timeliness of chemical applications. It was originally developed for the tomato industry in Ohio, USA however is currently being evaluated for Septoria blight in celery by DPI Victoria.

*Farm Management Software*

Software tools to assist with basic farm accounting and management are becoming increasingly common and accepted. HAL has already put considerable effort into these systems e.g. Macman (http://www2.dpi.qld.gov.au/macman/) and Avoman (http://www2.dpi.qld.gov.au/avoman/). However many of these systems are unable to cope with spatial data sets thus are not compatible with a move into precision agriculture technologies. Some farm management software are designed to either accept spatial data (e.g. Fairport Technologies suite of PAM tools) or are based initially on a Geographical Information System (e.g. Red Hen, SST, etc.). These software packages will allow better analyse and synthesis of the spatial data collected and better decision making. Primary producers interested in adopting and using PA technology should also invest in a suitable software package. Alternatively they should employ a consultant with the right tools (software and skills) to analyse their data. Given the complexities involved in learning new software the second option may be the preferred option, particularly for smaller producers who already outsource their agronomic decision making. The best advice in this situation is to make sure that as a producer you understand what capabilities you desire and what is offered by the different software platforms. As a guide Appendix 1 lists some of the more common software available and some of their capabilities.

The proliferation of the world wide web has permitted the development of web-based farm management software. One such application is Cropmaster (www.cropmaster.com.au) that provides growers with on-line spray and crop diary options. This is still based on production units, rather site-specific information, however it does permit remote access to the information. This allows agronomists, regulators or buyers access to farm management information. It is likely that this option will becoming more desirable from an end users perspective and may provide market security for producers. On-line data storage, including WebGIS, will become more common over the next decade.

# 4. Supply-Chain Oriented Precision Agriculture

This section focuses on a brief overview of the technology available to improve information flow in supply-chains to make them value-chains. The issues and requirements for traceability of vegetable crops, both nationally and internationally, are discussed in §5.

## 4.1 Existing Technology

**Vertical integration assists information flow.**

The issue of product traceability is becoming an important part of on-farm profitability. In general agricultural profit margins are decreasing and the economics of scale are increasing. To survive, growers need to increase the scale and efficiency of their enterprises and/or the quality of their product. Many growers are now realising that the bi-directional flow of information along supply chain lines can help maximise product quality. Information flow allows the grower to better understand consumer demands and also allows the consumer access to information on the production system behind the commodity. By selling information with their crop, growers are able to command a premium (Taylor *et al.*, 2003).

Examples of the flow of information along supply chains are becoming more common however they are not commonly reported in the scientific literature. Large supermarket chains actively promote the integration of the supply-chain but the actual level and quality of information-flow is uncertain. All along the supply-chain system there are a wide variety of parameters measured and large amounts of information collected. For example, fruit quality is often assessed in packhouses, information on conditions during storage and transport is logged and the price and saleability is logged at the sales counter. The challenge is to properly capture and centralise this data so that producers, consumers and middlemen in the supply chain can make use of it. Currently information flow is limited in most supply chains (Bollen, 2004 ).

The current trend in Australian vegetable industries towards corporate companies sub-contracting to smaller growers, should benefit from improved information flow along the supply chain. Small or contract growers however need to be careful that some of the profits gained from any market segregation of their fruit also flows the full length of the supply chain.

*Tracking technologies*

Tracking technologies have already been developed and used successfully in service industries to track product through supply chain systems. The most common forms of tracking involve barcodes with barcode scanners and radio frequency identification (RFID) tags. Their application to horticultural production is still in its infancy but shows great promise (Praat *et al.*, 2003). The ability to assign a geo-location to produce (at either fruit/vegetable, bin or bay/bed level) permits information captured in the supply chain to be spatially transferred back to the producer (see Fig. 4.1 for an example). It also potentially provides additional information to consumers. The technology selected needs to be considered from several points of view:

a) Reliability – what rate of failure does the technology have, especially in on-farm situations

b) Longevity – how long before it needs to be replace or serviced

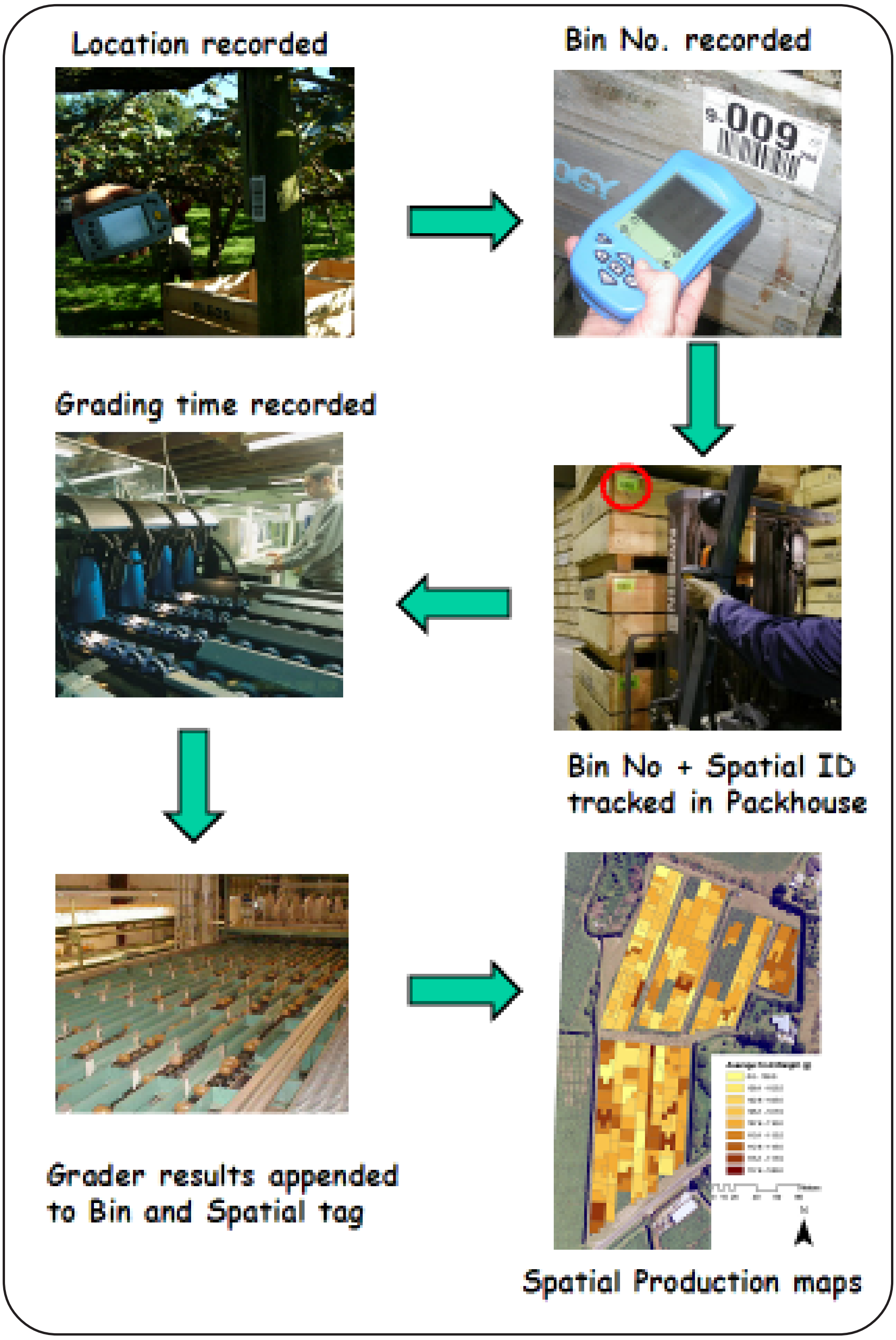


**Figure 4.1:** The use of tracking technologies to allow the spatial flow of fruit quality information from packhouses back into the production system (Images courtesy of Lincoln Ventures Ltd, Hamilton, NZ).

c) Recoverability – if a physical sensor is used then a fail safe method of retrieving the sensor is needed before the commodity reaches the consumer.

*Data capture and Software options*

Product tracking and marketing software is freely available. These programs primarily provide quality assurance, however the opportunities for information flow are starting to be exploited (Coggan, 2000). Precision Agriculture technologies can assist in this process by digitally capturing data on management processes. This data can then be incorporated into production-orientated software and used not only to optimise management through DSS (see §3.4) but also to automatically generate profiles for quality assurance processes. The ability to do this exists however specialised software and hardware applications still need to be developed or adapted for each crop and only a few attempts have been made to date (e.g. PAMAusVit software (Fairport Technologies, 2005) and the baby green DSS of Paenneton and Broulliard (2005) see §3.4).

*Communication and Information Dissemination*

On-farm communication can be achieved using hard-wired communication, wireless networks or with mobile phones. Communication is generally between a sensor (e.g. soil moisture probe), a local data hub, that administers several sensors, and a control point, usually a desktop PC. Hard-wired systems are often expensive to install (particularly buried systems), are incompatible with farming practices and can be difficult to troubleshoot and fix when a connection is lost. Various wireless networks exist that eliminate the need for physical links. Radio-based systems can broadcast information over relatively large areas but need a steady power supply to operate. Generally they are used as a data hub or for sparsely spread sensors Embedded mesh networks use low powered sensors that broadcast short distances. They require many relays in the target area to form a route from a sensor to a data hub. The relatively dense population of the network means that if a relay fails an alternative route can be achieved and data is not lost. The need for a dense population currently prohibits their use in broadacre production on economic grounds. However smaller producers may find them useful and they will become more accessible as the cost of the system and individual nodes decreases. Mobile phones connections provide a reliable method of data communication between hubs and a control point in areas with good mobile phone coverage

**Wireless and web applications are revolutionising communication in agriculture**

Web-based technologies are redefining the way that we communicate. Linking geographic information systems with web technology (WebGIS) provides a powerful tool for spatial information dissemination. While this has obvious advantages on-farm for management if information is displayed site-specifically, there are also possible applications for data display at regional and national levels to assist with industry logistics. This will be particularly beneficial to vertically integrated industries, such as sweetcorn, where management practises (e.g. harvesting) are performed by a single company. On-farm data can also be automatically uploaded into the WebGIS to provide remote access to production information (e.g. the web network of Thysen *et al.*, (2005))

# 5. Desktop Economic Analysis

A desktop analysis using known literature has been prepared on some of the economic constraints and considerations regarding PA. This provides some ballpark figures to reflect on when considering the cost of PA implementation

## 5.1 Production

*Profitability of PA in horticulture*

The main economic aim of precision agriculture (PA) in the horticultural production process would be to allocate inputs efficiently, based on the spatial and temporal variability of the field. The conventional whole-field farming approach assumes spatial and temporal homogeneity within a field and fails to take into account many soil and agronomic characteristics that vary within the field (Watson *et al.* 2003). Variable rate application (VRA) takes account of the heterogeneity found within fields and matches inputs to the crop requirement. In this way, inputs can be applied at appropriate levels so as to maximise profits to the grower. On the other hand, from the perspective of society as a whole, applying inputs at just the right amount reduces the costs of environmental damage that could potentially result from horticultural production.

**Economics need to be considered from production, environmental, and social perspectives**

*For VRA of inputs, a field may be divided into numerous discrete management zones or the management can be continuously variable. Some specific properties of these zones, such as soil composition, levels of fertiliser residue and water levels can be estimated using spatial technology including GPS and remote sensing combined with yield monitors and GIS software. These data collected are used to form maps that can aid in the economic decision making.*

In evaluating the profitability of PA the potential benefits must be weighed against the costs. An appropriate model is suggested by McBratney *et al.* (2004). It incorporates benefits and costs from both private and social perspectives when assessing the total benefits of production. Without taking into account social and environmental costs, the economic objective of the farmer is to maximise total profit. The profit maximising levels of input use for each site or management zone can be determined based on the site-specific or zone-specific yield response function. These yield response functions are dependent on the inputs that are under the direct control of the farmer, such as fertiliser and irrigation levels, effects from past management, such as the residual levels of fertilisers and pesticides, and environmental yield determinants that cannot be readily controlled, which include soil properties such as texture, water holding capacity and salinity.

The use of spatial technologies allows the levels of these uncontrolled inputs to be estimated. Then through the use of PA, the levels of controlled inputs can be adjusted to optimise expected yields, and hence expected profits across different management zones given the inherent variability of uncontrolled inputs across these zones. Based on this variability across management zones it will be optimal to expect ‘lower than average’ yields in some zones and ‘higher than average’ yields in others. But overall, productivity resulting from a VRA should effectively be greater than productivity obtained using uniform rate application (URA). Swinton and Lowenberg-DeBoer (1998) found that for increased profitability the value of crop yield gains were particularly important, thus PA should be suited to high-value crops that respond to variable rate treatment. For example, VRA of fertiliser for sugar beet was found profitable, while results for corn were mixed, and those for wheat and barley indicated limited profitability (Bullock *et al.* 2002). This suggests that VRA is likely to be profitable in horticultural production, given the high economic value of the produce per unit area. However, there are no solid data in an Australian context that could be used to rigorously test this hypothesis. **This is clearly a key research need for proper economic evaluation of PA in horticulture in Australia**.

Methodologically, the profitability of VRA in horticulture can be determined similarly to other types of crops (Swinton and Lowenberg-DeBoer, 1998). When considering the profitability of using PA in the horticulture industry the costs of PA can be considered as additional controlled inputs to the production process. Therefore the relative profitability of VRA compared to URA can be gauged by comparing the total expected profit for each technique. Uniform rate application (URA) considers a field (or farm) to be a single management zone, ignoring the variability within the field. In essence URA considers only the 'average' values and characteristics within the field. A single yield response function is estimated for the entire field and inputs are applied uniformly as per the optimising process described above and using 'field-averaged' levels of uncontrolled inputs. On the other hand profit for VRA can be determined using the site-specific yield response functions (either by discrete management zones, or continuously variable functions over the whole field).

If total profit is greater using VRA than URA, remembering to take the costs of PA into account, then from a purely private perspective it is rational to adopt PA. When considering the net returns to PA, important factors other than pure production costs and benefits should also be taken into account. These are the possibility of quality monitoring and classing, consistency in terms of marketable characteristics, traceability of the produce and environmental friendliness. These factors are all extremely important for horticultural production and have the potential to result in price premia for produce grown with PA technology. The size and existence of these price premia will depend on the degree of integration and coordination within the horticultural industry supply chain. Alternatively a farmer may wish just to consider the possible economic gains from using VRA compared to URA, without incorporating the cost of the spatial analysis necessary for PA. The difference between returns from VRA and URA will then represent the breakeven cost of PA.

### *Cost of PA*

Estimates of the costs of using PA are highly variable and often imprecise. As a result this is an area that warrants additional research. For a farmer wishing to gather their own data and perform their own analysis the main costs of PA are the purchase of:

- a yield monitor costing upwards of $4,000+
- a guidance system costing from $15,000 to $50,000 including automated steering assistance or GPS subscription
- GIS software costing from $200 to $1,000
- a handheld GPS for field scouting costing from $200 to $1000

Additional costs include:

- remote sensing usually costing $3-5 per hectare, however the cost may vary depending on the size of the area mapped
- wages for any casual labour required to carry out field scouting
- technical training in the use of spatial technology, with courses costing approximately $3,000 (Lucas, 2005)

When considering the costs of capital equipment such as yield monitors and guidance systems it is necessary to take into account the useful life of this equipment. For example it may take three to four years for a guidance system to become outdated and obsolete.

Ancev *et al*. (2004) base their costs estimates of PA on anecdotal evidence and the experience of precision agriculture professionals. When simply dividing a field into only two or three management zones, based on farmers own observations and experience, the cost of site-specific management of inputs might be as low as $1/ha. Of course these costs will increase as the density of management zones increases. With respect to continuous site specific management there are commercial providers that offer the service of continuous spatial management of fertiliser application costing around $10/ha.

Information services such as GPS monitoring, research, data evaluation, soil and yield maps are also commercially available at a cost of approximately $8-10/ha. Ancev *et al*. (2004) conclude that the total cost of PA may vary between $2-25/ha based on the field size and topography, type and number of management zones, type and number of managed inputs and various other characteristics. This range of costs is consistent with the value of US$6/ha suggested by Anselin *et al.* (2004) as well as the cost structure suggested by Jeff McSpedden (2005), a sweet corn grower from Bathurst. His additional costs for using PA are $19/ha for aerial imagery plus an additional charge of $2000 for plane hire a service that is only required on average every five years. An additional cost of $2/ha was that of a consulting agronomist for interpreting the data and providing recommendations. Note that this cost structure fails to take account of further costs such as the purchase of VRA-capable machinery or field scouting.

Whipker and Akridge (2005) report average costs of PA operations in the U.S.A. based on surveys of retail agronomy dealerships. Their estimated cost structure is as follows:

- GPS soil sampling - US$5.91/ha
- Yield monitor data analysis - US$1.02/ha
- Field mapping with GIS - US$4.18/ha
- Agronomic recommendations based on GPS or GIS - US$1.53/ha
- Satellite/aerial imagery - US$1.79
- Variable rate seeding using GPS - US$2.24
- GPS controller driven, single nutrient, variable rate fertiliser application - US$5.76/ha

Combined these give a total average cost of US$27.42/ha. In Australian dollars this cost is approximately $36/ha, which would provide a basic layer of information in Australia. This reflects the higher cost of information in Australia due to lower demand and smaller economies of scale.

*Broccoli case study*

In Australian context, there have not been many experimental results on the use of VRA in horticulture. Therefore, results from a US study on broccoli are used here to illustrate the potential for economic performance of PA. The following analysis is based on data from two papers by Thompson *et al.* (2002b) and Thompson *et al.* (2002a). These companion papers examine the effects of nitrogen and irrigation treatment on marketable yields and unaccounted fertiliser (residual or leached fertiliser) for drip-irrigated broccoli over three separate growing seasons from 1993 to 1996. Experiments for each season consisted of combinations of three irrigation regimes and four nitrogen regimes. Irrigation was applied on a daily basis to maintain target soil water tension levels in each of the three irrigation regimes. The experiments were conducted on randomised complete blocks but for the purposes of the current analysis, data from the three sets of four blocks with identical irrigation regimes have been combined to estimate, what can loosely be defined as, a site-specific response function for each set. Given site-specific response functions for the three management zones the profitability of URA and VRA can be compared. For URA, a single fertiliser level is chosen to maximise total profit across the three zones. For VRA, fertiliser levels are chosen to maximise profit for each zone. Tables 5.1 and 5.2 below show the breakeven per hectare costs of using PA and VRA for a range of nitrogen fertiliser and broccoli prices using data from 1993-94 and 1994-95 seasons respectively.

**Table 5.1:** Projectd revenue increse per ha from PA adoption in broccoli using 1993-94 data (adapted from Thompson *et al.* 2002b). ( Does not consider adoption costs)

| **Cost of N fertiliser ($/kg)** | **Price of broccoli ($/t)** | | | |
|---|---|---|---|---|
| | **500** | **1000** | **1500** | **2000** |
| 0.50 | 95 | 197 | 299 | 400 |
| 0.75 | 92 | 194 | 295 | 397 |
| 1.00 | 89 | 191 | 292 | 394 |
| 1.25 | 86 | 187 | 289 | 391 |

**Table 5.2:** Projectd revenue increse per ha from PA adoption in broccoli using 1994-95 data (adapted fromThompson *et al.* 2002b)

| **Cost of N fertiliser ($/kg)** | **Price of broccoli ($/t)** | | | |
|---|---|---|---|---|
| | **500** | **1000** | **1500** | **2000** |
| 0.50 | 12 | 24 | 37 | 49 |
| 0.75 | 11 | 24 | 36 | 49 |
| 1.00 | 11 | 23 | 36 | 48 |
| 1.25 | 10 | 23 | 35 | 48 |

Readily evident from the tables is the large difference in returns from PA across the two time periods. This is evidence of the impacts of uncontrolled inputs, such as rainfall, on the horticultural production process. The amount of rainfall plus irrigation water applied in 1993-94 after planting was generally greater than in 1994-95. This led to greater variation in yield response across the three management zones and hence enhanced the economic performance of VRA compared to the URA. Secondly, changes in the price of fertiliser have little effect on the returns from using PA. This is because absolute levels of fertiliser use are very similar when using either VRA or URA.

Assuming the cost of using PA lies within the range discussed above of $2-25/ha the use of PA would have been profitable for all of the cost-price combinations shown in Table 5.1. In 1994-95 (Table 5.2) the potential returns to PA were relatively very small. The use of PA would have been profitable given a high price for broccoli but would likely not have been profitable for a low price. It is worth noting that this analysis considers only one of the many variable inputs, nitrogen fertiliser.

Even though, given a low broccoli price, PA may not have been economically profitable Tables 5.1 and 5.2 do not take account the economic value of potential environmental gains from the use of PA. Thompson *et al.* (2002a) found that unaccounted nitrogen ("nitrogen lost by gaseous emissions from plants or soils, leached below the root zone, or immobilised in soil organic matter") increased rapidly when optimal nitrogen rates were exceeded. For example, based on the broccoli data, the unaccounted nitrogen under the URA in 1993-1994 was found to be 120 kg/ha, while the unaccounted nitrogen under VRA was found to be 97 kg/ha. Thompson *et al.* (2002b) continue that similar results were found by Pier and Doerge (1995) for subsurface drip-irrigated watermelon and Thompson and Doerge (1996) and Thompson et al., (2000) for leaf lettuce and cauliflower (*Brassica oleracea* L. var. botrytis L.) respectively. Given these findings the social returns from PA are likely to be greater than the values suggested in the above tables.

**Production economics favour large-scale highly mechanised crops**

*Gross Margins*

The following tables (5.3-5.7) summarise typical per hectare variable cost budgets for five selected horticultural crops Sweetcorn, Carrots, Broccoli, Lettuce and Beetroot. (Full budgets are shown in Appendix 2 (NSW Agriculture, 2001))

The partial farm budgets represent the cost structures of typical farms not using PA. The two inputs currently of most concern in PA are fertiliser and irrigation water. In absolute terms, the cost of fertiliser is fairly similar across industries, ranging from $283.15/ha for sweet corn to $375.00/ha for broccoli. However, relative to total variable costs, fertiliser ranges from 2% of variable costs for lettuce to 20% for sweet corn. The costs of irrigation water used vary more widely across industries from $69.44/ha for lettuce to $260.48/ha for beetroot. Relative to total variable costs, irrigation water ranges from 0.5% of variable costs for lettuce to 12% for beetroot. It is worth noting that harvesting and handling represent the most significant cost across every industry.

The potential for profitability of PA varies across these crops, dependent on the crop price, price of inputs managed with VRA and the importance of those inputs in the overall cost structure, as well as the yield effects of the PA technology. Other things equal, the VRA will be more profitable if it is yield augmenting, and in particular if the price of the crop is high. It will also be profitable if the cost of input that is managed using VRA increases, and in particular if that input represents a significant proportion of the cost structure (e.g. fertiliser in Sweetcorn).

**Table 5.3:** Variable costs for Sweet Corn – Processing – Furrow Irrigation (NSW Agriculture 2001)

| **Variable costs:** | **2001 dollars** | **% of total variable costs** |
|---|---|---|
| Seeds | 192.00 | 13 |
| Tractor, large equipment (incl. labour, fuel, oil, etc.) | 192.15 | 13 |
| Irrigation | 138.88 | 10 |
| Fertiliser | 283.15 | 20 |
| Pest control | 130.60 | 9 |
| Weed control | 54.53 | 4 |
| Aerial spraying | 84.00 | 6 |
| Harvesting | 336.80 | 24 |
| Levy | 11.25 | 1 |
| **Total** | **1423.36** | |

**Table 5.4:** Variable costs for Carrots – Fresh – Furrow Irrigation (NSW Agriculture 2001)

| **Variable costs:** | **2001 dollars** | **% of total variable costs** |
|---|---|---|
| Seed | 900.00 | 10 |
| Tractor, large equipment (incl. labour, fuel, oil, etc.) | 238.15 | 3 |
| Irrigation | 95.48 | 1 |
| Fertiliser | 285.20 | 3 |
| Pest control | 84.48 | 1 |
| Weed control | 89.10 | 1 |
| Harvesting | 1544.88 | 17 |
| Handling | 3090.00 | 35 |
| Freight | 1350.00 | 15 |
| Levy | 51.00 | 1 |
| Agents commission | 1224.00 | 14 |
| **Total** | **8952.29** | |

**Table 5.5 :** Variable costs for Broccoli – Furrow Irrigation (NSW Agriculture 2001)

| **Variable costs:** | **2001 dollars** | **% of total variable costs** |
|---|---|---|
| Transplants | 2000.00 | 22 |
| Tractor, large equipment (incl. labour, fuel, oil, etc.) | 366.00 | 4 |
| Irrigation | 104.16 | 1 |
| Fertiliser | 375.00 | 4 |
| Pest control | 211.21 | 2 |
| Weed control | 91.70 | 1 |
| Casual labour | 406.00 | 5 |
| Harvesting | 3515.00 | 39 |
| Freight | 480.00 | 5 |
| Levy | 56.00 | 1 |
| Agents Commission | 1344.00 | 15 |
| **Total** | **8949.07** | |

**Table 5.6 :** Variable costs for Lettuce – Fresh – Furrow Irrigation (NSW Agriculture 2001)

| **Variable costs:** | **2001 dollars** | **% of total variable costs** |
|---|---|---|
| Seed | 225.00 | 2 |
| Tractor, small equipment (incl. labour, fuel, oil, etc.) | 526.75 | 4 |
| Irrigation | 69.44 | 0 |
| Fertiliser | 305.35 | 2 |
| Pest control | 572.13 | 4 |
| Weed control | 870.00 | 6 |
| Harvesting | 8118.00 | 55 |
| Freight | 1980.00 | 13 |
| Levy | 88.00 | 1 |
| Agents Commission | 2112.00 | 14 |
| **Total** | **14866.67** | |

**Table 5.7:** Variable costs for Beetroot–Processing–Sprinkler Irrigation (NSW Agriculture 2001)

| **Variable costs:** | **2001 dollars** | **% of total variable costs** |
|---|---|---|
| Seeds | 200.00 | 9 |
| Tractor, large equipment (incl. labour, fuel, oil, etc.) | 167.75 | 8 |
| Irrigation | 260.48 | 12 |
| Fertiliser | 307.70 | 15 |
| Pest control | 84.48 | 4 |
| Weed control | 365.83 | 17 |
| Harvesting | 700.00 | 33 |
| Levy | 20.60 | 1 |
| **Total** | **2106.84** | |

## 5.2 Environment

When considering the adoption of PA in the horticulture industry it is essential to evaluate the potential environmental benefits of its use. The degree of environmental damage that results from horticultural production will depend on current and previous levels of use of controlled inputs, as well as current levels of uncontrolled inputs. In evaluating the amount of environmental damage from agriculture two separate methodological issues must be considered. One is the quantification of agricultural pollution and its dependence on agricultural practices (i.e. the use of controlled and uncontrolled inputs) and the other is the economic valuation of the environmental damage caused by that pollution (Ancev *et al.* 2005). In the context of horticulture, an economic study of agricultural pollution in Sydney's Eastern Creek (Ford, 2003) has provided some indication of the benefits of reducing pollution from horticulture through reducing the rate of fertiliser application.

Agricultural pollution emissions can be estimated using various simulation models, for example WAVE (Water and Agrochemicals in soil and Vadose Environment), which combines four existing models (van Alphen 2002). The challenge lies in placing an economic value on these emissions. Sonneveld and Bouma (2003) describe some of the regulations currently in place in the European Union (EU) with regard to the impact of agriculture on the environment. Levies are imposed on the surplus use of phosphate and nitrogen fertilisers. As of 2003 the levy-free surplus standards for these fertilisers were set at 20kg/ha/year for phosphate, 180kg/ha/year for nitrogen on grassland and 100kg/ha/year for nitrogen on arable land. A levy-free surplus refers to the acceptable soil level of nutrient that is surplus to crop needs before the levy is being paid. The accompanying levies were • 2.27 per excess kg of nitrogen and • 9.08 per excess kg of phosphate. Using an exchange rate of A$1 = • 0.63 this is roughly equivalent to A$3.60 per excess kg of nitrogen and A$14.41 per excess kg of phosphorus. It could be argued that these levies provide proxy values for the economic valuation of environmental damage. When calculating this value the cost of the lost fertiliser must also be added to the levy i.e. over fertilising incurs a double penalty.

When considering the environmental benefits of PA it is worth noting that the use of PA does not necessarily reduce ‘average’ levels of input use. Instead PA may identify some zones where it is economically/socially optimal to use more than ‘average’ levels of an input (e.g. fertiliser) and some areas where it is optimal to use less than ‘average’ levels. The environmental benefits of PA are not likely to accrue through the use of lower ‘average’ levels of inputs but rather through the more efficient use of inputs. For example providing less fertiliser to a site where the crop has a low biological response (i.e. the crop is less able to absorb and use this fertiliser, leaving a surplus) is likely to decrease the incidence of fertiliser runoff and leaching. As noted by Wong *et al.* (2005) temporal and spatial variation in yield, drainage and leaching losses is large because of variation in soil properties that are critical for deep drainage and hence nitrate leaching. As a result, site specific management should be effective as a means of minimising the off-site effect of nitrogen use and allow PA techniques to be used to deliver products that are more environmentally friendly. A similar argument can be made with regard to irrigation water. More efficient use of water, based on biological response, is likely to result in lower impacts on the level of the water table, salinity and waterlogging of soils. Dryland salinity is estimated to cost $250 million per year nationally. In terms of environmental effects, salinity makes river banks unstable and may cause trees to die, resulting in a change to the physical structure of an ecosystem and causing habitat and species loss (Murray-Darling Basin Ministerial Council, 1999).

**Input over applicatio has a production and environmental cost**

Poor nutrient management within the horticulture industry may result in many environmentally and economically damaging consequences. For example, Ford (2003), presented data suggesting that the average nitrogen and phosphorus load from market garden tomato production in Sydney’s Eastern Creek is 160 and 9 kg/ha respectively. High concentrations of nitrates in ground water can cause illness in humans, while the accumulation of nutrients contributes to eutrophication of surface water and the development of blue-green algal blooms (White 2001). The economic impacts of fertiliser runoff include damage to fisheries and the lowering of the value of real estate and tourism in affected areas (Summers and Kingdon, 2002). To combat a poor public perception of fertiliser use, the Fertiliser Industry Federation of Australia (FIFA) released the Australian Soil Fertility manual in 1999. The manual describes the types of agricultural soils, the interaction of soil, water and nutrients, and the management of individual nutrients for profitable and environmentally safe production (White 2001).

From a social perspective, the total benefit from a horticultural practice is total profit net of the environmental damage cost associated with the production process. The socially optimal objective for the farmer is then to maximise the expected stream of future-discounted total benefits for each management zone. This will ensure sustainable profitability to the growers, but also improved environmental outcomes, and maintenance of the “clean–green” image of the horticultural industry.

When considering the potential environmental impacts of the horticultural production process a farmer may also wish to include an additional ‘sustainability’ criteria when making production decisions, such that the levels of certain soil characteristics do not drop below (or rise above) a certain value. For example such criteria might be soil pH or residual nutrient levels.

**Environmental payments are being offered for sustainable management**

In Europe, and a lesser extent the USA, environment and sustainable practices are being rewarded financially. Thus under environmental schemes, such as the Environmental Stewardship program in England (http://www.defra.gov.uk/erdp/schemes/es/default.htm), growers receive a financial bonus (compensation) for removing land from production and allowing it to revert back to its 'native' condition. The intent here is to facilitate local flora and fauna propagation. Financial incentives also exist to maintain the aesthetic nature of the countryside e.g. the maintenance of stonewalls. British society views the countryside as an important part of the country thus are willing to pay to retain this.

### 5.3 Supply Chains

There is no single supply chain in today's vegetable industry, with a wide variety of pathways to markets. The future profitability of vegetable growing in Australia depends on a full industry strategy and approach that addresses all components of the supply chain (Kiri-ganai research 2005). The performance of the whole chain from producer to consumer is crucial for the industry to remain viable, especially given increased competition from overseas markets. The business models identified as being internationally competitive in modern supply chains favour suppliers who are (after Kiri-ganai research 2005):

- largely vertically integrated
- large scale and very efficient
- part of a consolidation network
- part of a strategic alliance to supply product to required specifications year round

**Information flow is vital in supply chains for export markets**

Before examining Australia's export markets it is important to determine the relative importance of exports to domestic production. Table 5.7 shows that only the carrot and broccoli industries have developed substantial export markets relative to their industry size. However, it is quite likely that export markets will develop further in the future, for example sweetcorn exports to Japan.

Of critical importance for export success are increased coordination and consolidation, and well-developed relationships through the supply chain. PA can be instrumental in achieving this through provision of superior information compared to conventional uniform management approaches. In recent years Australian exporters have faced increasing competition, especially in Asian markets, from countries such as China, South Africa and Chile. Producers from these countries are able to supply at a lower price than Australian producers. Table 5.8 and Figures 5.1 to 5.4, sourced from (Collins *et al.* 2004), show the destination of exports of selected horticultural crops in 2002/03. It is readily evident for these crops that the vast majority of Australian exports are to Asian countries. Therefore increased competition from low-cost producers, such as those mentioned above, represents a significant threat to Australia's horticulture industry. If the Australian horticulture industry wishes to compete in these Asian markets it must expand niche markets for differentiated products. PA can be instrumental in developing differentiated horticultural products based on:

**Table 5.8:** Composition of trade for selected horticultural industries

| Industry | % of production exported by mass (2002)* |
|---|---|
| Sweet corn | 2 |
| Carrots | 23 |
| Lettuce | 3 |
| Broccoli | 16 |
| Beetroot | 0 |

**Table 5.9:** Value of exports of sweet corn to selected countries (2002)

| Importing country | 2002 (tonnes) |
|---|---|
| New Zealand | 13 |
| Japan | 1633 |
| Singapore | 1 |
| Taiwan | 0 |
| Malaysia | 5 |

- Quality monitoring / classing
- Traceability (information flow)
- Environmental quality (‘clean and green’ image)
- Sustainability

Kiri-ganai research (2005) recognised the following attributes of the vegetable industry supply chain:

- Consumers – includes households, restaurant and quick service restaurant diners, aircraft, train and ship passengers, etc. Total consumption is rising slowly with major changes in food preparation and eating styles as a result of an increased focus on healthy eating and lifestyle. Consumers’ attitudes express a preference for healthy, ‘environmentally-friendly’ and Australian products but their buying behaviour is influenced most strongly by taste, convenience and value.
- Retailers – includes the large retail chains, Woolworths and Coles as well as small chains such as Aldi, Franklins, IGA, and many small retail businesses. Woolworths and Coles account for about 50% of the retail industry market share (Coles Myer Ltd, 2005). These two chains have a high degree of market power and as a result many producers are concerned these retailers will be able to drive prices down and buy from the cheapest source, possibly imports. However, consolidation is a common feature of retail supply chains in developed countries and is driven by economies of scale and technological advancement. The drivers of the retail sector are consumer preferences, quality and food safety (including traceability), year round supply, environmental management systems, stock and supply management, competitive pricing and supplier rationalisation (CDI Pinnacle Management, 2005). Retailers are now moving towards increased product differentiation, possibly including ‘Australian home grown’ options.
- Food service – includes institutional caterers, hotel chains, restaurants, quick-service restaurants etc. Changes in consumptive patterns mean this industry is continually growing. This sector generally sources its product through wholesalers rather than directly from growers.

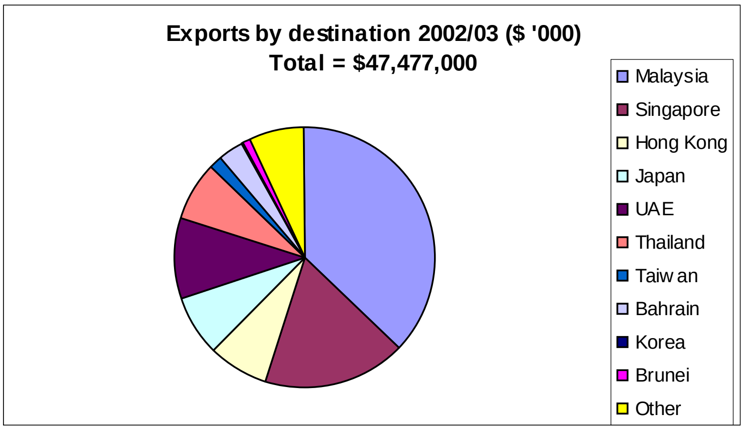


**Figure 5.1:** Value of exports of carrots (2002/03)

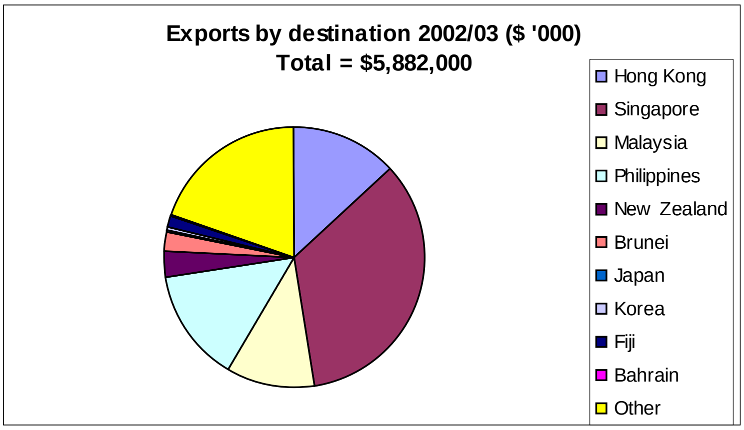


**Figure 5.2:** Value of exports of lettuce (2002/03)

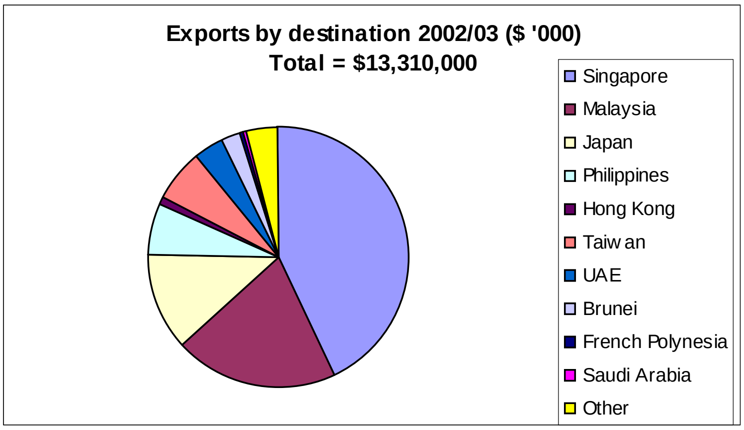


**Figure 5.3:** Value of exports of broccoli (2002/03)

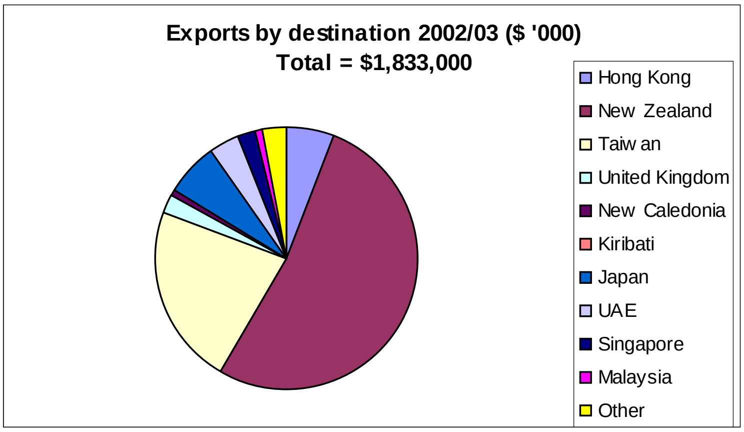


**Figure 5.4:** Value of exports of beetroot (2002/03)

- Vegetable growers – this industry is extremely diverse in terms of scale of production. This means that suitability of using PA will also vary widely within the sector. This sector is undergoing rapid restructuring in response to marketing conditions, economic conditions and trends in the supply chain. Generally, businesses in this sector are not internationally competitive in terms of production costs and sometimes in terms of yields. However, there are some businesses in this sector that are internationally competitive. The models that offer the best prospects for future business profitability are network grower and producer consolidation.
- Consolidators – includes pre-packers, processors, exporters and nutraceutical manufacturers. This sector accounts for about 5% of the total vegetable market. The nutraceutical market is growing rapidly as is the use of imports in the processed foods sector.
- Intermediaries – wholesalers/merchants who buy produce from growers and marketers and sell to the retail sector. Agents/brokers who sell produce for growers on a commission or fee basis. Providers buy from wholesalers and sell to the food services sector. The margins of intermediaries significantly affect the prices received by growers.

*Traceability*

Increasingly there are requirements for traceability in the food supply chain, A prime example of this is the EU traceability regulation, that became effective in 2005 (EC regulation 178/2002). Logistics providers have the opportunity to add value to the basic traceability information by supporting traceback of product for food safety or quality issues, tracking and tracing within the freight system and improving segregation of product to allow individual supply chains to maximise revenue from increasingly sophisticated future market segments (Bollen, 2004). Ancev et al. (2005) proposed an economic model for traceability in agriculture using PA technology. This shows how PA can be used to provide the necessary traceability information at no extra cost, and how superior information can result in a price premium.

**Traceabilityis required in many export markets**

Within the Australian horticulture supply chain there are currently many quality assurance (QA) schemes available, with a large number of them based around the Hazard Analysis and Critical Control Point system (HACCP). HACCP is an internationally recognised food safety standard that requires the analysis of all processes within the business to identify food safety hazards (Bennett, 2005). HACCP also forms the basis of Freshcare, SQF 2000$^{CM}$, SQF 1000$^{CM}$ and Woolworths Quality Assurance Standard (WQA). Australia's two major retailers, Woolworths and Coles, generally require compliance with some kind of QA scheme. As a result these schemes are necessary to facilitate market access rather than secure price premiums. Increased traceability of produce through the use of PA allows any produce to be easily evaluated for its suitability for these QA schemes.

On the international scene, the traceability requirements of Australia's major export markets are of a similar high standard to those of Australian produce sold domestically. The Malaysian government has encouraged its growers to meet the stringent agricultural and food standards set by a consortium of European retailers, known as the European Retail Produce Good Agricultural Practices (EurepGAP). These standards require detailed record keeping and traceability with regard to pesticide use, soil history, environmental protection and labour standards (Anon.). Malaysia has its own farm accreditation schemes as well as the Malaysia's Best programme. The Malaysian government is currently working towards getting its accreditation schemes recognised as equivalent to EurepGAP standards.

**Traceability promotes biosecurity and food safety**

In Singapore the Agri-Food and Veterinary Authority (AWA) is responsible for undertaking regular checks and inspections on end products. The AWA's standards apply throughout the supply chain, with the requirement for accreditation of foreign farms and food processing plants. This ensures that food imports comply with the AWA's stringent and internationally aligned standards. The Good Agricultural Practice for Vegetable Farming Scheme (GAP-VF), which was adapted from the EurepGAP scheme, was recently introduced to reduce the risk of contamination during food production and ensure quality and safety of vegetables produced locally. The GAP-VF is a voluntary scheme that applies HACCP and quality management principles. The scheme is tailored to vegetable farming activities with the focus on farm location, structure, environment (soil and water), hygiene and cleanliness, agricultural practices, fertiliser and pesticide use and management, including record-keeping and traceability. GAP-VF certified farmers can distinguished their produce from others in the market with a GAP certification mark (Anon.).

In Japan the Ministry of Agriculture, Forestry and Fisheries (MAFF) is responsible for the labelling and standardization of food, through the Labeling and Standards Division of Food Safety and Consumer Affairs (The Ministry of Agriculture). All food sold for consumption must be labelled according to the regulation with all relevant information required to be passed along the supply chain. Japanese Agricultural Standard (JAS) is a voluntary certification scheme, which is also open to imported produce. To receive JAS certification foreign produce may be inspected directly or alternatively must have been produced in a country that is recognised to have a certification system equivalent to JAS. JAS certified produce is differentiated by a mark.

Hong Kong uses an Accredited Farm Scheme, established in 1994 to combat outbreaks of food poisoning caused by the intake of vegetables contaminated with high levels of pesticide residue. The scheme is voluntary and promotes good agricultural practice in vegetable production. The Agriculture, Fisheries and Conservation Department (AFCD) monitors the horticultural practice of participating farms, with a particular focus on the safe use of pesticides. Once accredited, produce is further checked by the Vegetable Marketing Organisation (VMO) before it is marketed to accredited retailers. Accredited produce is easily differentiated through the use of a logo at retailing stalls.

In addition to meeting the standards of importing country, Australian horticultural exports must also be accredited by the Australian Quarantine and Inspection Service (AQIS). Exporters can electronically lodge all export documentation through the EXDOC system, which has been available to horticultural exports since 2001.

### *Quality monitoring using PA*

The quality of produce has an enormous impact on its price. For sweetcorn the relevant quality parameters include mechanical damage, percentage insect and disease damage, cob colour, flavour, texture and appearance, moisture levels, cob weight, length and diameter (Beckingham, 2005). Simplot producers currently receive a base price for crops with a rejection rate of 12% or higher and a bonus for each percentage point of rejection below 12% (Jeff McSpedden *pers. comm.* 2005).

Employing PA in quality monitoring, produce classing and marketing could prove to be very advantageous to the horticultural industry in the quest for differentiating the product and obtaining price premia. Experiments with protein monitoring in wheat have been done, but there has been no work done in horticulture. This is another area that should be of immediate research interest.

Delivery of a high quality product is the key to success in global export markets for primary fresh produce. Variability in quality attributes, such as size, colour, shape, flavour, sweetness and firmness will all influence prices at the point of sale (Praat *et al.* 2000). Maintaining a consistent quality of produce is an issue of prime importance in the horticultural industry, as variation in quality attributes will influence prices at the point of sale. If there is a perception that the use of PA delivers a more consistent level of quality in output and through a production process that results in less environmental damage there exists a potential for a differentiated 'clean, green' product to be marketed. It is partly due to poor environmental management practices that some overseas growers are able to produce with very low cost, which Australian producers cannot match. Therefore if farmers recognise the potential for 'clean, green' products and adequate markets for PA produce exist then the differentiated PA product should command a price premium.

# 6. Recommendations

This section outlines our key recommendations to assist HAL strategic planning for the *initial* introduction and adoption of PA technologies in the vegetable industries. Production, environment and supply chain systems are addressed separately. A complete overview of a potential PA programme is presented in Appendix 3.

## 6.1 Production-Oriented PA

These recommendations form the basis of a programme to try to understand how much variation occurs within vegetable production systems and what factors are driving this variation. This will lead into variable-rate management and site-specific decision support systems that form the next phase of PA management.

- ***Adoption of Guidance/Autosteer***

  Assisted or automatic tractor navigation has been the most commonly adopted PA technology (as it requires little decision support and shows immediate benefits).

  Research Recommendations: None
  Industry Recommendations: Promotion of GPS technology through field days targeted at vegetable growers. Field days are common in grains/cotton and can be easily organised in conjunction with equipment manufacturers, grower groups and/or PA associations. Case study of benefits to early adopters. Promotion through industry media.

- ***Identifying opportunities to optimise input usage***
  - From a production/profit perspective differential management is usually only practical if increased efficiency can be made with variable cost inputs. Priorities should be given to crops that have a high variable cost in a potentially variable input, e.g. fertiliser or chemical applications.

  Research Recommendation: None
  Industry Recommendations: In the first instance focus research efforts on Sweetcorn and Beetroot that have 43% and 48% of their variable input costs associated with irrigation, fertiliser, pest control and weed control (from average farm budget information). (NB. This does not mean that other production systems do not have an opportunity to benefit from other aspects of PA apart from variable rate management). Protocols and knowledge gain from investment in a few select crops can then be transferred to other crops.

- ***Identifying if variability in the vegetable production system exists***

- is there a pattern of variation in production that can be managed variably at a scale smaller than the whole field. This can be done cheaply with an initial multi-spectral survey, using aerial/satellite imagery, over a densely cropped area(s). This will identify if variation is occurring and provide a background for ground-truthing. Priority should be given initially to crops with large production areas where variation is likely to be greater.

Research Recommendation: Identification of optimal vegetative indices for recognising variation in crop production. At the time of imaging on-ground measurements (e.g. leaf greenness, crop density etc.) can be taken to relate the crop physiology to the sensor data. This may provide some ability to predict crop response as well as the pattern of variation.

Industry Recommendations: Imagery results from the analysis should be disseminated to local growers. This is an opportunity for HAL to provide growers in the survey areas with cheap/free imagery of their production. This should increase their interest in PA as well as promote goodwill.

➢ ***Development of crop sensors.***

- The ability to spatially audit the quantity (yield) and quality of produce being removed from a production system is important to understand the flux of inputs and the efficiency of production. This provides both production and environmental benefits.

Research Recommendation: For hand-harvested crops, applied research is needed to adapt existing semi-automated yield data collection systems Australian conditions and crop management. These systems may need to be at the tray, bin or plot scale.

For mechanical harvesters that are incompatible with existing yield monitors, a programme to develop new yield sensors is needed. This is an opportunity to work in collaboration with agricultural machinery companies to share costs and promote commercialisation.

In the medium term a programme is needed to develop or support the development of on-harvester and infield *quality* sensors. This may need some basic sensor and chemometric research before prototypes can be developed.

Industry Recommendation: Priority should be given initially to the adaptation of existing horticultural yield sensors to mechanical harvesters. Harvesters can be retro-fitted with yield monitors and the quality of the monitor measured using weigh bins. We recommend that HAL partial fund the initial purchase, installation and calibration of the monitors on selected trial sites. Further financial contributions could come from machinery manufacturers and individual growers.

There is an opportunity to also trial existing real-time variable rate nitrogen spreaders such as the Yara N sensor or Cropcircle systems. These are established systems requiring a minimum of development to test on vegetable crops.

- ***Identifying yield determining factors***
  - If there is a pattern to the variation in the crop then the next step is to identify what is causing the variation. Yield determining factors may be the soil, the local weather or management errors. Management and weather effects should be eliminated first before conducting detailed soil surveys.

Research Recommendation: The development of a suite of tools to assist growers/consultants to collate and analyse spatial data sets collected at different scales. This tools include options for data clean-up, yield mapping and management zone delineation. This is a generic research area for PA and again an opportunity to co-fund the project with other RDCs however some issues will be unique to horticulture.

Industry Recommendation: The aerial imagery results (and any other available spatial data) can be used to identify a number of suitable research sites on commercial properties. At these sites a detailed soil survey using on-the-go sensors to collect *at least* apparent soil electrical conductivity and elevation data is required to gather some basic environmental data. The data can be used to test current established approaches to creating management zones to assess if the approaches are transferable from broadacre to vegetable production. Crop and soil sampling can be used to validate the management zones. Constraints to production and possible management solutions can be identified using the spatial data and local (grower/agronomist) knowledge.

The preceding recommendations mimic current approaches in PA and will require minimal investment in research but some investment in validating these approaches in new production systems. The next steps will depend on the information gather and the success in adapting these approaches, however it will need to be more research intensive to fill the decision support gap. The next phase will have a focus on designing on-farm experimentation to improve site- or zone-specific knowledge, the development of decision support tools to utilise this information and a focus on understanding variability across the entire farm as well as within individual fields.

### 6.2 Environment-Oriented PA

The adoption of PA technologies will be driven primarily by the economic gain in production. However PA also has the goal of minimising environmental damage. If producers are able to record what they are applying as a map, rather than a field average, then the local environmental effects of production can be determined. Demonstrating the environmental value of PA should promote uptake, even if the production advantages are marginal, and also provide a possible tool for market segregation.

- ***Quantifying the fiscal value of environment-orientated PA practises***
  - Environmentally (and socially) responsible producers should be rewarded for good management practises. Currently only degrading practises are penalised. There is a poor understanding of the monetary value of benefits from sustainable practises, both to the producer and society. Deriving this value will allow the industry to petition for compensation from the wider society for any production loss or environmental benefits achieved through improved sustainable production.

Research Recommendation: Commission a resource economics report to estimate fiscal production and environmental values for BMP and PA management systems. This information can be used to establish if there is an economic and risk management benefit in PA adoption (particularly automated production/environmental auditing systems and variable rate management) and the benefit society receives from the on-farm adoption of such systems.

Industry Recommendation: None

- ***Development of spatial on-farm management (inc. DSS) software***
  - Existing farm accounting software generally lacks both a spatial component and decision support component. Similarly existing DSS are based on uniform treatment and lack a spatial component. There is a good opportunity to integrate existing applications and knowledge onto a GIS platform to form a comprehensive package (like PAM AusVit or Baby Greens example).

Research Recommendation: Adaption of existing decision support tools will require some further research and on-farm experimentation to transform them from uniform to site-specific tools. [Outcomes from the futures steps in Production-oriented PA should also provide new and/or improved decision support systems]

Industry Recommendation: Investigate options for adapting existing software to vegetable production by forming a collaborative venture between HAL and software developers (starting with Fairport Technologies, WA). Preference for crop selection should be given to production in sensitive areas, such as peri-urban locations. The software should be designed to accept future models as new decision support tools are adapted or developed.

To properly account for the site-specific environmental impact all farm operations should be recorded site-specifically. Control systems are available to do this. They allow growers to identify areas of overlap, double-worked or missed areas etc. They also form a digital record of farm operations. The use of these systems, as first stage auditing systems, should be promoted by HAL.

### 6.3 Supply Chains

- ***Identifying strongly vertically integrated systems***
  - Improving bidirectional information flow in supply chains is easier if the process is vertically integrated from growers to consumers. Vertical integration may be through a centralised marketing board or through growers contracting to a dominant company. Vertical integration may be regional, national or even global.

Research Recommendation: None

Industry Recommendation: Focus supply chain investment on strong export industries such as broccoli and carrots to try and maintain a competitive advantage particularly in SE Asia. Also identify vertically integrated corporate structures (such as Simplot or McCain) that will be responsive to improve supply chains. (Supermarkets????)

- ***Establishment of tracking protocols from "farm to fork" and "fork to farm"***
  - Packaging information with produce can provide profit opportunities by commanding premiums at the retail end or improving production efficiency at the production end. Information collected (from production auditing systems) such as the type of production (organic, sustainable etc.), time since harvesting, quality attributes etc. can be used to gain a competitive edge over produce from other regional net exporters and potential price premia by targeting niche markets.

Research Recommendation: The development of precise tracking technologies will benefit export-orientated industries like broccoli and carrots. A pilot project can be established to trial different tracking technologies. This should be done in collaboration with an exporting organisation(s), associated packhouse(s) and contracted growers to take advantage of a vertically integrated system and the potential for commercial co-contribution to the project.

Industry Recommendation: None

- ***Development of WebGIS applications for data dissemination***
  - This complements the previous recommendation and provides a means of both quickly distributing information and regulating access to the information to relevant parties. It has the potential to assist both the logistics of production and the marketability of the end product.

Research Recommendation: This should be done in conjunction with tracking technology studies to make use of the information generated. A database with functionality to accept production, logistic and retail information needs to be set-up and spatially referenced. WebGIS technology is relatively new and this project will require investment into web technology and applied research in practical applications of the technology, particularly running it in real-time commercial situations.

### 6.4 General Comments

**It is crucial that all of the above recommendations involve the development of *decision support* and *extension* processes to help growers and consultants utilise the information gather effectively. Without these processes growers and consultants may fail to properly use or incorrectly use the information and have negative experiences hindering the adoption and use of the information**

**PA technology provides an avenue for HAL and other industry bodies to drive production (particularly quality) and environmental regulation within the vegetable industry. Inaction in this area will allow either governments or multinationals to dictate terms to the industry. In Europe there are strong external pressures on production from blanket government regulation to minimise the environmental impact of agricultural production. The opportunity is there to proceed on terms favourable to producers.**

**Many of the recommendations above are favourable to the 'middlemen' as well as the producers. This provides a good opportunity for the industry to co-invest with commercial enterprises to maximise their investment in this area. By investing in collaborative projects with big business , HAL will be able to ensure that the rights of the producer are maintained.**

**The high cost of labour in many vegetable/horticultural industries will put emphasis on the development of mechanised management, particularly for harvesting and handling operations. Mechanisation is not PA. However for any new mechanised processes under development, efforts should be made to ensure that information on the production process is measured and recorded. For example new harvesting systems should either incorporate specially designed yield sensors or be built with consideration to how existing yield sensors operate**

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## APPENDIX 1: A summary of the features of a number of agricultural GIS for SSCM. (August, 2005)

| Company | | Mapping For Precision Agriculture | | | | | | | | Other Features | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Supplier** | **Software name** | Yield Data | Elevation Data | EM Data | Other Data | Complex Surface Creation | View Imagery | Imagery Analysis | Create Variable-Rate Maps | **Analysis of Precision Agriculture Information** | **Reporting Capabilities** | **Import/ Export Features** | **Comment** | **Approx. Price inc GST** |
| **Agco** | **Fieldstar Open Office** | yes | yes | yes | some GIS data | no | no | no | yes | Interpretation with some analysis features. | yes | typical | Basic software for SSCM | See Dealer |
| **Ag Leader** | **basic** | yes | yes | yes | some GIS data | no | yes | no | yes | Most -farm/ field variability + geo-referencing | yes | advanced | Standard SSCM GIS. | $1000 + annual fee |
| | **advanced** | yes | yes | yes | all GIS data | yes | yes | yes | yes | All -farm/ field/ zone variability. Spatial & statistical analysis. Economic analysis | yes | advanced | A very comprehensive SSCM package | $2500 + annual fee |
| **Delta Data Systems** | **AGIS** | yes | yes | yes | all GIS data | yes | yes | yes | yes | All -farm/ field/ zone variability. Advanced spatial & statistical analysis. Economic Analysis | yes | advanced | A complete SSCM GIS package | Varied pricing structure. Contact Precision Cropping Technologies. |
| | **Viewpoint** | yes | yes | yes | most GIS data | no | yes | no | no | Most -farm/ field variability. Limited processing features. | yes | typical | Standard SSCM GIS. | |
| **Fairport** | **FarmStar (PAM QA + mapping )** | yes | yes | yes | most GIS data | no | yes | no | yes | Most -farm/ field/ zone variability. Spatial & statistical analysis. | yes | advanced | A comprehensive SSCM package for all hardware. | $3850 |
| **FarmScan** | **Farmscan DM** | yes | yes | yes | some GIS data | no | yes | no | yes | Interpretation with some analysis features. | yes | typical | Basic software for SSCM. | $695 |
| **Farm Works** | **Farm Trac+ Farm Site** | yes | yes | yes | most GIS data | no | yes | no | yes | Most -farm/ field variability. Limited spatial & statistical analysis. | yes | typical | Standard SSCM GIS. Add -ons available | $1210 |
| **Countrywise** | **Pin.point** | yes | yes | yes | most GIS data | no | yes | no | yes | Most -farm/ field variability. Limited spatial & statistical analysis. | yes | typical | Standard SSCM GIS. | $1650 |
| **John Deere** | **JDOffice 1.3** | yes | yes | no | little other GIS data | no | no | no | no | Yield variability & some field/variety/treatment performance features | yes | limited | Not intended as a stand alone GIS package. | $30 |
| **Mapshots** | **EaSi Suite Farm Edition** | yes | yes | yes | most GIS data | no | yes | no | yes | Most -farm/ field/ zone variability. Limited spatial & statistical analysis | yes | advanced | Standard SSCM GIS. Add -ons available. | $1800 |
| **SST** | **SSToolbox** | yes | yes | yes | all GIS data | yes | yes | yes | yes | All -farm/ field/ zone variability. Advanced spatial & statistical analysis. Economic analysis | yes | advanced | A complete SSCM GIS package. | $6421 |
| | **SSToolbox Lite** | yes | yes | yes | all GIS data | yes | yes | yes | yes | All - less stastical & spatial anlysis features than SSToolbox | yes | advanced | A very comprehensive SSCM package | $4993 |
| | **SSToolkit** | yes | yes | yes | most GIS data | no | yes | yes | no | Most -farm/ field variability. Some spatial & statistical analysis. | yes | advanced | A comprehensive SSCM package | $2493 |

*** During this study it was not possible to review all available software. (Courtesy of Stewart *et al.*, 2005)**

# APPENDIX 2: A proposed program framework for future PA research & development (Adapted from McBratney *et al.*, 2005).

A programme structure that addresses the key research and implementation issues that could be applied at varying intensities within individual countries and commodity groups would be as follows.

## Hardware and sensors programme

***Objectives***

Such a programme would need to develop new equipment and technologies that can be

- extended to farmers as new techniques
- marketed by manufacturers as improved equipment.

<u>Possible subprograms</u> - Positioning and guidance, Crop sensing (stress, nutrient, yield potential),

Environmental Sensing (soil moisture, compaction, nutrient, disease), Seeding (seed bed preparation, seed zone versus rooting zone management, placement in the profile, moisture seeking, uniformity across machine), Fertilising (placement in profile), Spraying (incorporation into soil profile, spot spraying), Mechanical weed control (inter row and inter plant), Harvesting (quantity and quality assessment and separation).

## Data analysis and decision support programme

***Objectives***

Such a programme would need to develop:

- protocols and standards for the production of yield maps and other key data layers;
- robust methods for data analysis and integration, and delineation of management zones;
- innovative designs for the implementation of whole-of-field experimentation based on the principles of process control and methods for the analysis of the results of such experiments; and
- easy-to use software and other packaged tools to facilitate the use and adoption of the above by farmers, their consultants and researchers.

<u>Possible subprograms</u> – Data management and processing, On-farm experimentation and process control, Software development.

## Commodity & whole-farm focus programme

***Objectives***

Such a programme would try to:

- Apply developed technologies and DSS strategies commercially on-farm.
- Cost-benefit analysis of commercial site-specific management including environmental cost and evaluating the triple-bottom line.
- Integrate technologies to achieve a whole-farm focus to site-specific crop management rather than the current unit (field) by unit (field) approach.

- Establishment of protocols for site-specific management for different commodities e.g. cotton, grape and wine, grains, horticulture, livestock, sugarcane, coffee.

Possible subprograms – Evaluation (including economic appraisal) of site-specific on-farm operations (sowing, chemical application, harvesting), Precision commodity production, Whole enterprise optimisation.

**Environmental auditing & product tracking programme**

***Objectives***

Such a programme would attempt to improve the quality and decrease the environmental impact of an agricultural product through promoting greater vertical integration and would:

- Provide the consumer of a product with information on the environmental impact and quality assurance of a production system.
- Provide a grower with consumer and supply-chain feedback on the product and where possible spatially apply the information within the production system.
- Attempt to understand the economics of environmental information in Precision Agriculture and apply this knowledge to benefit on-farm profitability.

Possible subprograms – Supply chain information systems (tracking), Environmental auditing, Quality auditing, Economics of site-specific environmental information.

**Community empowerment and capacity building programme**

***Objectives***

Such a programme would need to:

- Improve adoption of PA technologies at the farm level. Specific activities within this sub-programme would include: Raising awareness of PA technologies through presentations to schools, community groups, field days and local media outlets. The idea would be to compare the current situation with the one to be made possible by PA and place matters in a context of sustainable development. Provision of short PA training programmes for farmers. Exposure of commodity specific PA demonstration sites. Facilitation of local PA interest groups.
- To develop the next generation of PA professionals through: Training of masters and doctoral research students in PA. The development of new PA curriculum materials at undergraduate and postgraduate levels. The development of graduate courses in PA particularly aimed at the education of agronomic consultants.
- Develop linkages between researchers, farmers, farm machinery manufacturers, sensing, positioning and instrument manufacturers and consultants within the PA sector to: Enhance adoption of existing PA technology by facilitating information exchange between these sectors. Promote the adoption of new technologies developed by researchers as

well as consultants and other firms within the small and medium enterprise (SME) sector. Encourage the adoption of data standards to enhance the exchange of data between sensor technologies and farm-machinery delivery platforms.

Possible subprograms – On-farm adoption of PA management practices, Professional training in PA, Commercialisation of PA technologies.

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