

A whole-farm investment analysis of some precision agriculture technologies

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Abstract. This study used information about a farm in the Victorian Mallee during the period 1998 – 2005 to analyse the profitability of investing in Precision Agriculture and Site-Specific Crop Management technology and farming systems. Two equipment guidance systems were evaluated. Both guidance systems earned more than 8 percent real return p.a. on the extra capital invested. A Real-Time Kinetic (RTK) guidance system with a precision of 2 cm and a capital cost of $50,000 was less profitable than a Sub-Metre guidance system with 20 cm accuracy and costing $20,000. Producers investing in RTK guidance technology would be well-paid to also adopt supporting management practices that enhance crop gross margins or provide other benefits. The capital cost of GPS technology has to be spread over sufficient hectares. Investment in Zone Management technologies to fine-tune applications of nitrogen within paddocks did not meet the required return on capital of 8 percent p.a. With the spatial variability on this farm, 1670 hectares of crop were required for the investment to break-even with alternative uses of the capital. Alternatively, with 900 hectares cropped on this case study farm, spatial variation of at least 2.5 t/ha in yield across paddocks was required to justify the investment in the Zone Management technology.

Keywords: Precision Agriculture, GPS technology, investment.

Introduction

Adoption of Precision Agriculture (PA) technology is increasing in Australia, though environmental and economic benefits are not well established (Kondinin 2006, Zhang et al. 2002, Stafford 2000). The key to the economics of adopting PA technologies is the change in whole-farm performance that derives from change in crop performance per hectare, and the number of hectares over which the capital cost is spread.

In highly uncertain, volatile and uncontrolled activities like agriculture, more sophistication in decision-making, or more fine-tuning of applications of inputs, does not necessarily increase farm profit or wealth. The effects of risk factors such as weather and price may outweigh potential benefits from more precise production decisions and methods. As well, as Pannell (2006) has reminded agricultural scientists and economists, production plans that represent a maximum profit or optimum method are surrounded by a host of variations that generate very similar results. The jargon is that ‘payoff functions are flat’, meaning there are many ways to run a farm system to achieve similar outcomes, close to best. This is, in part, a result of the operation of the law of diminishing returns to extra inputs. This principle also applies to extra inputs of information to production decisions. It leads Pannell (2006) to surmise that using precision farming technologies to fine-tune applications of variable inputs might not be of much benefit to farmers.

Defining PA and Site Specific Zone Management

One definition of PA is information technology applied to agriculture (Lowenberg-DeBoer and Boehlje 1996). In this study, PA and Site Specific Zone Management methods are analysed as a technology incorporated into an existing farm system, rather than a change in farm management system. The definition of PA for this study is:

A system involving the use of technology in monitoring and controlling the production system, enabling data collection to improve information. Through the use of technology, PA aims to optimise (spatially and temporally) long-term, whole-farm productivity and minimise the environmental impact of the farming system (Knight 2006).

Site Specific Crop Management (SSCM) is well-described as doing the right thing, in the right place, at the right time (Bongiovanni and Lowenberg-DeBoer 2004). Whelan and McBratney (2000) write of: "Matching resource application and agronomic practices with soil and crop requirements as they vary in space and time within a field."

A management zone to be managed in a particular way is defined as "a portion of a field that expresses a homogeneous combination of yield-limiting factors for which a single rate of a specific crop input is appropriate" (Zhang et al. 2002). To be operationally meaningful, management zones have to display significant differences in yield (Cupitt and Whelan 2001). Yield maps integrate all the factors affecting crop growth, such as soil and climate effects (Welsh et al. 2003) and can help delineate zones.

Economic studies

PA has been given more attention in the literature about agriculture and soil science than in the agricultural economics literature (McBratney and Whelan 1999). The benefits of PA fall into three broad categories: immediate private benefits; benefits from gains in both private and social sustainability, and benefits from changes in the environment (McBratney and Whelan 1999). The focus in this study is on direct private benefits only.

There are several potential benefits of precision farming, including increased crop yields, cheaper input costs through improved process control, and a reduction in environmental impacts (Weiss 1996). Controlled traffic and inter-row sowing technology may achieve yield benefits, though these are hard to quantify and vary over time (Rainbow 2004). Fuel, seed, chemical and fertiliser can be saved (Rainbow 2004).

Economic evaluation in the United States, such as that from Lowenberg DeBoer and Boehlje (1996), found that when the full cost of developing and implementing variable rate application methods was considered, variable rate application of fertiliser was not profitable, especially if restricted to one or two fertilisers. James and Godwin (2003) reported there was no economic benefit from applying nitrogen at variable rates to different soil units based on historic yield, or any other form of zone delineation. Godwin et al. (2003) outlined an economic analysis of the potential for precision farming in United Kingdom cereal production. They looked at several different systems and determined the likelihood of profitability and break-even farm sizes. The cost of practising PA depended on the technology purchased, depreciation and current interest rates, and the area of crops managed. McBratney et al. (2005) noted that existing PA research lacked a whole-farm focus.

Method

A 1400 hectare farm near Birchip in the Victorian Mallee was used. There were 11 paddocks. Median Growing Season Rainfall (GSR) (April to October) in this Mediterranean environment is 246 mm per annum. Soils in the area are mostly Vertic Calcarosols generally with gilgai microrelief. The depressions associated with gilgai often contain Vertosols (Rodriguez et al. 2006). Water use and crop yields are strongly related to the presence of gilgai, and associated variability in the depth at which sub-soil constraints (high levels of salinity, sodicity, and boron) are found (Rodriguez et al. 2006).

The 11 paddocks varied between 22 ha and 200 ha. During 1998-2005 the efficiency of water use in these paddocks ranged from 14.18 kg/mm/ha to 22.19 kg/mm/ha. The standard deviation of Water Use Efficiency (WUE) measurements varied between 2.67 and 9.41, and the coefficient of variation (cv) of WUE of paddocks ranged between 0.18 and 0.42 (Table 1).

Producing data through simulation

A yield potential model developed by French and Schultz (1984) was used, under different PA systems, to simulate yields and nitrogen inputs. For this study, monthly rainfall data from the Birchip Post Office were used in crop yield simulations to analyse two PA technologies. Crop activity gross margins were estimated. Frequency distributions around the expected value of activity gross margins were estimated using randomly sampled values for key input variables. This information was used in discounted cash flow analyses to evaluate the return on capital and contribution to wealth (net present value) of using the PA methods in question.

Empirically-derived WUE measurements provided a standardised means for predicting yields under different production technologies, given complex soil-water-atmosphere interactions across paddocks. The only nutrient accounted for endogenously is nitrogen, thus nitrogen and water were the only factors limiting yield. In reality, there are many more possible factors limiting yield but the assumption is that these two factors account for the majority of yield limitation during any year. Lopez-Bellido et al. (2005) outline a similar model for predicting yield and nitrogen use.

The comparisons

Two types of PA technologies are analysed:

- GPS guidance systems (Sub-Metre and Real Time Kinetic);
- Uniform Management versus Zone Management.

These technologies are analysed to find: profitability; and investment break-even levels of key variables: the cost of technology, paddock variation and the area managed under crop (hectares).

Three comparisons of GPS guidance systems are made in this study: (i) farmer practice without the technology, called the Base Case; (ii) cost savings from reduced overlap using the technology and (iii) GPS technology with cost savings from reduced overlap plus additional cost savings and yield gains. A comparison is also made of profitability of the Base Case with GPS technology, with and without zone management for nitrogen applications[1].

The Base Case

The Base Case for both the GPS and Zone Management comparisons involved:

- eight-year period for the case study farm, 1998-2005;
- Farmer practice – uniform management, no GPS guidance, actual costs and returns;
- 11 paddocks, 1400 ha, on average 886 ha cereals (wheat and barley) sown annually.

GPS guidance systems

The analysis used information about the width of implements and the overlap under different GPS guidance technologies. The Base Case for comparisons has the largest overlap (Table 4). The Kondinin Group (2003) reported the precision of different GPS guidance technologies and their cost (Table 2)[2]. The RTK guidance system is assumed to have 2cm overlap (Table 4). It is assumed that the reported level of precision in the literature is correct and is achieved.

The case study farm is used for a comparison between not using a precision guidance system and using either of two guidance systems:

- A Sub-Metre guidance system with precision of 10 cm, initial capital cost of \$20,000, and annual costs of \$500;

- An RTK guidance system with precision of 2 cm, initial capital cost of \$50,000, and no annual costs.

Using GPS guidance can reduce overlap and potentially increase yield and gross margin. This comes from being able to plant crops precisely using RTK guidance for inter-row sowing and from using controlled traffic.

Uniform versus Zone Management

The net benefits from Uniform Management of paddocks of the case study farm are estimated. These estimates are compared with the case of delineating zones within these paddocks and treating them separately with nitrogen. Zone Management involves investing about \$36,000 in enabling technology and an annual 'start-up' cost of \$3,600[3]. In both cases, the same principles for predicting yield are used. Nitrogen is the only variable being analysed. It is assumed that all other inputs are applied equally in each case.

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[1] Also compared in this paper is the separation of seasonal versus spatial variation and the impact on investment. In particular, uncertainty due to seasonal variation is taken out of the analysis in some parts to focus on spatial variation. For a more in-depth look at spatial versus seasonal variation consult Knight (2006). Further, key formulas and concepts used in the analyses presented here are explored in more detail by Knight (2006).

[2]The identities of makes of these alternative technologies are not important. While the accuracies and capital costs used in the analysis are of technologies that are available, the emphasis in the research is on estimating the implications for a particular case study farm of adopting alternative technologies with a range of accuracies and capital costs. As such, no implications are intended about the appropriateness of alternative models for different farm businesses. Such questions have to be answered on a case by case basis.

[3]Consultants/advisory \$2,600, training/education \$500 and office software/hardware \$500.

Under Uniform Management, the average WUE of a paddock is used to estimate yield potential. This determines the amount of nitrogen that is applied uniformly. Under Zone Management, the average WUE of each zone determines the amount of nitrogen that is applied to each zone.

Results and discussion

The findings of the study are given below.

GPS guidance

The main benefit from GPS guidance is that overlap of machinery in cropping operations is reduced. The Sub-Metre GPS guidance system allows accuracy to 10 cm, while the RTK system is accurate to 2 cm (Table 4). Estimates of the activity gross margin in the Base Case include the costs of overlap routinely incurred without using GPS guidance. In the analysis the cost of production varies according to the amount of overlap. Reduced overlap from GPS guidance saves costs.

The expected median minimum input cost saving from reduced overlap with Sub-Metre guidance is $8.29/ha/yr. The maximum saving is $12.98/ha/yr (Figure 4). The median minimum cost saving from reduced overlap using RTK guidance is $9.74/ha/yr. The maximum saving is $14.54/ha/yr (Figure 4). The RTK guidance system is likely to have a slightly larger benefit from improved accuracy than Sub-Metre guidance, because RTK is more precise. Table 7 shows the variation in gross returns from different Sub-Metre GPS receivers, demonstrating the large effect of receiver precision on potential returns from GPS guidance investment.

In each of the eight years in the analysis, RTK guidance provided a greater input cost saving than Sub-Metre guidance, of $1.00-$1.50/ha/yr. Note that the Sub-Metre overlap is 10 cm, which is at the upper end of the accuracy available in a Sub-Metre guidance system.

Under the assumptions of this model, the benefits from Sub-Metre guidance only came from reduced overlap. RTK guidance may also provide yield and gross margin benefits from enabling the use of controlled traffic and reducing soil compaction, or from using inter-row sowing.

The benefits of the technology include annual cost savings but the extra costs also need to be considered. Thus a discounted cash flow analysis of all costs and benefits has to be carried out over the number of years being analysed.

Net investment benefits from GPS guidance

Unless otherwise stated, all discounted cash flow analyses are carried out over an eight-year planning horizon (1998–2005), at a real discount rate of 8 percent, with no salvage value for technology. Results are given in real dollars. For the purpose of the investment analysis, the cost and returns to Zone Management are considered separately to those for RTK and Sub-Metre guidance. While GPS guidance technology is necessary to use Zone Management, the assumption when considering returns from Zone Management is that the GPS investment cost is sunk. Also, the same level of Zone Management is possible with both Sub-Metre and RTK guidance technology.

Table 2 shows details of the various types of Sub-Metre guidance analysed (Kondinin 2003). Of particular interest is the R50 precision information, which is the observed pass-to-pass (15 minute) precision[4] of the GPS receiver in question, as tested by the Kondinin Group (2003).

Simulated net benefit diminishes quickly for various types of GPS receiver as the precision of the receiver declines (Figure 5). While the cost of the receiver will partly determine the net benefit of the technology, in this case, the precision of the receiver influences profitability the most (Figure 5).

In the simulation, Receiver 1, with 10 cm accuracy and a cost of $14,500 (annualised cost of $22/ha/yr) returns a minimum total net benefit of $29/ha, a median of $33/ha and a maximum of $99/ha during the eight years (Table 7 and 8). In comparison, Receiver 2 only costs $8,700 (annualised cost of $15/ha) for an R50 precision of 30 cm, and has a median simulated total net benefit of $23/ha (Tables 2, 7 and 8).

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[4]The R50 measure refers to the distance at which there is a 50 percent level of confidence that the receiver position is actually within that distance (i.e. 10 cm for Receiver 1 DGPS signal). The distance increases for increasing levels of confidence (i.e. the R95 for Receiver 1 is 20cm).

The preceding analysis was carried out on the average area sown to cereals of 884 ha per year (out of the 1400 ha in the analysis). The break-even number of hectares required to earn the minimum necessary return on capital managed using the PA technology increases exponentially as the precision of the receiver declines (Figure 5).

If there are no added gross margin benefits from extra yield from changes to the cropping system as a result of adopting RTK guidance, the Sub-Metre guidance (10 cm precision) returns a higher NPV over the life of the project. The advantage is $4.50/ha/yr versus $1.76/ha/yr for the RTK guidance system. The Sub Metre guidance investment is less risky too (CV of 0.23 versus 0.6) (Table 5). At a farm level the gains equate to an NPV of $12,500 for RTK compared with the NPV for Sub-Metre guidance of $32,000 (Table 5). Sub-Metre guidance, in this analysis, also requires a lower start up cost ($19,500 versus $49,500), making it more attractive financially.

The break-even levels of key parameters for most of the Sub-Metre guidance products were low. For the investment in Sub-Metre guidance to earn the required rate of return, between 329–412 ha had to be sown each year (Figure 5). Receiver 3, with an R50 precision of 40 cm, has a much greater break-even sown area of 836 ha (Figure 5). Further, Receiver 7, which uses a beacon receiver with a precision of 70 cm, has a simulated break-even sown area of 1675 ha. These results demonstrate how small decreases in precision have dramatic effects on profitability of a system compared with the Base Case, with no guidance technology.

The larger investment in RTK guidance (including yield benefits from related system changes) has a considerably larger break-even sown area of 707 ha. Under this model, there is a linear relationship between break-even hectares and the cost of technology (Figure 2). On the case study farm, to be indifferent between Receiver 1 Sub-Metre and RTK guidance, the cost of the RTK technology would need to be about $25,000, not $49,500 (Figure 2).

Extra yield and gross margin benefits from changes to cropping precision as a result of adopting RTK guidance

Yield and gross margin benefits from RTK guidance were built into the model to account for other possible benefits available from this technology, with extra growing and harvesting costs included to derive gross margin benefits.

Including yield and gross margin benefits in addition to the savings from reduced overlap from the greater precision made possible under RTK guidance, significantly affected the net investment results. The mean NPV for RTK guidance with no yield benefits is much lower than if yield benefits are included. One research area important to future analyses like this study is the estimation of yield benefits from inter-row sowing made possible through RTK guidance. The NPV for RTK guidance with no yield benefits ranged from $1.00-$9.00/ha/yr, averaging $1.70/ha/yr. This compares with NPV of $14.00-$26.00/ha/yr and an average of $18.00/ha/yr if yield benefits of the size assumed are possible.

If the assumptions about yield benefits are valid, producers investing in RTK guidance also need to undertake management changes to make maximum use of the technology. Such changes may include inter-row sowing and/or controlled traffic to increase yield. Also, the simulated net benefits under RTK with yield benefits exhibit less variation than the case without yield benefits (CV of 0.1 versus 0.6).

When the managed area is taken to 2000 ha per year, the mean NPV ($/ha/yr) increased to $24.50 under RTK with yield benefits included, with a small reduction in the variability of return.

Uniform versus Zone Management

The simulation of crop performances under the Base Case outlined above produced an average farm gross margin of $76/ha during 1998-2005. This is undiscounted and before the capital costs of the equipment. In the bottom 10 percent of possibilities from simulation, the average farm gross margin was $25/ha compared with just over $132/ha in the top 10 percent of scenarios (Figure 1). In the Base Case the average annual farm gross margin varied significantly between years (Knight 2006).

The estimated farm average annual gross margins (1998-2005) from a full SSCM system involving the combined technologies for Zone Management and RTK guidance were better than the Base Case under all states (Figure 1). Zone Management combined with RTK guidance returned, during the eight-year period, an average farm gross margin of $133/ha. This was $58/ha greater than for the Base Case (Figure 1).

Activity gross margins do not tell anything about the net profitability of investment in the activity. The capital cost and opportunity *interest cost also have to be accounted for to derive the net benefits of the investment.*

Net investment benefits in Zone Management

For the 1400 ha case study farm, with an average of 886 ha of cereals cropped annually, the investment in Zone Management technologies to apply nitrogen at variable rates did not meet the required rate of return of 8 percent p.a. The mean simulated Net Present Value at 8 percent was -$27,000, or -$4/ha/yr (Table 5). The outcomes varied from -$37/ha/yr to +$30/ha/yr (Table 5). The main point is that a critical number of hectares of crop is needed to justify the capital cost involved. Cropping more than 2000 ha per year using Zone Management in a farm system that performs like the case study farm produced a NPV of $10,000, or $0.65/ha/yr – a return slightly more than 8 percent p.a. The range of outcomes also widens, varying from –$37/ha/yr to +$42/ha/yr. The minimum potential simulated return of -$37/ha is the same for the Base Case and 2000 ha cropped. The potential maximum return increased by $12/ha (Table 6).

The investment in the 1400 ha case study farm was unprofitable because it was spread over insufficient hectares; because the technology was used on insufficient variable inputs; or because the case study paddocks were not sufficiently variable to justify investing to gain the benefits of reducing the adverse effects of variability. In this case, the small net benefit and low return on capital from applying nitrogen more precisely seems consistent with the notion of flat payoff functions around the optimum in-farm systems.

Break-even

Break-even in the context of this analysis is the level at which the farmer would be indifferent between using or not using the PA or zone management technology. There is a positive linear relationship between the cost of technology and the number of hectares to be sown each year for the returns from the investment to break-even with costs, including opportunity cost of capital (Figure 2). For Zone Management technology, in this farm system with the spatial variability that existed, the break-even (zero Net Present Value) hectares were 1670. If the cost of the technology could be reduced from $36,000 to $10,000, the break-even hectares would be 904 (Figure 2).

Break-even paddock variation

Analysing the farm size over which to spread the investment is quite straight-forward. Analysing the 'break-even' amount of spatial variation within paddocks on a farm is complicated. The variation of WUE around the paddock mean determines the net benefit from using Zone Management technology. The coefficient of variation (standard deviation divided by mean: CV) shows the level of paddock variation needed to justify the investment in variable rate input application.

The simulated data showed that for every 0.1 increase in CV above 0.17, there was an average increase of $3.30/ha/yr in the benefit of Zone over Uniform Management, before the capital cost of the technology was considered.

If the farm already had the GPS technology and the cost of guidance is considered sunk, a Zone Management system on this farm would cost about $5.60/ha/yr (Table 5). The level of variability required to break-even would be a CV of 0.34 (Figure 3). If the cost of RTK guidance is also considered, at an extra cost of about $7/ha/yr, the break-even CV becomes 0.55.

Looking at break-even costs another way, for every $1/ha/yr increase in the cost of technology, paddock variation needs to increase by about 0.03 CV units (Figure 3). So if the total cost of the technology was $10/ha/yr, paddock CV would need to be 0.47 to meet break-even returns.

Consider a year with median GSR of 246 mm (soil evaporation 110 mm), in a paddock with WUE of 16.7 kg/ha/mm (farm average) (Table 1). In this year, the average expected yield would be 2.3 t/ha. Considering only the costs of Zone Management technology[5], there would have to be slightly more than 1.5 t/ha difference in yield between the top and bottom yielding thirds of the paddock for Zone Management to produce a greater gross margin than Uniform Management. If the cost of RTK guidance is considered too, this break-even requirement becomes 2.5 t/ha. If the technology cost was $10/ha, the break-even difference in yield between the top third and bottom third of the paddock yield would be 2.1 t/ha.

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[5]Consider the cost of the GPS guidance required to undertake Zone Management as a sunk cost

Conclusion

The main findings are:

On this case study farm during the eight-year period, an investment in Zone Management technologies to crop 1400 ha (886 ha on average annually under cereals) would not make the required return of 8 percent and the annual net benefits are volatile. The minimum average cereal crop area required to be sown annually to achieve the minimum return on capital from using both RTK guidance and Zone Management was 1670 hectares for this crop system. There was considerable variation in profit over runs of five years after allowing for yield and price risks.

In this study, a paddock had to exhibit at least a 2.5 t/ha difference between the top and bottom yielding thirds of the paddock for RTK guidance with Zone Management (a full SSCM system) to meet the required rate of return on investment. If the costs of RTK guidance technology are considered sunk, the variability within paddocks needed to justify the investment is reduced to 1.5 t/ha.

On this case study farm during the eight-year period, when the costs of technology were considered along with the gross benefits, the expected NPV at 8 percent real discount rate for RTK guidance with additional yield benefit as well as cost savings from reduced overlap was $18/ha/yr. This compared with $1.70/ha/yr when cost savings from reduced overlap was the only benefit and there were no benefits from extra yield. This demonstrates the need to maximise potential benefits from the technology by adopting complementary management practices.

Returns with the Sub-Metre guidance technology exceeded the required 8 percent real return p.a. The break-even crop area required for the less expensive GPS receivers with precision less than 30 cm was between 350–400 ha.

Investment in GPS guidance technology can be worthwhile – a conclusion endorsed by many Australian farmers who have implemented GPS guidance systems (Kondinin 2006). Investment in variable rate technology for more precise nitrogen applications did not earn a competitive rate of return in the case study analysed.

Limitations

It is important to remember that this research explores only a small part of potential PA/SSCM benefits. The non-financial benefits of GPS guidance are not included. Only the variable rate treatment of one crop input, nitrogen, is analysed. As a result, the net benefits identified are the minimum net benefits. The analysis and model could be extended to consider variable rate chemical application for weed management, other fertilisers such as phosphorus and soil ameliorants such as lime and gypsum. Additional technology such as variable rate spraying and spreading of fertiliser also could be analysed.

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Appendix 1

Table 1. Paddock details and the Marginal Gross Margin ($/ha) attributable to Zone Management

	Paddock Details					GM benefit of Zone over Uniform 1998 - 2005	
Name	**Size (ha)**	**No. Zones**	**WUE**	**SD**	**CV**	**Total**	**Average**
Barrell	22	3	16.29	2.93	0.18	$25.17	$5.03
Bishes West	152	4	17.16	3.21	0.19	$18.43	$6.14
Clovers East	120	4	14.18	2.67	0.19	$14.71	$2.94
Far West	66	4	18.72	6.74	0.36	$33.44	$8.36
Jack Sheans	140	3	17.43	4.81	0.28	$57.76	$11.55
Jil Jil East	156	4	22.19	9.41	0.42	$31.66	$6.33
Landers	181	4	16.12	4.18	0.26	$50.66	$8.44
McKenzies North	110	5	14.88	3.07	0.21	$26.31	$5.26
Perns	200	6	17.02	5.04	0.30	$29.64	$5.93
Sandhill South	88	5	17.72	5.90	0.33	$39.48	$6.58
Spittles	160	4	12.34	5.27	0.43	$60.81	$12.16
Totals	**1395**					**$388.07**	
Averages			**16.7**	**2.56**	**0.29**	**$35.28**	**$8.22**

Table 2. Comparison of costs savings from reduced overlap with different GPS guidance technology (from Kondinin 2003)

DGPS Receiver	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Visual Equipment	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Cost GPS Signal ($)	$7,645	$8,740	$8,800	$7,150	$7,590	$10,989	$7,150
Cost Visual ($)	$6,801	$0	$14,850	$3,025	$8,360	$0	$3,025
Total Cost	$14,446	$8,740	$23,650	$10,175	$15,950	$10,989	$10,175
Annual Costs ($/yr)	$500	$500	$500	$500	$500	$500	$500
Precision R50 (m)	0.10	0.30	0.40	0.20	0.10	0.30	0.70
Precision R90 (m)	0.20	0.40	1.30	1.00	0.60	0.90	1.30

Table 3. Implement widths of equipment used on the case study farm

	Implement Width (m)
Sowing	9.1
Spraying	27.4
Harvest	9.1
TD	27.4

Table 4. Guidance cases

PA Type	IRS % Yield benefits	Overlap (cm) Sowing	Spraying	Harvest	TD	Other PA % Yield benefits
Perfect Overlap	0.00%	0	0	0	0	0%
Sub-Metre	0.00%	10	10	10	10	0%
RTK	90.00%	2	2	2	2	100%
None (Base Case)	0.00%	75	150	75	150	0%

Table 5. Comparison of costs savings due to reduced overlap for different guidance brands over the simulated period 1998 - 2005

DGPS Signal	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 5	Receiver 6	Receiver 7
Average	$10.92	$7.92	$6.46	$9.39	$10.91	$7.86	$1.77
Minimum	$9.11	$6.57	$5.29	$7.84	$9.11	$6.52	$0.34
Maximum	$13.90	$11.33	$10.07	$12.40	$13.83	$11.27	$5.58

Table 6. NPV ($/ha) of guidance at 8% discount rate (1998 dollars)

DGPS Signal	Receiver 1	Receiver 2	Receiver 3	Receiver 4	Receiver 5	Receiver 6	Receiver 7
Minimum	$29.91	$19.83	-$3.75	$26.24	$28.49	$17.32	
Median	$33.16	$23.26	-$0.14	$29.71	$31.59	$20.51	
Maximum	$99.66	$89.72	$67.23	$96.12	$98.14	$86.61	
Break-even[1]	351	360	836	329	375	412	1675
Cost ($/ha)	$21.99	$15.53	$32.39	$17.16	$23.69	$18.08	$17.16

[1] Area (hectares) to earn 8 percent required rate of return

Table 7. Net Present Value ($ and $/ha) between 1998 - 2005 at discount rate of 8% for different PA technologies on the case study farm

Measure	RTK Guidance (No other GM Benefits)	RTK Guidance (Inc. other GM Benefits)	Zone Management	Sub-Metre Guidance
Total Returns				
Mean	**$12,452.58**	**$129,435.14**	**-($27,693.91)**	**$31,992.31**
Standard Deviation	$7,331.63	$11,631.59	$88,240.47	$7,334.92
Minimum	$7,085.49	$98,554.38	-($259,486.56)	$26,455.43
Maximum	$68,756.31	$184,043.11	$209,736.12	$88,152.10
Total Initial Costs	$49,446.00	$49,446.00	$36,000.00	$19,446.00
Annual Costs	$0.00	$0.00	$3,600.00	$500.00
Returns per hectare/year				
Mean	**$1.76**	**$18.29**	**-($3.91)**	**$4.52**
Standard Deviation	$1.04	$1.64	$12.47	$1.04
Minimum	$1.00	$13.93	-($36.67)	$3.74
Maximum	$9.72	$26.01	$29.64	$12.46
Total Initial Costs	$6.99	$6.99	$5.09	$2.75
Annual Costs	$0.00	$0.00	$0.51	$0.57

Table 8. Net Present Value ($ and $/ha) between 1998 - 2005 at discount rate of 8% on the case study farm, extrapolated out if 2000 ha of cereals are grown on average each year

Measure	RTK Guidance (Inc. other GM Benefits)	Zone Management	Sub-Metre Guidance
Net Present Value			
Mean	**$375,796.50**	**$10,385.33**	**$97,057.94**
Standard Deviation	$26,750.07	$219,281.13	$13,319.60
Minimum	$302,116.85	-($592,943.62)	$86,107.93
Maximum	$486,136.46	$671,459.37	$198,981.79
Total Initial Costs	$49,446.00	$36,000.00	$19,446.00
Annual Costs	$0.00	$3,600.00	$500.00
Net Present Value per hectare/year			
Mean	**$23.49**	**$0.65**	**$6.07**
Standard Deviation	$1.67	$13.71	$0.83
Minimum	$18.88	-($37.06)	$5.38
Maximum	$30.38	$41.97	$12.44
Total Initial Costs	$3.09	$2.25	$1.22
Annual costs	$0.00	$1.80	$0.25

Figure 1. Overlap cost savings attributable to GPS guidance - minimum and maximum benefit over simulated period 1998 – 2005

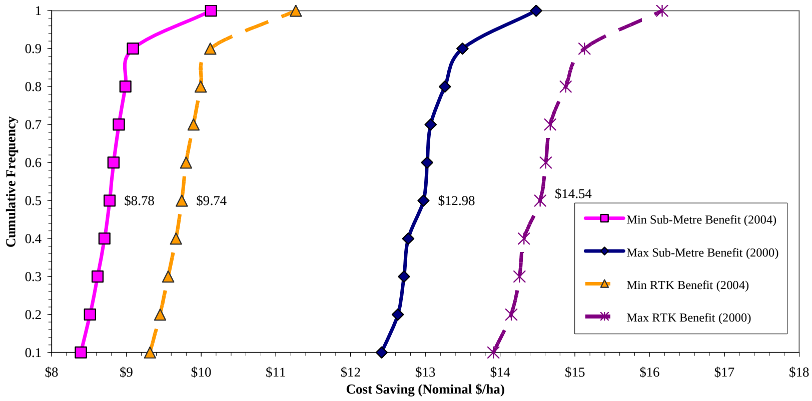

Figure 2. Net Present Value of various Sub-Metre guidance technologies and the break-even area sown versus the precision of the Sub-Metre GPS receiver

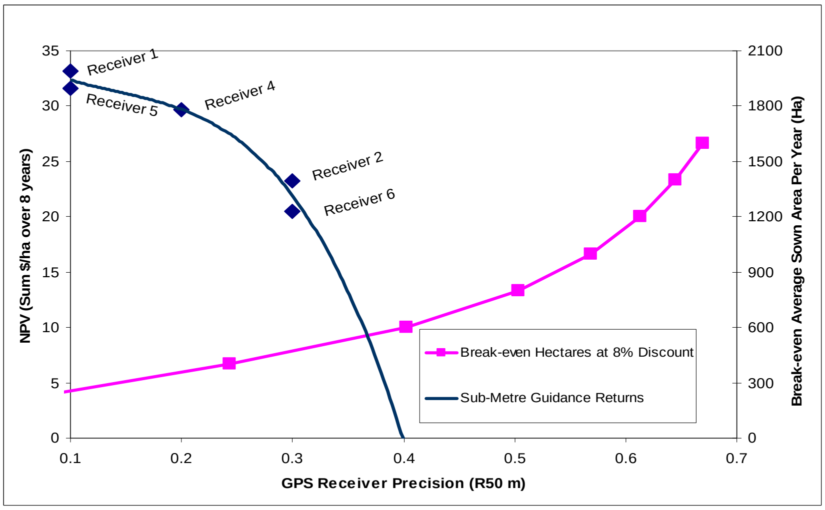

Figure 3. Distributions of simulated whole-farm average AGM during the period 1998 - 2005

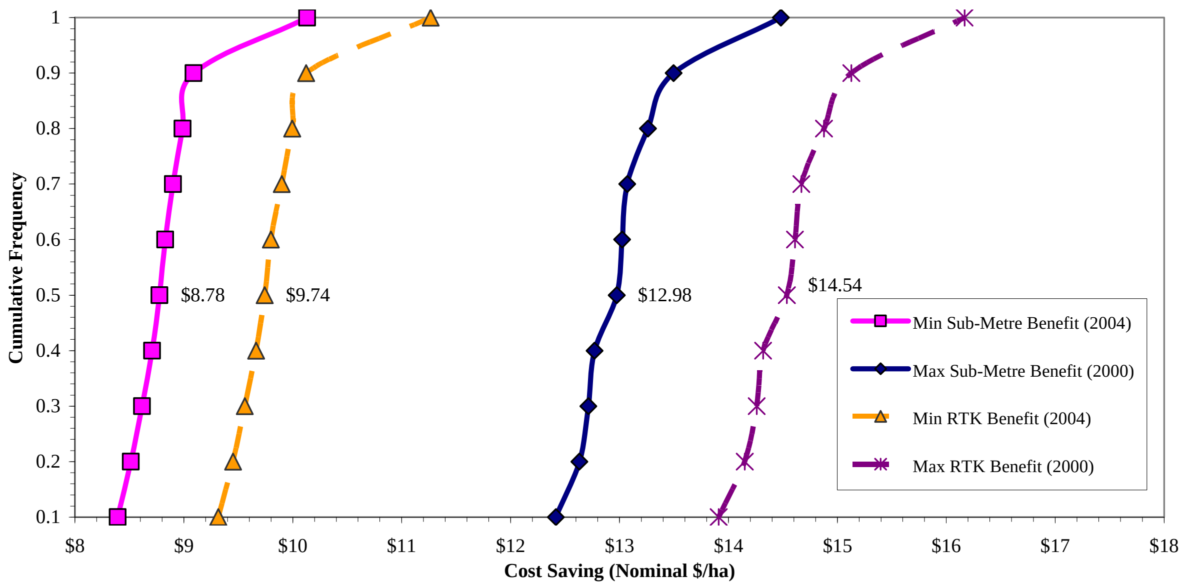

Figure 4. Break-even analysis of PA technologies against both area sown (ha/yr) and cost of the enabling technology

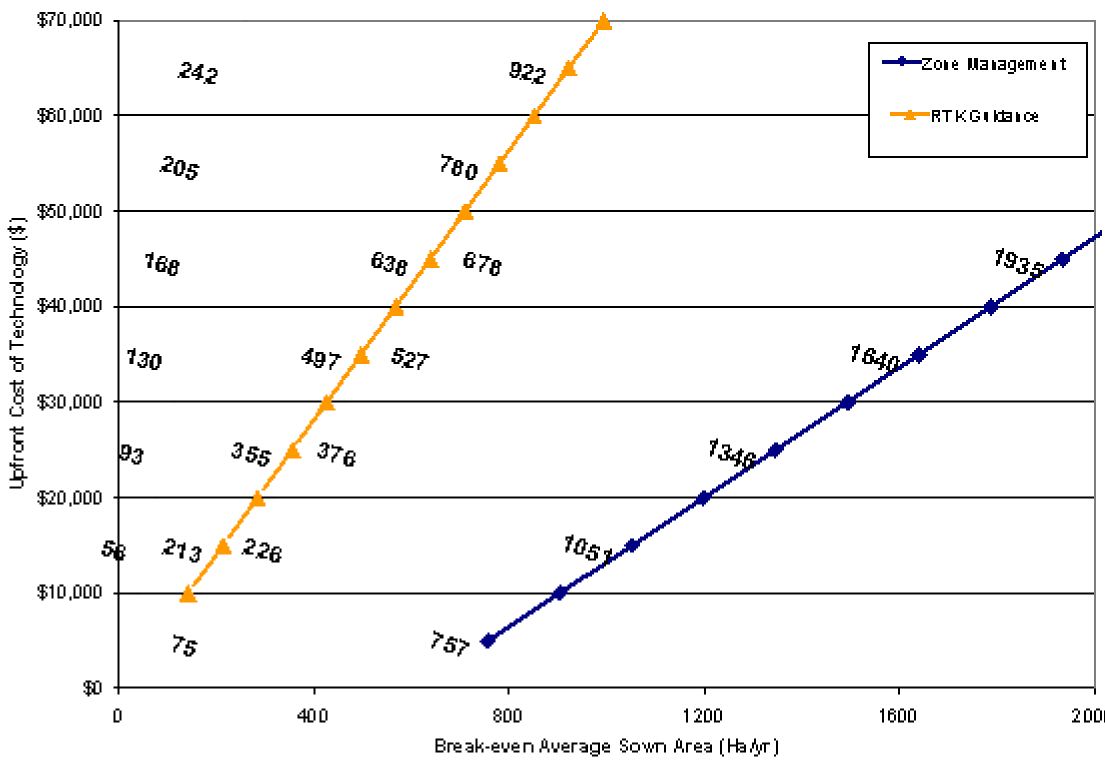

Figure 5. Break-even paddock variation: Coefficient of Variation of paddock mean WUE vs. the benefit of Zone Management with RTK guidance over a uniform approach with no GPS