Can NZ arable farmers profitably adopt GPS guidance Technology?

For Kellogg Rural Leadership Programme 2009.

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Executive Summary.

For most farmers the thought of investing $20,000 to $40,000 just to drive straight and accurate would seem ridiculous!

Today's farmers are under increasing pressure to adopt more efficient agricultural principles, making the best possible use of resources by minimising high energy inputs, such as pesticides, fertilisers, fossil fuels and water, without loss of food quality and yield. The challenges are to maintain and increase productivity and profitability, while reducing any potentially negative environmental impacts.

Investing in new technology will help farmers meet these challenges.
GPS (Global Positioning System) is one area that has the potential to meet some of the challenges faced by farmers today.
However it is important to know that there is a timely economic return from any new investment in technology.

The price of GPS/ precision farming technology has continued to decline as its capabilities increase.
This could be a good time for the NZ arable farmer to invest in GPS.

The three major uses of GPS in farming are mapping, input control and machine control. This allows farmers to improve agronomy, reduce error and change practice i.e. strip tillage farming. The advantage of using GPS / precision farming technology is input savings from more precise field application of seed, fertilizers, chemicals, fuel, and labour, as well as increased benefits to the farm production process, the ability to work over a longer period, reduced driver fatigue, and improve agronomy.

Reducing error by better machine control would seem a logical place to start as savings are instantly realised as soon as error is reduced.

GPS guidance systems vary in their capability, precision, and costs and, therefore, provide varying levels of input savings. The process of evaluating an investment in any new technology is straightforward and centres on comparing annual costs to annual benefits. If the benefits are greater than the costs, then it's time to invest in the new technology. Some benefits and costs are easily measured, while others must be evaluated by the farmer based on their own experiences.

Visual guidance methods currently used can have overlap errors of up to 10%
The recent availability of high accuracy RTK GPS auto steer guidance systems has made it possible to reduce overlap errors to less than 1%.

Investing in this technology can involve significant amounts of capital, but significant savings of seed, labour, fuel, chemical and fertilizer are possible, making it a wise investment.

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1. Introduction.

One of the issues facing growers starting down the GPS path is cost.
Will the investment give a return?

This report aims to assess the financial benefits of using high accuracy GPS auto steering for guidance on arable farms.
This report outlines why investing in new technology might be beneficial and how GPS technology could help arable farmers meet some of the challenges facing them today,by outlining the three main uses for GPS in crop farming, mapping, input control and machine control.

The main focus of this report is to assess the use of GPS guidance (machine control) in arable farming and its ability to reduce error in field operations (such as planting and fertilizer spreading) when compared to visual guidance methods. Visual guidance methods can have overlap errors of 10 % or more.
A case study is used to assess the financial benefits and to establish the return on the investment of high accuracy GPS auto steering guidance.

2. Why do NZ arable farmers need to invest in new technology?

2.1. Efficiency

Today's farmers are under increasing pressure to adopt more efficient agricultural principles, making the best possible use of resources by minimising high energy inputs, such as pesticides, fertilisers, fossil fuels and water, without loss of food quality and yield. The challenges are to maintain and increase productivity and profitability, while reducing any potentially negative environmental impacts

Successful optimisation of inputs offers multiple benefits--lower production costs, improved environmental protection, reduced energy inputs and enhanced consumer confidence. Are arable farmers 100% efficient?

2.2. Competition

Many of the arable producing areas around the world have the advantage of scale and therefore a lower cost of production. NZ arable producers have to compete on price and quality with imports of feed grains and milling wheat from Australia and the US. Exports of small seeds from NZ also have to meet high quality standards and be competitively priced.

If arable farming in NZ is to remain competitive with the rest of the world, technology that lowers the cost of production and improves quality needs to be adopted.

2.3. Risk management

Markets are demanding guaranteed supply and quality. Production methods need to be able to guarantee this is the case. This can be difficult in farming when the weather can have a big impact on production. However we have seen what irrigation technology can do in reducing supply and quality risks. While it is hard to plug every hole in the bucket, new technology needs to be adopted to plug the next hole up to reduce production risks.

2.4. Human error

"We are only human". Like it or not we make mistakes. We have different skill levels. Our ability to repeat a task exactly as before varies- we get tired- we have limitations. Technology can overcome human limitations. For example tasks can be repeated by robots again and again at the same rate and at the same quality standards 24 hours 7 days a week, removing an area of uncertainty and reducing the cost of errors.

2.5. Environment

As the world population continues to grow so too will the demand for food adding pressure on the environment also. The United Nations and the Food and Agriculture Organisation have estimated that to feed the population of the world in the future, we will need to produce twice the current amount of food and we must achieve it in a sustainable way.

"An important point to note is that historically yields have been improved by increasing the chemical input, the change in farming practices advocated today are intended to increase yields while at the same time potentially decrease chemical input." **(Lorimer, 2008)**

History has shown that adopting new technology affects outcomes, not all of them positive for the environment, for example DDT. However there are many examples of how technology helps farmers improve sustainability for example soil moisture monitoring for irrigation scheduling.
A key objective for adopting new technology is "to increase production but not the production area or production inputs".
The challenge for the arable industry is to adopt new technology that can achieve this objective and still remain profitable and environmentally friendly.

2.6. Why GPS?

GPS technology gives farmers the ability to measure where they are and the ability to return to that same place or to a known distance from the original place at a later time. If you can measure it you can manage it. No more guess work.
It also allows data to be attached to each GPS point for latter reference. For example crop yield and soil tests.

3. GPS and uses for GPS in arable farming

3.1. GPS – What is GPS?

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites.
GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. In fact, with advanced forms of GPS it is possible to make measurements to better than a centimetre!
In a sense it's like giving every square meter on the planet a unique address.

GPS Facts

- First GPS satellite was launched in 1978.
- Current system is composed of second-generation GPS satellites, called Block II.
- First Block II satellite was launched in 1989.
- Defense Department declared GPS fully operational in 1995.
- When the system was first introduced, miscalculations (called SA – Selective Availability) were programmed into GPS transmissions to limit the accuracy of non-military GPS receivers. This operation was cancelled in May 2000.
- There are 24 GPS satellites in orbit at this moment.
- The 24 satellites cost an estimated $12 billion to build and launch.
- Each satellite weighs about 786 kg.
- Satellites are orbiting about 20,000 km above the Earth.
- Satellites take 12 hours to orbit the Earth once.
- The Russians have a system identical to the U.S. system called GLONASS

3.2. Precision Farming

Precision farming is a term often used to describe the use of GPS and other technologies in improving farm productivity and operating efficiency. It is not a single technology, but rather a set of many component technologies from which farmers can select to form a system that meets their unique needs and management style.

GPS technology forms the base to precision farming.

The applications for GPS in agriculture are vast and complex, knowing where to invest first requires some back ground understanding of its capabilities and limitations.

Figure 1 illustrates three major applications for GPS in arable farming.

- Mapping
- Input Control
- Machine Control

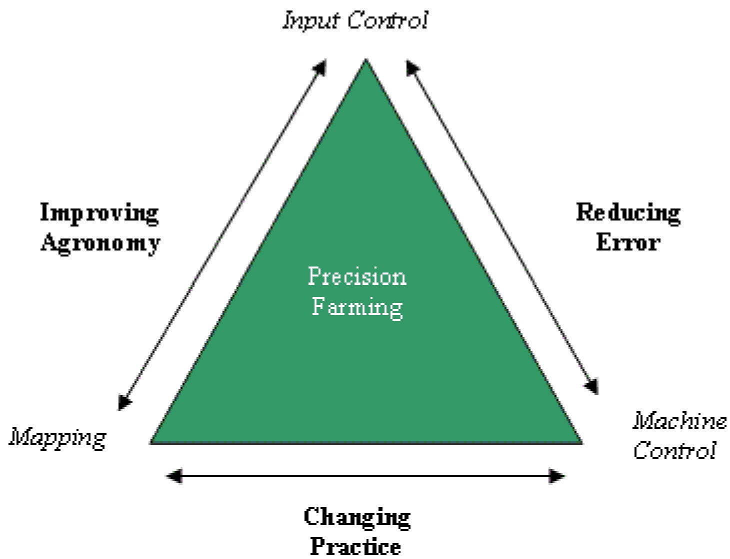

Figure 1 GPS Adoption in Cropping Agriculture

Mapping describes using GPS as part of a data collection system which includes geographical position. The purpose is to collect geographically referenced data for subsequent analysis and decision making. For example yield mapping from the combine harvester or soil test results.

Input Control refers to using GPS to monitor, control and precisely apply inputs such as fertilizers, pesticides and seed at variable rates.

Machine Control is using GPS to better control the steering of agricultural machinery and implements.

By combining all or some of the above applications it is possible to

- **Improve Agronomy**
- **Reduce Error or**
- **Change Practice.**

Improving Agronomy

Improving agronomy is a "scientific" approach to Precision Farming. It typically involves a considerable amount of data collection (Mapping) of the farm property including soil composition, pest concentrations and yields. This information can be built up over successive seasons and the grower then uses techniques such as Variable Rate Technology (VRT) to place chemicals only where required (Input Control). The objective is to progressively improve yields by optimizing input usage to each specific area and applying inputs only where required. **(Lorimer, 2008)**

One of the limitations with this approach is that a lot of the decision making is based on historical data. With farming seasons varying from year to year, changes to inputs to the current season crop based on historical information may not achieve the desired result. The result in fact could be negative. Several years' data (climate included) may of course improve accuracy of decision making. It could also complicate it, with lot of data to analyze.

Also there are many factors that can affect plant growth. Knowing what input to vary to make an economic difference could be like picking the winning lotto numbers. Is it a combination of inputs? Is it more or is it less? Is the timing of the input correct? What effect will the weather have? These are some of the scientific questions complicating the economic return of input control.

However there is a move to use "real time" data to help over come some of the limitations of using historical data on its own. The technology is being developed using infrared and satellite imagery or tractor mounted sensors to measure crop requirements on the go. Then combining this data with historical data and a geographic reference to vary inputs and improve agronomy! The availability and the backup support of this technology is limited in NZ.

In the future an important area for NZ agriculture will be the use of VRT to apply irrigation. Such technology will help improve agronomy and production efficiency as well having environmental benefits. Projects looking at VRT irrigation are being looked at in NZ but it maybe some time before it is able to be widely adopted.

Improving agronomy with the help of GPS requires scientific knowledge that is not yet fully understood, making investment in this area more challenging to be profitably adopted by the majority of farmers.

Reducing Error

Reducing error can perhaps be described as the "practical" approach to Precision Farming. It most commonly involves helping the operator drive the machinery in a straighter line through the use of a visual guidance system or an automated steering system. (Machine control). By reducing the amount of overlap (where the ground is covered twice) and under lap (where a strip may be missed) seed, chemical, fuel, time and labour input can be reduced by up to 10%. Further advantages are reduced fatigue, a decrease in the time taken to perform operations and a reduction in the need to repeat operations to fix up skips or misses. **(Lorimer, 2008)**

The limitations of night time or low visibility conditions are also reduced.

Additional techniques include methods such as boom-section-control where each spray nozzle or groups of nozzles can be switched off if overlap is detected offering significant economic and environmental benefits.

More accurate "Machine Control" reduces errors and savings begin to be realised as soon as the second pass is made.

Changing Practice

Changing practice, often with the joint goals of both improving both farm productivity and operating efficiency. An example of this is the adoption of control traffic. With this practice the grower permanently divides his field into crop zones and driving zones. Every pass of machinery for sowing, fertilizing, spraying and harvesting is along the same wheel ruts (driving zone) significantly decreasing compaction in the crop zone which improves soil structure, water retention and root penetration. Control traffic farming has the potential to improve crop yields as the effects of compaction are reduced season by season. The investment is considerable as machinery needs to be standardized to "fit into" the new driving patterns. **(Lorimer, 2008)**

Figure 2 Modified tractor used in controlled traffic farming

To adopt all three approaches of Precision farming at once would not be practical. To do so would require a large capital and knowledge investment. It would be impossible for most farmers. A better choice is to start with one and move on to others when ready.

GPS Precision Guidance Technology ("Machine control") is a logical place to begin as it offers benefits to reduce error without the steep learning curve and knowledge requirement for "improving agronomy" and the capital investment for "changing practice" as in control traffic farming.

Savings begin to be realised as soon as the second pass is made.

The remainder of this paper will focus on GPS auto steering guidance, (machine control) and comparing it to visual guidance methods analyzing the cost and benefits of both methods.

4. Current guidance vs GPS guidance

4.1. Current Methods of Guidance

Arable farming requires multiple passes (i.e. cultivation, planting, weed control- mechanical and chemical, and fertilizer) across each field each season. This requires a method of guidance with a high degree of repeatability in order to minimise damage to the crop and unnecessary overlap (extra cost of seed, fertilizer, chemical and machinery) and skips (loss of production).

Cultivation and planting guidance in most cases is all visual guidance by the driver. Accuracy is affected by driver skill, fatigue, implement width and visibility conditions i.e. dust, darkness etc. The addition of marker arms are often used during planting to improve accuracy.
Research shows that errors of between 6 - 12 % are made when cultivating using visual methods and between 2.5 – 5% for planting with the addition of marker arms. (HGCA Research review No 71 May 2009 pg30)

Current methods of repeatability are following wheel marks from previous passes or following tramlines made in the crop at the time of sowing. (Tramlining is where the seeding drill has the ability to shut off the seeding coulters which match where the fertilizer spreader or sprayer wheels would travel giving a visual guidance once the crop has emerged)

Figure 3 Tramlines used for visual guidance of machinery through the crop.

The problems with tramlining are firstly, all operations prior to crop emergence rely on visual methods of guidance which can have errors between 6 and 12%.
Secondly with the tramlines having an error of between 2.5 and 5% then all following passes will have the same error.
Not all arable farmers use tramlines so it is possible that the error could be even greater.

A 2.5 to 12% error range would translate to a measured range between 0.08m to 1m depending on operation and implement width.

4.2. GPS Guidance Accuracy

Not all GPS systems offer accuracy that is better than current best methods of guidance employed by arable farmers.

The two key accuracy specifications for GPS used in agriculture are day to day (static accuracy) and pass to pass (relative accuracy).
Pass to pass accuracy refers to relative accuracy within a 15 minute period. This is the key consideration where the aim is to carry out accurate parallel passes across the paddock.

Static accuracy determines repeatability of positioning over a period of days weeks and years and is relevant if it is required to return to the exact same place again and again. Static accuracy is an important consideration for arable farmers where multiple passes through the crop are required.

There are many factors that influence the accuracy of GPS (appendix 1) most of these have been over come with special correction systems to provide the repeatability required to better current methods of guidance used in arable farming.
With out any correction GPS would provide a pass to pass accuracy of 0.3 to 1 meter at best, with even less accuracy in repeat operations over a longer time span.
A rule of thumb is that uncorrected GPS drifts 1m per hour.

Many farmers and contractors are using uncorrected GPS for guidance, for example fertilizer spreading. However the question is- is the accuracy of uncorrected GPS guidance better than current methods employed by arable farmers as described above?

As can be seen in table 1 below the accuracy of uncorrected GPS offers little accuracy benefit over visual guidance methods as used by arable farmers and therefore will not be considered further in this paper.

Only corrected GPS has the potential to better the best visual guidance methods.

It also important to note that it is only possible to achieve the accuracy level offered by DGPS and RTK GPS with the use of auto steer. Using light bar guidance only, it would be very difficult for the driver to maintain this level of accuracy all day.

Table 1. Relative accuracy of types of guidance

Guidance type	Accuracy (relative) Pass to Pass +/- m	Accuracy (static) +/- m
Visual - estimation Guidance	0.08 to 1m	
Uncorrected GPS	0.3 to1m	5m plus
DGPS	0.15-0.3m	1m
RTK	0.02-0.05m	0.02-0.05m

4.3. Methods of correction.

Differential GPS (DGPS) with Beacon correction

Figure 4

The vehicle with a GPS antenna receives GPS signals from the GPS satellite constellation. The Beacon receiver, at a known location, receives GPS signals. The beacon generates an equation that changes the location of where the GPS satellites say it is, to where it knows it is, and then sends the equation known as the 'correction message' to the GPS antenna on the vehicle, which then applies the correction.

RTK (Real Time Kinematic) GPS Guidance

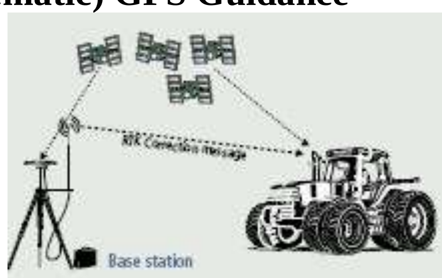

Figure 5

This is a highly precise technique that results in 2.5 cm year-to-year accuracy. RTK GPS requires two specialized GPS receivers and two radios. One GPS receiver is set up as a base station within an 11 km radius of the field you are working so it can send the correction message to the roving receiver. Both receivers collect extra data from the GPS satellites, known as L2 Band that enables better precision.

4.4. Potential Benefits of corrected GPS

Consider a good operator in good conditions using a 6m drill using visual guidance with marker arms then you would expect an overlap of between 2.5 - 5%.

If you then replaced visual guidance with GPS auto steer guidance then you could expect the following.

Table 2 Comparing Driver accuracy accuracy when using a 6m implement with marker arms to GPS auto steer

Guidance Method	Overlap m	Overlap % Pass to Pass
Visual - Poor Driver	0.3 m	5% or more
Visual - Average Driver	0.2 m	3.3%
Visual - Good Driver	0.15 m	2.5%
DGPS auto steer	0.15-0.3m	2.5 – 5 %
RTK auto steer	0.02-0.05m	Less than 1 %

Comparing traditional methods of guidance (when planting with the addition of marker arms) to DGPS guidance, there is little advantage if you consider only overlap savings.

While it would appear that when looking at the best GPS system, with a benefit of only 1.5 to 4% saving in overlap it seems like a marginal exercise to invest in GPS guidance. The following case shows otherwise.

5. Investing in GPS guidance – A case study.

5.1. Farm Overview

Area

- 1100 ha arable farm
- 400 ha irrigated
- Rolling to flat topography
- Irregular shaped fields

Crops

- Wheat
- Barley
- Ryegrass
- Lucerne silage
- Hybrid rape
- Other break crops

Machinery

- 270 hp (7500 hrs) used for sowing-fitted with RTK GPS auto steer
- 300 hp (4000 hrs) used for all cultivations-fitted with DGPS auto steer
- 24 m self propelled sprayer- fitted with uncorrected GPS light bar and graphic guidance

5.2. Reason for investing in GPS Guidance.

- Identified overlap of operations as a problem.
- Large area of dry land. Yields can be low so need to keep costs down.
- High costs for irrigation water- reduce errors to maximize yields and return from irrigation.
- Attention to detail essential for maximum sustainable production.
- Need to increase scale and minimize capital investment.
- Overcome the issue of lack of skilled labour
- Reduce maintenance.
- Work at night – better timing and utilisation of capital equipment

5.3. GPS Guidance Annual Costs

Using the initial purchase price formed the basis for determining the annual cost of GPS guidance. How ever as GPS guidance is a relatively new technology there are no common industry standards to determine useful life and likely repair costs and assumptions have to be made.

Assumptions made in determining the annual costs.

The useful life of the units has been determined as 10 years as these particular units have free software and firmware upgrades available that can be installed by the user.
It is possible that newer technology may make them obsolete sooner but any improvement would have to provide economic benefits for upgrading to be considered.
Repairs have been estimated at 3% of the initial purchase cost. There is very little information available to determine what possible repairs may be needed over the useful life time of the equipment.
A study by Virginia State University "Investing in GPS Guidance Systems" used 10% of initial purchase price. This would equate to spending $36,000 over a 10 year life. This would seem excessive as most computer problems are with the software, which in this case is currently free to reinstall and upgrade. This may not be the case with every GPS manufacturer and may add to the annual cost if using another system.

Other considerations

Base station- correction signal costs.

The correction signal is provided by the GPS retailer and in this case is a flat fee of $1500 and provides a correction signal suitable for RTK (+/-2cm). The base station is sited on a hill in a fixed location with the signal able to reach all corners of the farm.
A moveable field located base station was not an option for this farm as the signal was required in different paddocks at the same time.
With this system as many GPS units as required by the farm can be corrected for the one fee.
The cost of the correction fees can vary with different providers for example some correction signal providers charge for each unit used.
Owning the necessary hard ware is also an option for getting correction signal but at considerable capital cost ($10,000 to $30,000) and possible maintenance costs.

Table 3 and Figure 6 below show the annual cost of investing in two GPS units. Both systems are auto steer.

Table 3 – Annual GPS Guidance Costs

	GPS Auto Steer		DGPS	RTK	Total
1	Initial investment $		$14,000	$22,000	$36,000
2	Salvage value		0	0	0
3	Amount to be recovered (1-2)		$14,000	$22,000	$36,000
4	Interest Rate		8.00%	8.00%	8.00%
5	Estimated life of asset in years		10	10	10
6	Insurance % of initial investment	2%	$280	$440	$720
7	Deprecation		$1,400	$2,200	$3,600
8	Annual repair cost % initial investment	3%	$420	$660	$1,080
9	Annual subscription fee		$660	$840	$1,500
10	Opportunity cost	10%	$1,400	$2,200	$3,600
11	**Total annual costs**		**$4,160**	**$6,340**	**$10,500**

The high accuracy RTK system was fitted to the sowing tractor to insure tramlines were sown as accurately as possible so following passes could also be accurate.
The medium accuracy DGPS system was fitted to the cultivation tractor which mainly tows an 8m cultivator.

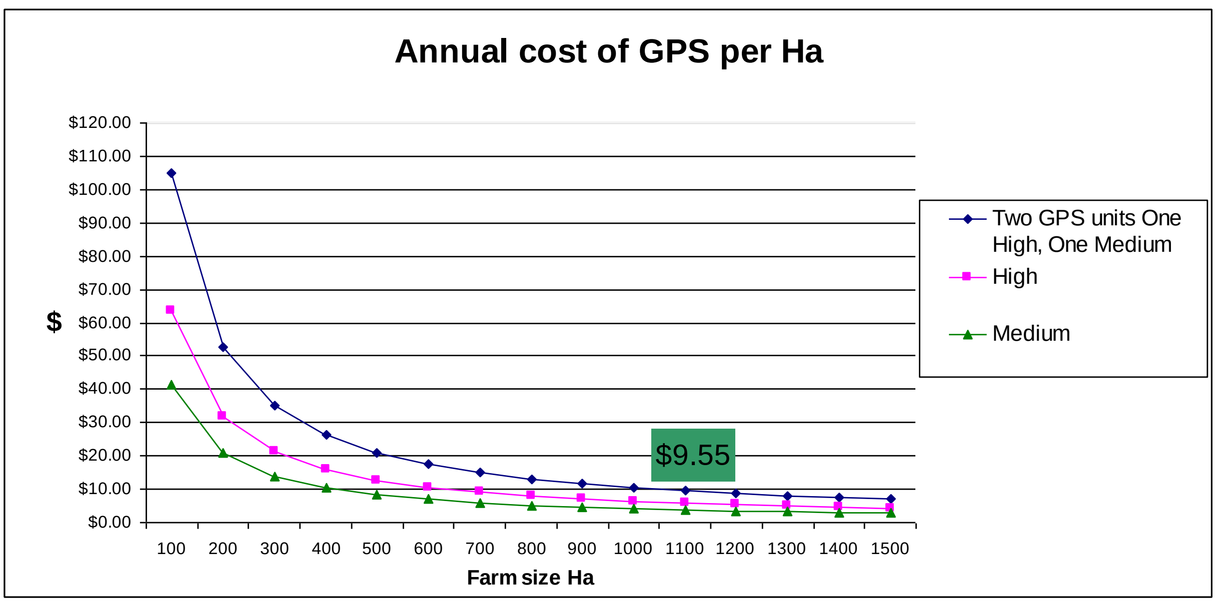

Figure 6 showing the annual cost per ha of each GPS system and the combined cost of both. In this case study based on a farm size of 1100 ha, the combined cost is $9.55 per ha. Therefore to break even savings of $9.55/ha need to be realised.

5.4. Benefits from using GPS guidance

Pre GPS

The farm prior to investing in GPS was relying on visual- guidance for all cultivations, marker arms for sowing and tramlines for post emergent operations (fertilizer and spraying). Pre emergent sprayer guidance was with foam marker. This required a high level of driver skill and good visibility to ensure consistent accuracy.

Taking the first step

The first GPS system was purchased to replace the foam marker in the sprayer to over come the frustrations of foam markers not making consistent foam, having it blown by the wind and the continual cost of running them. Cost of foam was about $0.50 per ha plus maintenance, labour etc easily covering the purchase cost of the GPS unit in two years. The GPS has been in operation in the sprayer for three years with out any further running costs.

This was an uncorrected GPS light bar guidance system but with most of the spraying being guided by tramlines the accuracy or lack of it was not an issue and it worked extremely well to show the operator where he had been on the screen in the cab to ensure no spray runs were missed. It also made it possible to spray in the dark.

Taking the first step leads to the next

Using GPS immediately showed that the tramlines did not line up with the GPS even though the GPS was set to the same width as the tramlines were supposed to be, in this case 24m. Some of this misalignment was probably from using an uncorrected GPS system. However the question was asked, how accurate are the tramlines?
Physically measuring the tramlines showed that there was an overlap of between 2 - 6%. This error is inline with overseas research.
Each tramline pass is made up from 6 passes of the 4m drill (making 24m). An overlap of 8 to 20 cm with every drill pass is all that is required to produce the above error. Equivalent of sowing one row on top of the other with each drill pass.

Figure 7 the centre of this photo shows one row sown on top of the other. A 15 cm (4%) error. This clearly shows that savings could be made if overlap could be reduced.

The need for tramlines was also questioned - Should GPS be used for guidance for all passes / operations through the crop instead of tramlines?
The short answer was no, because planting with GPS would improve the accuracy of the tramlines. Therefore the following passes would also be accurate.

Accurate tramlines offered the following benefits.

1. Having accurate tramlines to follow would mean that fertilizer could be spread accurately without the need of investing in another GPS guidance unit for fertilizer spreading.
   (Swapping The GPS from one of the other tractors was not an option as spreading, sowing, spraying and cultivation take place at the same time, all with different tractors.)

2. Spraying could also be done accurately with out the need to up grade the GPS to a more accurate system.

3. Having tramlines means that no crop gets run over, which causes those plants to mature at a different rate, resulting in green grains in the harvest sample and higher drying costs.

4. If the GPS for some reason wasn't working then the work could continue using tramlines.

By investing in a high accuracy GPS system to do the planting and by retaining tramlines, overlap savings in all post emergent passes could be achieved. The overlap would be reduced to less than 1% realising a saving average of 3%.

Typical overlap during cultivation averaged 0.85m an error a little more than 10%.

By investing in a medium accuracy GPS system for the cultivation tractor, savings of 8% could be achieved compared with visual guidance.

Table 4. Average overlap savings using GPS guidance vs visual guidance

Operation	Measured Overlap (m) with visual guidance.	Accuracy of DGPS. Overlap (m)	Accuracy of RTK. Overlap (m)	Average Reduction of Overlap (m)	Average % Saving
He-va 8m	.5 to 1.2	0.15 to 0.3		0.63	8
Rolling 7.5m	.6 to 1.0	0.15 to 0.3		0.6	8
Sowing 4m	.08 to 0.24		0.02 to 0.05	0.13	3.2%

These figures of overlap are similar to research from HGCA of between 2.5% and 12%

The total area now planted has reduced with the figures showing a 2.7% reduction in area. This shows overlap has been reduced.

Saving only 3% when planting would seem like a marginal exercise but spreading that saving over the farms annual fuel, machinery, labour, seed, fertilizer and chemical bill sounded exciting.

The following graphs show the financial savings achieved by reducing overlap using GPS auto steer guidance.

5.5. The Benefits of GPS in the Cultivation Tractor.

Area Ha	Cultivation Costs. Total $/Ha	Savings / Ha at 8% overlap reduction	Total savings over 1100 Ha
1100	$63.49	$5.08	$5,587

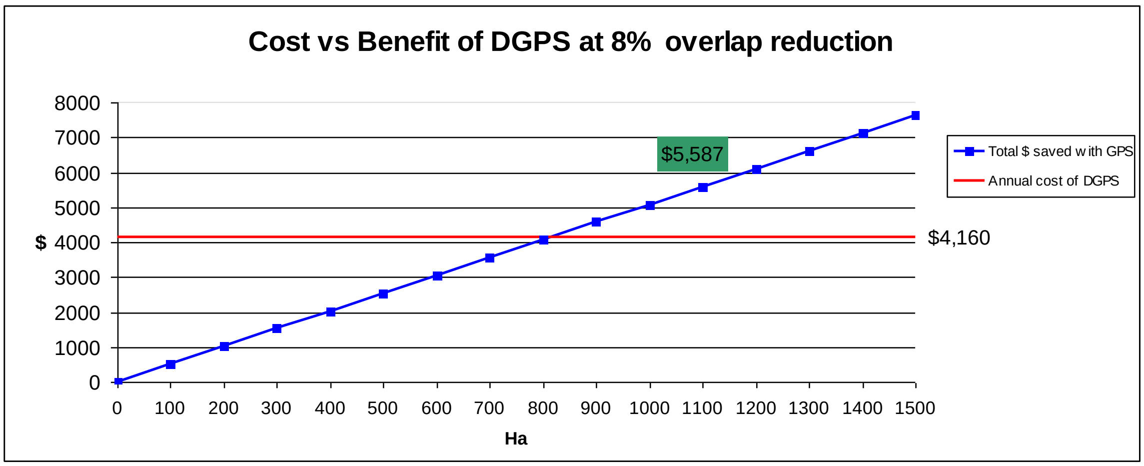

Figure 8 Annual savings on 1100 ha = $5,587 less annual cost of GPS $4,160 = annual profit $1,460 = $1.32/ Ha

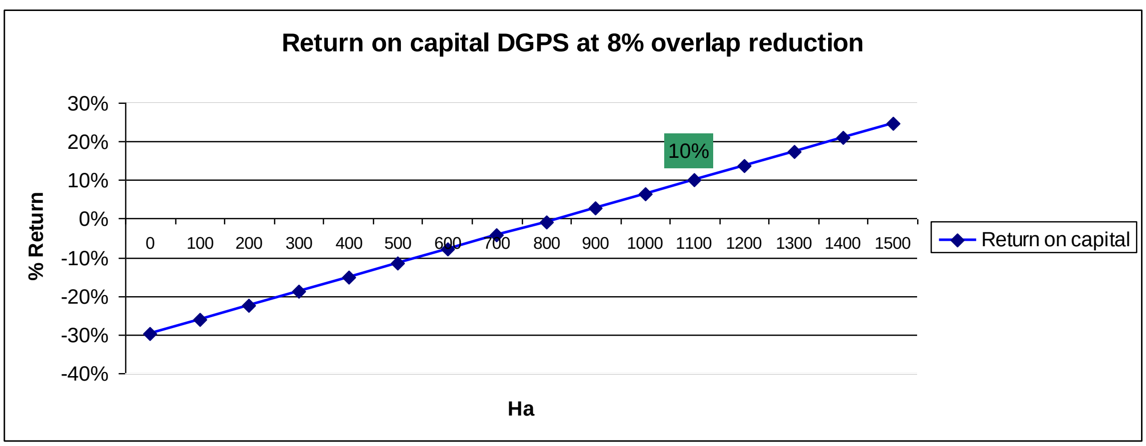

Figure 9 Capital invested $14,000 = return on capital 10%

Savings are made in labour, fuel, and machine R&M.
Savings from better timing of operations and less driver fatigue and maybe fewer breakages have not been accounted for and are worthwhile including as considerations when evaluating this technology.

5.6. Benefits of GPS guidance in the Sowing Tractor.

Area Ha	Cost of inputs- fertilizer, seed, chemical, machinery excluding harvest and cultivation. Total/Ha $	Savings / Ha at 3% overlap reduction	Total savings over 1100 Ha
1100	$706.4	$21.2	$23,311

Table 5

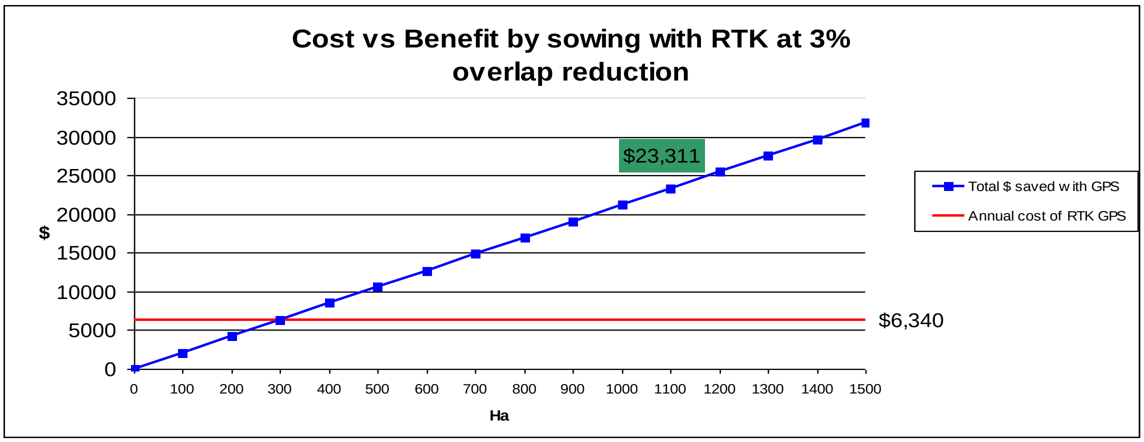

Figure 10 Annual savings on 1100 ha = $23,311 less annual cost of $ 6,340, annual profit $16,971=$15.42/ha

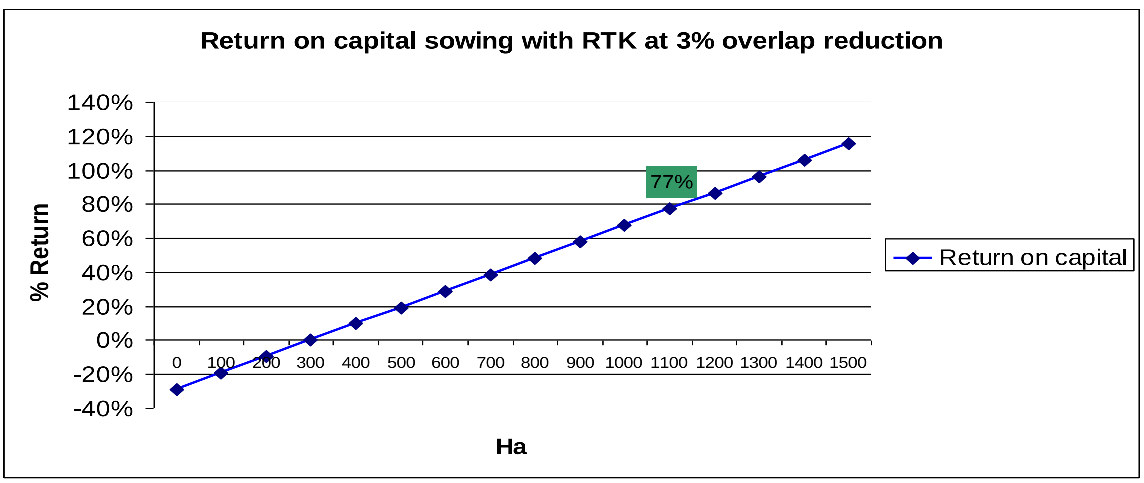

Figure 11 Capital invested $22,000 = return on capital 77%

Savings are made in labour, fuel, machinery R&M, fertilizer, chemical, and seed.
No analysis has been made for any savings resulting from better timing, less driver fatigue.
The adoption of GPS guidance has proved successful with a combined return on capital of 51% based on overlap only.

Using GPS technology has meant the discovery of additional benefits. For example being able to plant at night meant that an extra 100 ha of wheat was planted before the winter rain stopped planting until the spring.
Yield differences of autumn vs spring wheat is up to 2.1 t/ha extra (FAR 4 year Canterbury mean yield) for autumn wheat.

2.1 @ $300/t by 100 ha = $63000 !!!!

The use of GPS guidance for cultivation and planting is only the beginning.
In the future the harvester will be fitted with GPS auto steer. Annual savings could range between $1000 and $4000 plus saving time by not having part runs to do. By using one of the units from one of the tractors this could prove to be economic.

GPS boom section control on the sprayer to reduce “overlap triangles” at the headland in irregular shaped fields could save a further 2-5% of overlap. With many of these fields on the farm it could be possible to save 3% of the total chemical used on the farm, benefiting the bottom line and the environment.
The payback on boom section control could be as little as three years.

6. Summary

Investing $20,000 to $40,000 in order to drive straight and accurate is not as silly as it first sounds.

Reducing error by using GPS machine control has instant savings and is simple to adopt and therefore is a good place to begin investing along the GPS path.

Savings between 2 to 12 % are possible on input costs by reducing overlap. A good return or payback is possible. Farm scale and current visual guidance accuracy will affect the return the most. On an 1100 ha arable farm the break even area was 300 ha, suggesting farms bigger than 300 ha could benefit financially.

Experiencing GPS guidance will result in further investigation by farmers into the other applications GPS has to offer agriculture. Along with more research and education GPS will enable more farmers to improve agronomy and adopt new farming practices such as controlled traffic farming. Efficiencies will be further improved along with environmental protection and enhanced consumer protection.

More research and education will be required to fully utilise the potential benefits GPS has to offer NZ arable farming.

7. The last picture show.

This? Wasting seed, time, labour, fuel, fertilizer and chemical.

OR THIS

Perfect planting

Saving $$$

8. Reference.

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Research review No 71

9. Appendix 1 Common errors associated with GPS signals.

Clock

GPS satellites carry very accurate atomic clocks to generate timing signals. GPS receivers must also have a clock to compare the timing signals received from the satellites to internally generated timing signals. For cost reasons, most GPS receiver clocks are not as accurate as satellite clocks, nor are they tightly synchronized with satellite clocks. Though only three satellite signals are absolutely necessary for triangulation calculations, a fourth satellite signal is necessary to synchronize the receiver clock with the satellite clocks.

Ephemeris

Satellite orbits can vary slightly over time and require periodic adjustment by system maintainers.
Since the orbits vary, errors can exist in the satellite ephemeris (location) data used in triangulation calculations.

Dilution of Precision (DOP)

The configuration of the satellites in view to a receiver at any given time can affect the accuracy of position determination. For instance, if all of the visible satellites happen to be bunched close together, the triangulated position will be less accurate than if those same satellites were evenly distributed around the visible sky. The Dilution of Precision (DOP) is quantified from the satellite configuration. Many GPS receivers will display values for Horizontal DOP (quality of latitude and longitude data), Vertical DOP (quality of elevation data), Position DOP (quality of three-dimensional measurement), or Time DOP (quality of time determination). Lower values for DOPs indicate better satellite configurations. In general, DOPs less than four will give good position determinations.

Atmosphere

When radio waves from GPS satellites enter the Earth's atmosphere, their paths can be bent or refracted. This bending will actually change the length of the path the radio signal takes to get to the receiver. This change in length will cause an error in distance determination. Atmospheric effects are usually greater on satellites low on the horizon since the radio waves enter the atmosphere at more of an angle. Some GPS receivers allow the user to ignore or mask satellites below a set angle above the horizon.

Multipath

Multipath errors are similar to atmospheric errors but are often more severe. Multipath means that the same radio signal is received several times through different paths. For instance, a radio wave could leave a satellite and travel directly to the receiver, but it also bounces off a building and arrives at the receiver at a later time. Multipath can confuse position calculations and cause significant errors. The most common causes of multipath errors in agricultural settings are buildings, ponds, and lakes.