Precision farming: adopt or perish?

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Abstract

Precision farming has captured the imagination of many in terms of what it can offer. It is based on simple ideas that appear to make perfect sense. Firstly: feed a crop only to its potential in that particular location. Secondly: spray and treat only those areas that require treatment for control of disease and weed problems.

This technique offers improved profits through increased yield as well as potential savings in input costs. There are however additional costs that must be met. These include a global positioning system (GPS), additional controllers and monitoring devices on machinery, data storage devices on vehicles and additional software to manage and analyse the data produced.

Much of the work completed around the world has been directed towards combinable crops, there are however increasing numbers of yield mapping systems being developed for other machines such as forage harvesters, grape harvesters and root harvesters. Indeed higher value crops would appear to offer greater potential for increased profit.

This paper examines the technology adoption process and discusses some of the issues likely to affect adoption of precision farming here in New Zealand.

Keywords: DGPS, GIS, mechanisation systems, precision farming, variable rate applications

Introduction

When farmers first see a yield map from one of their paddocks, they often find it difficult to accept the level of variation in yield. Apparently uniform crops can give significant differences in value for spot yield. When soil nutrient and soil physical parameters are measured, we find the level of variation just as large. Conventional science has failed to alert us to the fact that these huge variations exist, variations which have a direct economic impact on farm performance. A study in New Zealand indicates similar trends in variation to those experienced in many studies overseas; Table 1 (Yule 1999) shows the level of variation in soil parameters on three sites. Sites 1 and 2 are 20 ha (containing 100 sample points), while Site 3 is 6 ha (containing 60 points). This study was also not unique in showing no strong trend between soil nutrient levels and crop yield. However, we need to collect data over a longer period and conduct more analysis on these data sets. A further trend in yield

Table 1 Statistical summary of soil parameters and production under an Agmardt precision farming study.

	Soil depth	p.H.	N kg/ha	P (MAF)	Ca (MAF)	Mg (MAF)	K (MAF)	O.M. (%)	D.M. (kg/ha)
Site 1									
Mean	32.41	6.21	58.36	25.16	10.34	19.09	4.11	3.83	2552
StDev	4.2	0.24	12.88	11.27	1.55	4.27	1.62	0.57	651
Min	23	5.6	26	13	7.0	11.0	2.0	2.4	1000
Max	45	7.0	105	79.0	15.0	36.0	12.0	6.5	5820
Range	22	1.4	79.0	66.0	8.0	25.0	10.0	4.1	4819
Site 2									
Mean	38.1	6.1	107.4	30.5	11	25.2	11.4	5.3	4145
StDev	12.9	0.2	16.8	8.4	1.4	4.3	2.5	0.5	389
Min	20	5.7	75	18	8	18	6	4.5	2932
Max	72	6.9	158	73	17	37	18	8.7	5043
Range	52	1.2	83	55	9	19	12	4.2	2111
Site 3									
Mean	38.5	6.5	90	25.5	12.6	17.6	8.5	4.2	1379
StDev	15.8	0.2	19.6	6.9	2.4	1.7	2.4	0.5	243
Min	20	6	60	15	9	14	5	3.2	590
Max	85	7.1	128	52	22	22	16	5.1	1900
Range	65	1.1	68	37	13	8	11	1.9	1310

mapping studies has been the instability of yield in terms of location, it is likely that only a proportion of the field will perform consistently well or consistently badly. For this reason a system of management zones as suggested by Blackmore & Lanscheid (1997) has been followed in a number of studies. Areas of a paddock are categorised as being: High yield and stable; Low yield and stable; or Unstable.

McBratney & Whelan (1999) further pointed out that temporal or seasonal variation is sometimes greater than spatial variation indicating that climate is a very strong driver of the system. All of the above makes it very difficult to give an exact value as to the benefit of precision farming. It changes with each location, farming system, climate, soil type, etc. It is also sometimes difficult to assess the current level of management and operation of each farming system. How do we establish these levels of accuracy because without such base information it is difficult calculate the impact of precision farming methods?

Precision farming must be viewed in the context of other technology adoption timetables. Meredith Corporation (1998) indicated the length of time for a technology to reach 25% of the population (Table 2). The trend is for more recent innovations to take less time to reach this level of market penetration but the problem with precision farming is that it relies on the integration of many technologies. Yield mapping is, however, one discreet part of the system and adoption figures are available for the U.S. A survey conducted by @gInnovator (Table 3) indicates that since 1995, at least 50% of all new combines released onto the market were sold with yield monitoring and yield mapping equipment.

Figure 1 is adapted from Lowenberg_DeBoer (1997) and offers an adoption curve for precision farming that is somewhat different from the standard S Curve. This adoption curve will be different for each industry sector and indeed every individual business. In general terms, the author proposes that the adoption of precision farming could be thought of as a four-phase process. Throughout the adoption timetable, these factors will vary in importance and can be referred to as drivers for change.

There are six main drivers to consider when examining the adoption of precision farming:

Table 2 Period required for a technology to reach 25% of the population (Meredith Corporation 1998).

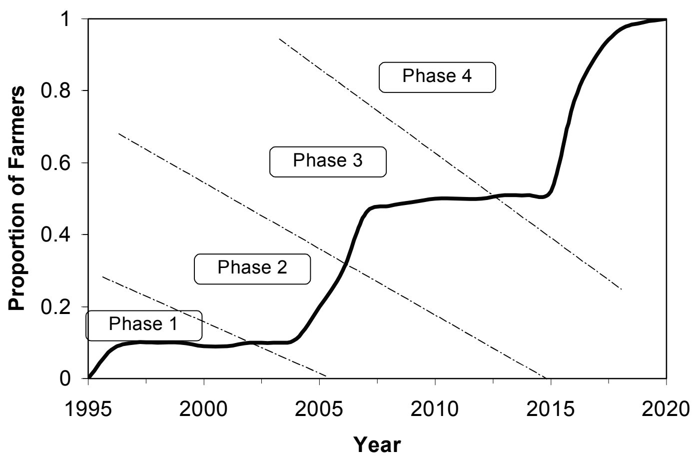
Year introduced	Technology	Years to reach 25% of population
1873	Household electricity	46
1875	Telephone	35
1885	Automobile	55
1903	Airplane	54
1906	Radio	22
1925	Television	26
1952	VCR	34
1953	Microwave oven	30
1975	Personal Computer	15
1983	Cellular phone	13

Table 3 Number of new combine harvesters sold that were equipped with yield monitoring and GPS.

Year	Yield Monitor	GPS
92	50	
93	300	
94	1,200	600
95	4,400	2,200
96	10,000	5,000
97*	17,000	9,500

* Indicates Canada included in figures

Figure 1 Adoption curve for precision farming with four phases of development suggested.



Phase 1 Technology (System Hardware) capable of delivering goals.
Phase 2 Development of decision support tools to assist management decision making, both agronomic and economic.
Phase 3 Marketing advanatage from providing traceability along with targetted chemical inputs.
Phase 4 Marketing requirement to provide traceability and minimise use of chemical inputs.

1. Global positioning systems (GPS) offer a worldwide location system offering good accuracy at an affordable price.
2. Yield mapping systems offer the opportunity to quantify yield variations as harvest is being

completed and record this information into a useable format.

3. Geographical information systems (GIS) offer us the ability to record, organise and analyse these spatial data to produce application maps for fertiliser and chemical sprays, for example.
4. Variable rate technology (VRT) is the ability to apply differential rates of fertiliser, chemical sprays and seed over an area. This has both economic and environmental benefits.
5. Use of guidance systems to assist in more accurate placement of crop inputs.
6. Product traceability is likely to be a major driving force in terms of farmers being able to demonstrate that they have recorded exactly which products have been used on their crops when and where. This may be the factor that causes most farmers to become involved because without this information, they may not be able to sell their products.

System hardware

Technology inputs correspond to drivers 1, 2, 4 & 5. Various technological developments have allowed the measurement of spatial variation to be completed. Precision farming is not a new idea, Sawyer (1994) reports work by Bauer, dating back to 1929, where researchers looked into the possibility of spatially variable lime applications. What has made the idea work is that technology has allowed many of the demands of the user to be satisfied. Rapid steps have been taken in improving yield mapping systems from prototypes in the late eighties to commercially successful systems. The same can be said for variable rate application (VAR) of fertilisers. We know that we can adequately control inputs for any location in the field. We can also use guidance systems to make sure the driver has the vehicle in the correct position.

Differential Global Positioning Systems (DGPS)

There are a large number of articles available describing the operating principle and performance characteristics of Differential Global Positioning System (DGPS) receivers and their integration into precision farming systems. Korte (1999) completed a review of DGPS systems in Europe and New Zealand and describes in some detail the results during the harvest seasons of 1995 to 1998.

It is safe to say that the present generation of sub-meter receivers now satisfies the demand for accuracy within precision farming activities. One of the main issues concerning farmers is the cost of the differential correction signal to achieve those levels of accuracy in real time. If trends in other parts of the world are followed then these should reduce for New Zealand producers in the coming years, however at the moment they do create a significant cost barrier. Using the example considered under "Economic Performance" 40% of the total annual system cost is required to provide the correction signal.

There are three main routes to providing this differential signal:

(i) Generate your own signal through a base station.
(ii) Use a UHF transmitter, which at the moment has limited coverage of New Zealand.
(iii) Use a satellite-based system for correction signal, in New Zealand this is provided through the Optus satellite with services provided through Ommnistar and Racal.

Using a local base station requires a second GPS receiver and a radio transmitter as well as a receiver on the vehicle. The author has successfully used such a system over a range of 20 km, no experiment has been conducted to find its maximum range. Actual range depends mainly on topography of the land between the base station and mobile receiver as well as the strength of the transmitted signal. There is a higher initial cost with this option and a modest annual fee for radio transmission.

Using a UHF transmitter provided by a commercial service could be cheaper than satellite options. The main problem is that coverage is limited in New Zealand. An example is the provision in Canterbury provided by Satlink. The cost of this service is presently $3,600 per annum.

The Optus satellite over Australia would also appear to offer good potential. Correction signals from this satellite are offered by Ommnistar and Racal. The differential correction signal is generated by the satellite although the Ommnistar and Racal correction messages are structured differently. The annual cost of these systems is approximately $4,000 per annum.

Measurement and control systems

Yield measurement has been most widely adopted for cereals and other combinable crops. The main reasons for this are the large market for combine harvesters (or headers) and the relative ease of measuring the flow of grain through the machine. Kutzbach *et al.* (1996) reviewed a number of systems available which utilised three main means of measuring grain flow. Light beam, pressure pad and gamma radiation source. A number of similar techniques have been adopted for forage harvesters. Root harvesting systems have tended to be developed around a load cell, or cells, on the conveyors of the machine. These are now commercially available.

Grape harvesting systems operate on a similar principle while trailer weighing systems have also been tried and have the benefit of being useable over a range of crops.

Control systems are now being used on a number of farm implements. One of the most advanced areas is in fertiliser application. These systems are designed to assist the operator in accurate spreading. For example, spinning disc speed is monitored and should it go out of range, the driver will receive a warning. A higher level of control can be achieved when used in conjunction with the tractor's radar speed sensor. If the tractor's speed increases or decreases then the feed gates from the hopper will adjust automatically to give the correct fertiliser rate. It is the next logical step to use the same method to adjust the spread rate on the move. A fertiliser application plan is formulated according to a number of criteria. The equipment is used in conjunction with a DGPS receiver and when in a given position it recognises what application rate should be applied. The gates are adjusted through linear actuators, these move the feed gates to a position which has been calibrated to achieve the desired spread rate. Calibration is extremely important and must be completed for each product used over a range of spreading rates, this is termed "multi-point" calibration.

Achieving accurate discharge rates and spread pattern is vitally important, the next element is to make sure that the machine is in the correct position. A guidance system based on a Trimble Ag132 DGPS receiver was trialed on pasture by the author and found to be extremely beneficial in terms of getting the driver to drive at the correct spacing. A number of experiments were conducted to ascertain the level of accuracy of student drivers. Using guesswork, the spreader was within 1 m of the correct position only 27% of the time and for 40% of the time, had an error level greater than 2 m. A 16% over-application of fertiliser occurred for two main reasons; not matching swath width and not keeping swaths parallel. Using a DGPS guidance system improved performance markedly to a point where 96% of all positions measured were within 1m and 61% of recorded positions were within 0.5 m of their required position.

System software "the knowledge base"

Due to the complexity of farming systems and the large number of spatial variables present as well as the influence of temporal variation, it is proving more difficult to develop satisfactory "experts" in the form of advice to the farmer. What is clear, however is that it is waste of money to throw large amounts of fertiliser on areas of low fertility. A suggested plan is to build up this information including yield maps over a number of years. Farmers could use the yield maps to try and identify problems, these may be either soil physical in nature, or related to nutrients. They could use this information to better target sampling, as grid sampling over large areas is currently too expensive. The crop is also a monitor – observations can be made throughout the growing season. New monitoring systems are also being developed such as the Hydro N Sensor which uses the near infrared NIR reflectance value from a crop to determine fertiliser rate. This techniques has been used from remotely sensed data but the Hydro N Sensor system is equipped with sensors on the spreading tractor.

Due to the complexity of the problem, it is likely that the adoption to precision farming will not be as rapid perhaps as was initially expected. There is a great deal of scientific effort being devoted to finding "cause and effect" relationships to explain variation in yield maps. However due to the huge number of variable factors we have to ask if it would be more effective for the scientific community to develop better analysis tools for farmers to use rather try to explain variation *per se*. It is farmers who have to make the management decisions and we need improved systems to give them the appropriate information to make better decisions. We are still in the initial enthusiasm phase, we will not achieve widespread adoption until the decision support systems for farmers are improved. However greater uptake could occur through farmers who are convinced the technology will mature and realise they need time to build up a sufficient database on their property. This can be done by using yield mapping alone without the need for VRT.

Traceability is a big issue with many consumers and this may be the final lever that will persuade farmers that they need to have far greater information on what they are producing. This will be coupled with a desire from the consumer for lower pesticide and herbicide inputs that could be achievable through precision farming. Systems capable of identifying the location and growing history of a packet of produce in the supermarket are nearing commercial realisation. This may cause a major step in the adoption curve.

Economic performance

Embarking on precision farming has significant costs and the expectation should be that these will be returned through improved economic performance brought about by increased yields and improved utilisation of fertiliser and sprays. Sensitivity analysis for most crops reveal that increasing yield should still be a higher priority than savings in fertiliser alone. Blackmore (1994) reported savings in fertiliser cost of 17–22%. This would correspond to the level of saving required to break even for a 200 ha arable property investing in precision farming technology. However, increasing yield at the same input cost has a far greater financial benefit.

This technology is much less expensive in 1999 than previously and we can calculate the costs on the basis of the following estimates.

Yield meter on header	NZ$10,000
DGPS receiver	NZ$8,000
Control system for fertiliser spreader	NZ$5,000
Annual fees for correction signal *	NZ$3,600
Annual cost of software upgrades and maintenance	NZ$1,000

**Provision of UHF differential signal through Satlink, Christchurch.*

Using a simple calculation, the average cost per annum can be estimated. Assuming an 8-year write-off and an interest rate of 10%, the average annual operating cost for the extra equipment would be $5,169 without the correction signal fee. The annual fee for the correction signal is a major additional cost which would bring the annual operating cost up to $8,769. Some service companies realise this is too expensive and are trying to offer the service for around $1,000. It is also possible to pay for only the months that you use the service, i.e., pay $1,800 for 6 months.

Earl *et al.* (1996) calculated the economic benefit of precision farming to be £33.68/ha (NZ$100) based on the series of assumptions stated in Table 4. Their UK scenario suggested an equipment cost of £9,480 (NZ$28,440), the net benefit calculated over 250 ha was £4,372 (NZ$12,817), or £17.09/ha (NZ$51.27). Although reductions in cereal price have taken place, there would still be a net benefit of £11.09/ha (NZ$33.27) for wheat at £80/t (NZ$240). If similar results could be achieved with higher value crops, then clearly there are tremendous potential financial benefits to be gained from using this technology.

Table 4 Assumptions made by Earl *et al.* (1996) on pricing of commodities and capital items for cost benefit analysis.

Prices	
Wheat	£100/t
Nitrogen	£0.35/kg
Subsoiling (Nix 1995)	£50/ha
DGPS License fee	£390/year
Capital Costs	
Software	£1,260
Combine kit	£6,220
Fertilser kit	£2,000
Total	£9,480

Other products such as vehicle guidance systems for fertiliser and spray applications can dramatically improve the accuracy of applying products. Farmers should get away from the idea that our present level of performance in applying fertilisers and sprays to crops is acceptable, it is not and should be improved regardless of whether precision or conventional farming methods are practised. Yule & Crooks (1996) estimated a financial loss due to inaccurate spreading on a UK arable rotation of two wheat crops, barley and oilseed rape. Where the spreader had a coefficient of variation in spread pattern of 15% the cost was £4.00/ha (NZ$12.00), where the coefficient of variation increased to 25% the cost was £10.00/ha (NZ$30.00). These values for spreader performance were well within the range found on UK farms.

Conclusion

Adopting these new techniques is not a take it or leave it situation. Parts of the package can be used. Indeed the first step in the process of achieving greater precision in our existing operations may be the most beneficial step to take. We should not be fooled into thinking that precision farming is the "holy grail", indeed it is only part of a much wider technical revolution in farming. We must become "a smart industry" if we are to take our farming systems to the next level.

We should not delude ourselves into believing that the present situation is good enough. It costs the same to drive a tractor up and down a paddock spreading fertiliser or spraying chemicals accurately as it does inaccurately, so why is our performance so poor? We are not utilising our present generation of farm machinery to its potential; clearly, before we adopt these new technologies we need to change attitudes as well as upgrading technical skills. Education and training are essential to make sure we improve upon the current situation.

Because product quality will become as important as quantity in determining financial success, much better control of our farming system is essential, especially in relation to the growing of a new generation of crops such as pharmaceuticals, nutraceuticals and genetically modified crops.

Better control will also need to be demonstrated to satisfy an increasingly aware and weary consumer. This is especially the case in many of New Zealand's main export markets. Supermarkets are responding by requiring a much greater level of product information on the food they are retailing.

Once some these basic problems have been tackled, then we should design our own adoption timetable for precision farming. The technology is ready but as producers, are we ready to adopt it?

REFERENCES

Blackmore, S. 1994. Precision Farming: an introduction. *Outlook on agriculture 23*: 275–280.

Blackmore, S.; Larscheid, G. 1997. Strategies for managing variability. *Precision Agriculture 97: Proceedings of the European Conference on Precision Agriculture 1*: 851–859.

Earl, R.; Wheeler, P.N.; Blackmore, S.B.; Godwin, R.J. 1996. Precision farming – the management of variability. *Landwards 51*:18–23.

Korte, H. 1999. The integration of wide area network differential global positioning systems (WAN – DGPS) into yield mapping on the combine harvester. PhD thesis. University of Newcastle upon Tyne.

Kutzbach, H.D.; Wacker, P.; Reitz, P. 1996. Developments in European combine harvesters. *Agricultural engineering*. Paper No. 96A–069.

Lowenberg-DeBoer, J. 1997. Dynamics of technical change in agriculture. Missouri Crops Institute, Missouri.

McBratney, A.B.; Whelan, B.M. 1999. The 'Null Hypothesis' of precision agriculture. *Precision Farming 99: Proceedings of the European Conference on Precision Agriculture 2*: 947–957.

Meridith Corporation 1998. AgInnovator News 14 Jan 1998. Http://www.agriculture.com/subscribe/

Nix, J. 1995. Farm Management Pocketbook. UK, Wye College. 254 pp.

Sawyer, J.E. 1994. Concepts of variable rate technology with considerations for fertiliser application. *Journal of production agriculture 7*: 195–201.

Yule, I.J. 1999. AgMardt First Year Report: Canterbury Precision Farming Group: Optimising yield and profit with precision farming.

Yule, I.J.; Crooks, E. 1996. Precision Farming: the price of imperfection. A case study using fertiliser distribution. *Landwards 51*: 5–9.

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