Is agronomy being left behind by precision agriculture?

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Abstract
Precision agriculture technology provides information to help manage variation within the agricultural system. Through yield maps and other information it provides evidence of manageable variation, which could be used to push towards better control. Experience suggests that improvement has been slow, partly because our capacity to explain the information is overwhelmed by a grower's capacity to acquire it. This failure reflects poorly on conventional agronomy, which appears generally unwilling to tackle problems of such complexity and scale. We suggest that three fundamental shifts in thinking would help agronomy address this problem: First, the information could be used in a more systematic explanation of agricultural processes. Second modelling could become more realistic by using more of the field data. Third, research could move more quickly towards a site-specific participatory mode, in which variation is explained, on-farm and at full-scale, in a form that is immediately relevant to growers.

Keywords
Precision agriculture, information, spatial variability, process control

Introduction
When precision agriculture first appeared in Australia, researchers generally saw it as a method of more accurate fertiliser placement within spatially variable paddocks. To paraphrase one seasoned plant nutritionist, it was about "Squirting super out in the low patches". We now know that better targeting of fertiliser is just one of a range of potential improvements which can be bracketed under the heading 'Management of controllable variation". Together, these improvements have profound implications for the industries and the science of agronomy which serves them.

It is, however, also true that precision agriculture has created more excitement than improvement over the 8 years or so since it first appeared to Australian farmers. While sceptics, many of whom are agronomists, might conclude that this lack of outcome proves that precision agriculture has been hyped, we have come to the opposite view. After several years experience and observation of developments overseas, we now believe that the changes presaged by precision agriculture technology are actually *larger* than we originally thought, and that one of the main obstacles to adoption is the fundamental nature of change required. We believe that we misunderstood the true nature of change, its extent, and difficulties of delivering it. At the same time, both the early adopters and researchers of precision agriculture have come to realise that effective adoption is an incremental process which needs to develop over a number of seasons of production.

Paradoxically, it appears that one of the last things to change within Australian agricultural industries is the scientific research base. This is not unique to Australia. By 1994, farmers and commercial providers in the U.S. had already complained to the first international workshop on precision agriculture that research was lagging behind them. Given the intensity of effort there, research proceeded regardless, often supported by commercial interests until it reached the phase of mainstream adoption. We have no such luxury in Australia, and have to back winners more carefully. But to back a winner you first need to know what to look for. Our purpose here is to help determine what the demands for agronomic research might look like so that those charged with supporting agricultural advancement can be more certain of facilitating progress.

In this paper, we shall not describe the technology or general methods of adoption - details can be found elsewhere (3, 9). Instead we focus on the changes the technology enables and the nature of agronomic research it demands. These are examined under three broad headings:

1. The realisation of spatial variation which new information technology brings to agriculture;
2. The implications of these changes for agronomic research; and
3. The constraints to changes in research.

While we concentrate mainly on broad-acre cropping, with which we have most experience, many of the changes apply equally to viticulture, intensive cropping and forestry (Figure 1.).

1 Realisation of spatial variation

The first thing that we generated when we started yield mapping in the early 1990's in the Western Australian wheatbelt was confusion. Exciting as these maps seemed to us, they were of little value to the farmer. Far from explaining variation in crop yield, the maps seemed merely to indicate how little we knew, although they did quantify and illustrate within-paddock variation in productivity (Figure 1), much of which had hitherto gone undetected. Each new map spawned a plethora of new questions we were unable to answer – at least in the normal 'scientific' way. Specialists we consulted could explain small patches, but little of the whole.

The following season things proved no better. We had more data, more maps, yet more questions, because the patterns of variation in the second year - driven as it was by our strongly Mediterranean climate – often bore only a passing resemblance to the pattern in the previous season. (In contrast, current research in viticulture suggests that this is not a ubiquitous problem with the perennial nature of grapevines contributing to some constancy in the patterns of within-vineyard variation).

We were somewhat perplexed about this confusion and so (to a lesser degree) were the farmers. We knew that precision agriculture research in the U.S. was already heading quickly towards the concept of 'prescription farming', in which tried-and-tested models of fertiliser response could provide detailed fertilizer recommendations from intensive soil sampling. Our observations did not encourage us to think that this approach would work. Not only was the cost of soil sampling prohibitive, but the analytical results proved incapable of predicting variation in crop response to fertiliser (4). What had happened was that the detailed observations of crop yield (and later observations of sugarcane yield, grape yield and grain quality) provided a mass of information which neither us or the growers could interpret with any certainty.

Spatial information, uncertainty and entropy

What we now realise is that we had opened a Pandora's box of uncertainty. The maps did not provide information in the theoretical sense (12), but merely data illustrating variation that we could not explain. Information, as we belatedly realised, can actually increase uncertainty if it merely emphasises the apparent disorder, or entropy. The relationship between the three related attributes of uncertainty, information and entropy has been illustrated neatly as a metaphor of three walls (7):

In the first image we see a blank wall. It presents minimal information, low entropy. It tells us nothing. The uncertainty is not realised. In the second we see the wall covered by a mess of graffiti. It presents more information but is of high entropy. It explains no more than the blank wall. Uncertainty, now realised, remains high. In the third we see a mural. The information content is high, but the variation is in the 'right place' so entropy is low, uncertainty reduced. We would say the system has been organised to advantage using knowledge.

The situation we were in after our early yield mapping was like the grafittied wall. We had information but could not order it. The challenge facing the 'new agronomist' is to help us understand the information. This will enable growers to use information to manage the agricultural system in a way which matches the underlying variation; the optimum order will have minimum entropy and maximum information. However, some seem to want to move from the second wall back to the first, apparently to pretend that the variation does not exist. We do not see this as a viable long-term option.

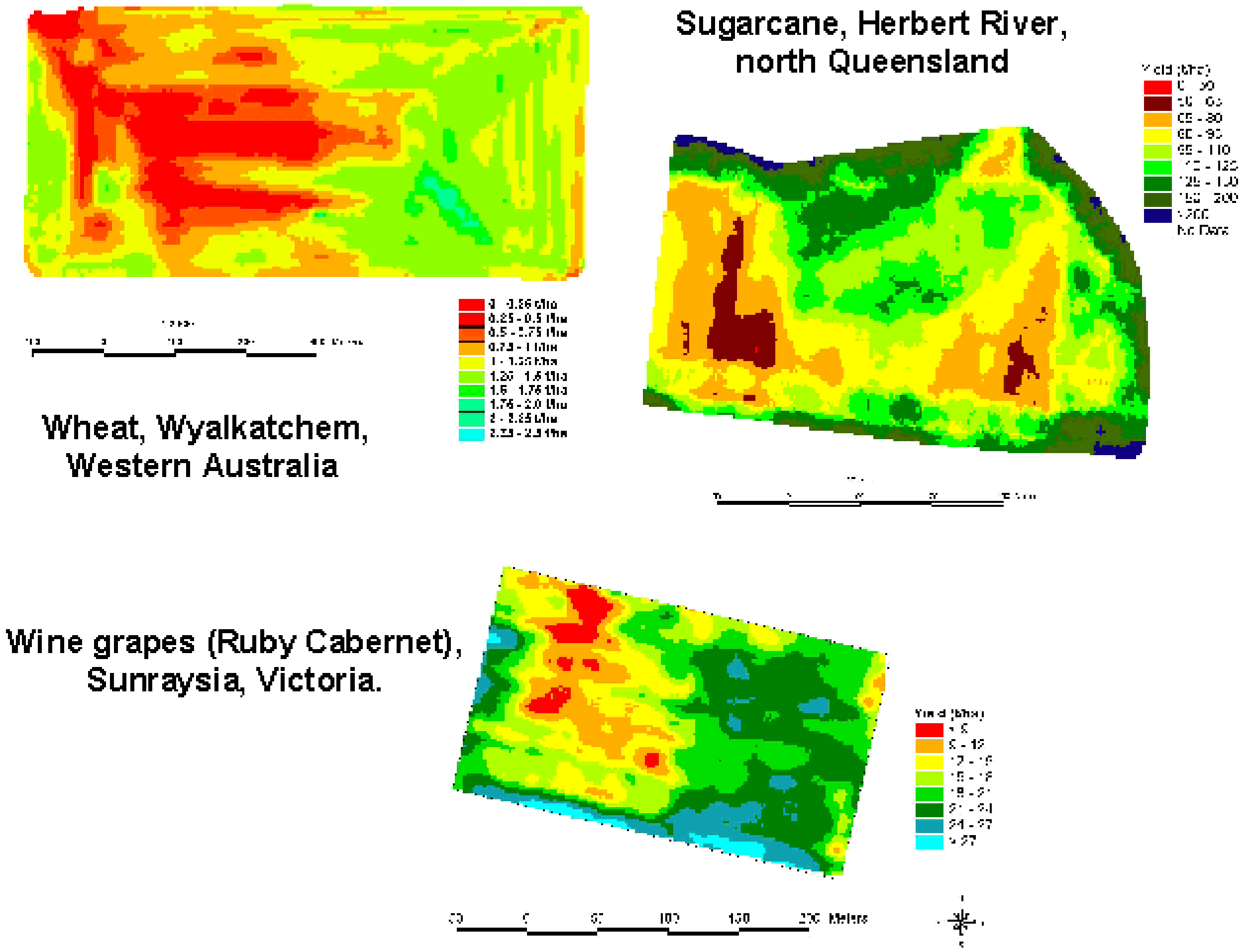

Figure 1. **Paddock-scale yield variation in a range of Australian crops**

Modelling spatial information

The importance of explaining spatial variation should become immediately obvious. Without explanation, the yield maps simply presented unstructured data which result in information overload - a serious problem for decision makers which we shall allude to later. The challenge is to determine how to use the new information with respect to decisions growers make. In other words, how to model the data in a way which is efficient, relevant and accurate to specific decisions.

After several years of analysing and modelling this data, and listening to the way growers in the grains, wine and sugar industries wish to use it, we believe that some of the assumptions underpinning the approach to understanding variation are misplaced. Whilst we have had some success in explaining variation through models (1), the agronomic reasoning within them is often quite rudimentary. Where the richness of agronomic reasoning improves, such as in the SPLAT model, predictive capacity may actually decline (1), so that it seems that fundamental changes are required in the way we model the agricultural system. New lessons are required in the way we understand variation and present it to growers. These lessons can be broadly described as a need to develop approaches that are more systematic, realistic, and specific.

Need to be more Systematic

Give a researcher a yield map on which to develop ideas and the most likely course of action is focus upon a specific theme with which they are familiar, such as soil water availability, protein variability or nutrition, at the expense of describing the paddock as a whole. While this approach eases tractability of the research problem, the insight which results tends to be piecemeal and hence difficult for the grower to apply because the decisions the grower must take need to address the *integrated effect* of factors within the paddock. We would claim the simplest representation of these are probably within the system output itself, that is, the yield map. The piecemeal approach misses the major opportunity presented by the information, namely that it describes the whole system at field scale, and invites the exploration of *systematic* approaches to process control, not seen in agriculture but used extensively in other industries.

Need to be more realistic

The main lesson we learnt from our early attempts to interpret yield maps was that models tend to either be too simplistic or general to address the questions being asked. Although they could identify specific features over parts of maps - an area of droughty soil, for example – simplistic models, based on generally accepted understanding of mechanism often explained too little of the total yield variation to be useful.

It is possible, in theory at least, to improve the realism of models by adding more and more components to reflect the complexity of biological systems. But while such an approach might improve the realism of models, this is contrary to the desirable principle of parsimony (8) and may simply deliver models that cannot be parameterised in the field. Furthermore, a model which focuses too strongly on an elegant scientific solution may be irrelevant to growers because it describes too little of the uncertainty surrounding their decisions (1, 11), in which case they may simply lose confidence in its ability to provide the right information.

Our feeling is that the sensible approach to this problem is to model what is achievable, in a way that refines, rather than replaces the grower's decision-making processes. This often means rejecting 'harder' analytical models that tackle metrical uncertainty in favour of methods, possibly qualitative or intuitive, which address other types of uncertainty (11). Thus, while prognosis may seem reasonable where the model is already a part of thinking, simple diagnosis from prior yield maps can be more effective as a means of exploring limitations to production.

Need to be more specific

The assertion that information needs to be specific to be of value to the decision-maker seems obvious. Yet scientific research, by and large, aims to develop statements which are *generally* true in the expectation that they can also be applied to specific situations later. Decision-makers, by and large, prefer pragmatic statements, which are robust and *specific,* to statements which are generally true but inappropriate to a given situation. This paradox has been noted elsewhere (13) and can be illustrated by the K-response trial we report elsewhere (4). In this case, the generally true statement that 'low K soils respond to K fertiliser' was not useful for detailed advice, because in practice, the assumptions behind this statement (eg. 'other factors not limiting') were violated; yield maps such as those shown in Figure 1 tell us that, to some degree, they always will be. In this case, a more useful inference would have been 'Where sites are of high yield potential *and* low K supply". This principle has been adopted by the Achiever method (6).

Of course, the most desirable position is to be able to make statements that are true in both the general and specific senses. We see two ways of achieving this: One is to condition the general statement to fit the case in question, ie. 'tune' the advice to local conditions using additional information such as a soil map. This can be difficult if the right information is not available. The other strategy is to clarify the specific, but 'unscientific' statement by enabling local objective analysis, perhaps by way of a whole paddock experiment (2). We see this as a more exciting prospect and explain the possibilities below.

2 implications of change for agronomic research

Implications of becoming more systematic

Yield maps, remotely sensed imagery and other directly monitored data provide indicators of performance of the production system. These data indicate the outputs of the growing system, and integrates the factors that control it. It could be included directly in diagnostic models to advise managers how the system is performing. With additional information, analysis could identify the response to controlled or uncontrolled variations of input. Research methods then need to provide structure to the information, to separate variation due to respective sources of control, and sensitivities to management or external forces.

The move towards process control philosophy would take agronomy towards the discipline of system engineering. It would acquire the objectives of describing how controllable inputs can be varied to achieve maximum response, minimum variation of product quality, or minimum loss (environmental damage). Examples could include:

- More precise budgeting of fertiliser, based on analysis of responses, uptake efficiency and expected leaching risk.
- Improved scheduling of harvest, based on variations of predicted yield and quality within blocks; this is a primary aim of precision viticulture but is equally applicable to broad acre grains systems with specific protein targets.
- Improved targeting of new germplasm, by quantifying the performance of new lines within entire regions.
- Improved monitoring of land use options within catchments by combining information about profitability with modelled estimates of water use.

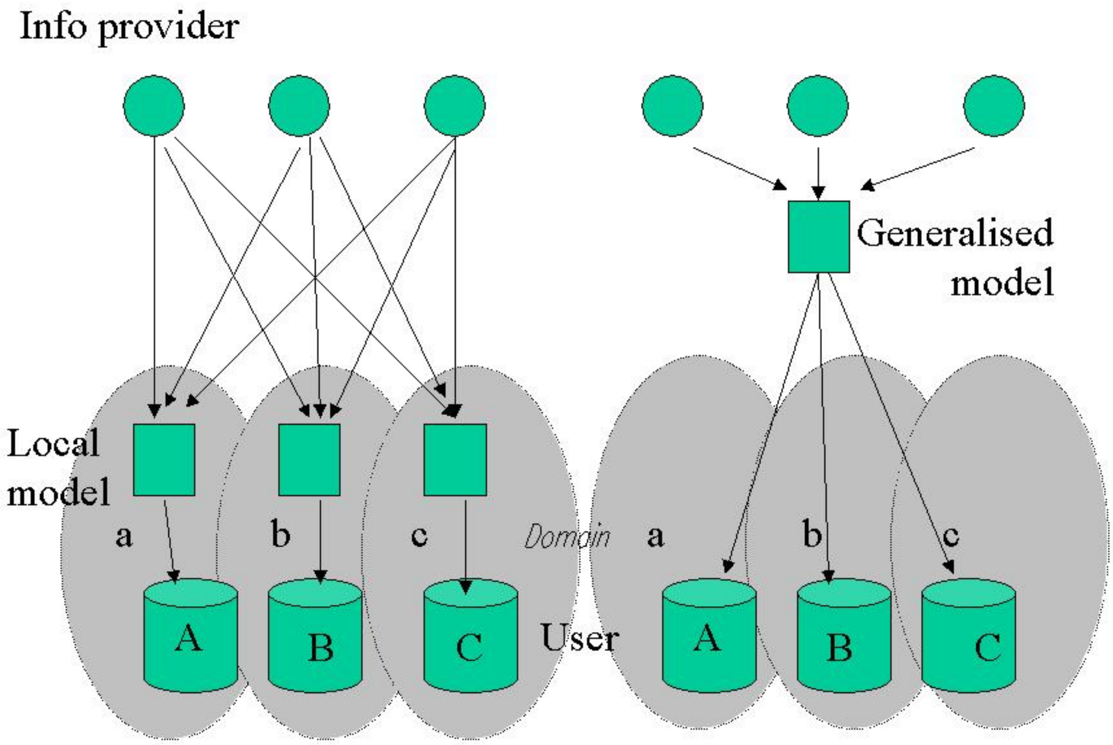

Figure 2 Shift of information flow. In the local model, interpretation occurs *within* the local domain and is site specific. The conventional (generalised) method interprets outside the local domain

Implications of becoming more realistic

The need for more realism can be addressed by describing a wider range of sources of uncertainty surrounding crop management decisions. This might occur by starting with the data provided in yield maps, imagery or product quality assays, rather than the idealised data from trial plots. Analysis could proceed from the data as a step-wise process of interrogation and refinement, learning as it goes. The yield data is interrogated to ascertain the accuracy of the model, and the model is refined in ways that are intuitively sound.

The conventional models would, where applicable, provide a valuable base model, against which actual observation of yield variation could be compared, and re-run using progressively more complex models to reflect features perceived to be important. Ultimately, we would expect models to be strongly data-driven because the field data of yield variation is ultimately likely to dominate the model parameters, if not the structure. An important feature of this process is that to address other aspects of risk, it should occur within the domain of the decision-makers. This, of course, demands further changes in the way research interacts with growers and their advisers, which we refer to below. The role of the research provider then expands towards an organisational role, trying to ascertain patterns and cross-validation between individual data-driven models (models of models) that are consistent with an emerging 'scientific' understanding of the system.

Implications of becoming more specific

Perhaps the most exciting feature of precision agriculture is that it dramatically expands the flow of information at the *point of production* and thereby expands the power to advise there. This change of information flow (Figure 2) has profound consequences for both the nature of research advice and the way it is generated because it releases the need for general solutions and favours interpretations which are specific to the local domain in which they are used.

Solutions generated 'on-site' have two main advantages over general (abstract) ones. The obvious advantage is that the solution is more likely to be correct for the site modelled, given measured or inferred variation. The second is that it is possible to include local experience in the solution, thereby addressing more of the uncertainty which confronts growers. Various methods exist to do this, either by using expert knowledge to develop the model or the data that is put into it (5).

This change draws agronomy closer towards the goal of participatory research which acknowledges, belatedly perhaps, that people who actually manage the land on a day-to-day basis have a lot to contribute to the formal understanding of the production systems.

3 What are the constraints to change in research approaches?

The changes we describe above face substantial challenges in terms of inertia and ignorance: inertia because a move away from tried-and-tested experimental methods is always difficult, especially if it involves complex technologies; ignorance in that until we explore the options, it is impossible to determine what is required to enable new methods to work.

The move towards a systematic approach to analysis imposes serious demands on the models it intends to use. The quantity of data available for individual paddocks may have increased by orders of magnitude, but most of the addition information seems merely to reveal the inadequacy of the original models. Consequently, there remains substantial uncertainty in the solutions provided and for this we require models appropriate to the conditions in which they are being applied. While a range of models exists (1), experience with them is limited so it is difficult to recommend 'standard' approaches. Surprisingly, we still find widespread indifference to this modelling challenge. In the absence of effective methods of interpretation, the potential user is faced with a mass of unstructured information which results in the serious problem of information overload (10).

The tracking of complexity faces a similar struggle. While it is enticing to endlessly model the rich data offered by yield maps or other spatial data, without an underlying agronomic understanding such models can quickly grow into complex monsters which bear, at best, a tenuous relationship to the system *as known* by growers and their advisers. Such models are unlikely to be used in practice. Skill and experience are needed to orientate the spatial modelling effort in a way which leads agronomy forward in ways which are congruent with current understanding. But, with some notable exceptions, we have noted a reluctance on the part of district agronomists and consultants to become involved and equip themselves with the skills that allow them to service this new agronomy.

Finally, there are difficulties of delivering site-specific solutions. If the major benefit of specific interpretation is accuracy and relevance, the major cost is the need for direct delivery to growers. Agricultural research traditionally overcame this problem by broadcasting general truths in ways which were appropriate to the demography of agriculture. A move towards participative research and site-specific management calls for on- or *near*-farm analysis of data – a much more difficult service to provide.

We appear to be caught in a Catch-22 situation: Without agronomists, the modelling cannot move forward knowledgeably, and without models, agronomists have no methods with which to apply themselves to explain the new observations of variation.

Conclusions

The major benefits of precision agriculture will not come about through fine-tuning of existing research insight, but through the development of new insights which enable growers and other stakeholders to handle detailed and realistic observations of the production system. The subject of research will not be an abstraction of the system, but the system itself. The new kind of research will explain variations within the production system in a systematic, realistic and site-specific manner. In this respect, it is a high technology, participative research process.

Precision agriculture technology has already shown itself capable of delivering the information required to enable this change. But the key to success lies in structuring the flow of information, so that it assists, rather than distracts, sound decision-making. After several years in this research area, we perceive this opportunity for whole-scale change is being largely ignored. The imperative for change is evident– after several years of effort, our main competitors have already advanced precision agriculture into their mainstream activity. But because the changes require a major shift and re-focussing of research thinking, persuasive arguments will be required to encourage more agronomists here to embrace the technology and learn how to use it.

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References

1. Adams,, M.L., Cook, S.E. and Corner, R.J. 2000. *Precision Agriculture.* **2:** 39-54.

2. Bramley, R.G.V., Cook, S.E., Adams, M.L. and Corner, R.J. 1999. Designing your own on-farm experiments: How precision agriculture can help. *GRDC*, Canberra.
3. Cook, S.E., and Bramley, R.G.V. 1999 A*ust. J. Exp. Agric.* **38**, 963-971.
4. Cook, S.E. and Bramley, R.G.V. 2000. *Comm. Soil Sci. Plant Anal.* **31** 1531-1551.
5. Corner, R.J.and Moore G. 1998. Expector Soil Mapping Method. *CSIRO*.
6. Corner, R.J. Achiever Software. *CSIRO*.
7. Liquid Information 2000. URL: http://www.liquid.org/hist_inf.html
8. McBratney, A.B. Whelan, B.M. and Shatar, T.M. 1997. Precision Agriculture: Spatial and Temporal Variability of Environmental Quality. *John Wiley*.
9. National Research Council 1997. Precision Agriculture in the 21st Century Geospatial and information technologies in crop management. *National Academic Press. Washington.*
10. Openheim, C. 1997. *Int. J. Information Management* **17**: 239-248.
11. Rowe, W.D. 1994. *Risk Analysis.* **14**: 743-750.
12. Shannon, C.E. 1948. *Bell System Tech. J.* **27**: 379-426. URL: http://cm.bell-labs.com/cm/ms/what/shannonday/paper.html
13. Stephanou, H.E. and Sage, A.P. 1987. *IEEE Trans. Systems, Man and Cybernetics.* **SMC-17**: 780-798.