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Madeleine Florin
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Abstract

Precision Agriculture (PA) strives towards holistic production and environmental management. A fundamental research challenge is the continuous expansion of ideas about how PA can contribute to sustainable agriculture. Some associated pragmatic research challenges include quantification of spatio-temporal variation of crop yield; crop growth simulation modelling within a PA context and; evaluating long-term financial and environmental outcomes from site-specific crop management (SSCM).

In Chapter 1 literature about managing whole farms with a mind towards sustainability was reviewed. Alternative agricultural systems and concepts including systems thinking, agro-ecology, mosaic farming and PA were investigated. With respect to environmental outcomes it was found that PA research is relatively immature. There is scope to thoroughly evaluate PA from a long-term, whole-farm environmental and financial perspective. Comparatively, the emphasis of PA research on managing spatial variability offers promising and innovative ways forward, particularly in terms of designing new farming systems. It was found that using crop growth simulation modelling in a PA context is potentially very useful. Modelling high-resolution spatial and temporal variability with current simulation models poses a number of immediate research issues.

This research focused on three whole farms located in Australia that grow predominantly grains without irrigation. These study sites represent three important grain growing regions within Australia. These are northern NSW, north-east Victoria and South Australia. Note-worthy environmental and climatic differences between these regions such as rainfall timing, soil type and topographic features were outlined in Chapter 2.

When considering adoption of SSCM, it is essential to understand the impact of temporal variation on the potential value of managing spatial variation. Quantifying spatio-temporal variation of crop yield serves this purpose; however, this is a conceptually and practically challenging undertaking. A small number of previous studies have found that the magnitude of temporal variation far exceeds that of spatial variation. Chapter 3 of this thesis dealt with existing and new approaches quantifying the relationship between spatial and temporal variability in crop yield. It was found that using pseudo cross variography to obtain spatial and temporal variation ‘equivalents’ is a promising approach to quantitatively comparing spatial and temporal variation. The results from this research indicate that more data in the temporal dimension is required to enable thorough analysis using this approach. This is particularly relevant when questioning the suitability of SSCM.

Crop growth simulation modelling offers PA a number of benefits such as the ability to simulate a considerable volume of data in the temporal dimension. A dominant challenge recognised within the PA/modelling literature is the mismatch between the spatial resolution of point-based model output (and therefore input) and the spatial resolution of information demanded by PA. This culminates into questions about the conceptual model underpinning the simulation model and the practicality of using point-based models to simulate spatial variability.
The ability of point-based models to simulate appropriate spatial and temporal variability of crop yield and the importance of soil available water capacity (AWC) for these simulations were investigated in Chapter 4. The results indicated that simulated spatial variation is low compared to some previously reported spatial variability of real yield data for some climate years. It was found that the structure of spatial yield variation was directly related to the structure of the AWC and interactions between AWC and climate. It is apparent that varying AWC spatially is a reasonable starting point for modelling spatial variation of crop yield. A trade-off between capturing adequate spatio-temporal variation of crop yield and the inclusion of realistically obtainable model inputs is identified.

A number of practical solutions to model parameterisation for PA purposes are identified in the literature. A popular approach is to minimise the number of simulations required. Another approach that enables modelling at every desired point across a study area involves taking advantage of high-resolution yield information from a number of years to estimate site-specific soil properties with the inverse use of a crop growth simulation model. Inverse meta-modelling was undertaken in Chapter 5 to estimate AWC on 10-metre grids across each of the study farms. This proved to be an efficient approach to obtaining high-resolution AWC information at the spatial extent of whole farms. The AWC estimates proved useful for yield prediction using simple linear regression as opposed to application within a complex crop growth simulation model.

The ability of point-based models to simulate spatial variation was re-visited in Chapter 6 with respect to the exclusion of lateral water movement. The addition of a topographic component into the simple point-based yield prediction models substantially improved yield predictions. The value of these additions was interpreted using coefficients of determination and comparing variograms for each of the yield prediction components. A result consistent with the preceding chapter is the importance of further validating the yield prediction models with further yield data when it becomes available.

Finally, some whole-farm management scenarios using SSCM were synthesised in Chapter 7. A framework that enables evaluation of the long-term (50 years) farm outcomes soil carbon sequestration, nitrogen leaching and crop yield was established. The suitability of SSCM across whole-farms over the long term was investigated and it was found that the suitability of SSCM is confined to certain fields. This analysis also enabled identification of parts of the farms that are the least financially and environmentally viable. SSCM in conjunction with other PA management strategies is identified as a promising approach to long-term and whole-farm integrated management.
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A general introduction

Continuing and future research into Precision Agriculture (PA) will impart on PA the status of a viable entity within society on a variety of different levels. An individual field, a whole farm, the agriculture industry, a research institute and the natural resource management industry are some of the places where PA is important. With this in mind a very general research issue for PA is continuous broadening of conceptions about what PA has the potential to do or where in society PA can exert influence.

PA can be approached as a philosophy or a concept that realises aspirations towards holistic production and environmental management. PA utilises advances in information technology with the potential to make agricultural production both economically and environmentally more efficient (National Research Council, 1997). This approach to PA enables scope for new and exciting contributions to many realms of society. Considering this scope, a serious premise for this research is that there is a necessity for diversity in research foci about PA.

Beyond this perspective of defining PA, some more focussed critical research issues exist. Various avenues for further research have been identified. For example, McBratney et al. (2005) suggested six critical issues for PA. Recognising and understanding temporal variation, movement towards a whole-farm focus and accounting for environmental outcomes are included in this list. Considering these three challenges further, allows identification of some subject-specific research opportunities.

Site-specific crop management (SSCM) is the subject of significant amounts of research. SSCM is an application of the idea that spatial variation in soil and crop factors can be managed. It is known that managing spatial variation is not a static activity. Consequently, temporal variation requires due consideration. Some research has addressed spatial and temporal crop variation at the same time. There have been a number of examples of research assessing the stability of yield patterns. A consistent result has been apparent instability across years (e.g. Bakhsh et al., 2000; Jaynes and Colvin, 1997). Most studies have had between three and six years of yield data available. It has repeatedly been reported that this volume of data is inadequate to properly assess spatial variability. A relatively small amount of literature has directly commented on the value of managing spatial variation in the light of temporal variation. Some examples are McBratney and Whelan (1999), Eghball and Varvel (1997) and Scherpers et al., (2004). The consensus from these publications is that temporal variation of crop yields is large. It is also clear that more research is required to enable quantitative understanding about spatio-temporal variation. This would provide particularly useful knowledge for assessing the value and furthering the scope of SSCM.

There is a substantial amount of research about whole-farm management that is not PA focused. Some of this research can be attributed to relationships between sustainability discussions, systems approaches to research/management and alternative agriculture systems. Something that is clear and consistent amongst most sustainability discussion is
a call for design and implementation of alternative agriculture systems. This challenge
has provided the impetus to reject a reductionist outlook and instead embrace a systems
approach. An overarching necessity perceived in all systems approaches is the integration
of knowledge from different disciplines in order to realise some well defined objectives
(Ison et al., 1997). Whole-farm planning, defined as the necessity to consider total assets
of a farm (soil, water, trees, stock, wildlife, etc.) in order to make best use of them
(Garrett, 1993) provides some examples of alternative agriculture systems. Mosaic
farming is one example of whole-farm planning. Mosaic farming provides a vision of a
land use system that is made up of patches of annual crops, pastures and perennial crops.
These three elements are matched to soil and landscape attributes in space to maximise
environmental and economic benefits (Brennan et al., 2004). Motivation behind mosaic
farming is the idea that diversity is a necessary aspect of a farm or landscape. Discussions
along these lines suggest that agro-ecosystem stability increases when land use diversity
increases (Carter, 2001).

There are a relatively small number of studies about PA that are applied to a whole-farm.
Stoorvogel et al., (2004) demonstrate a role for aspects of PA within an approach to
agricultural research that integrates whole production systems. Four research steps are
illustrated with an example on a Costa Rican banana plantation. They found that for the
whole farm site-specific fertilisation was deemed favourable over uniform applications
by the farmer while this was not the case for nematocide application. Johnson et al.,
(2004) undertook to link microbial scale findings to a farm-scale. They found that
electrical conductivity mapping delineated significant differences for some measured
biological parameters (microbial biomass C, microbial biomass N and potentially
mineralisable N). These results were discussed in the context of potentially monitoring
ecological and economic outcomes and agroecosystem trends. van Alphen and
Stoorvogel, (2002) looked at the effect of pesticide leaching at the farm level in the
Netherlands. An interesting finding was that precision management for pesticide leaching
risk using threshold values is different depending on the scale of assessment (sub-field,
field or farm). These studies are few, however, the outcomes from this work suggests it is
a valid undertaking.

This lack of substantial intersection between PA research and whole-farm approaches to
farm management implies that the research challenges are many. Some opportunities are
enhancement of current whole-farm planning approaches with a PA input. There is also
scope to apply current embodiments of PA across whole-farms. Prioritisation of parts of a
farm for SSCM is one potential benefit. Additionally, research about whole farms would
make the scale of physical research consistent with social and economic analysis
improving the point from which to quantify benefits from PA.

PA research with environmental considerations exist. Studies considering nitrogen (N)
management from a waste and hence water quality perspective have been particularly
popular. This is consistent with such a conclusion that the primary environmental benefit
from PA is the reduction in waste by better targeting inputs (Bongiovanni and
Lowenberg-Deboer, 2004). A number of studies have demonstrated that variable rate N
management can result in a reduction of excess N leaving a field as pollution (Eg. Wang
et al., 2003; Thrikawala et al., 1999 and; Roberts et al., 2001). Another application of this type of study has been potentially contributing to the derivation of harmonious environmental regulation and management (Bouma, et al., 2002). A research issue identified from these studies is how to measure N loss. Direct measurements, indicators and simulation modelling have all been attempted and there are opportunities for further development of these.

There is considerable scope to account for any number of environmental outcomes beyond N pollution. This assertion is well aligned with the prior mentioned whole-farm planning concept where a number of management goals are considered simultaneously. In terms of measuring environmental outcomes, simulation modelling has the potential to be a useful PA tool. This is because a valid model can provide output for a number of outcomes at the same time while different management scenarios can be tested with relative ease across time. This temporal extent also lends itself to the research challenge of understanding temporal variability.

Some PA studies are already utilising simulation models as tools (eg. Thorp et al., 2005). Notably, there is also a vein of research focused on the challenge of validating and adapting models for PA purposes. Given that the majority of crop growth simulation models are point-based, capturing yield variation at a spatial resolution that is relevant to PA is an issue. Another issue that using point-based models poses is capturing spatial processes impacting yield variability.

Broadly, three different approaches to obtaining a representative number of simulations across an area of interest have been documented in the literature. The most common approach is to divide the field (or farm) of interest into ‘homogeneous’ units and model representative soil profiles for each of these units (Eg. Booltink et al., 2001). Another approach is to model a number of soil profiles and interpolate model outcomes across the remainder of the study area (Eg. van Alphen and Stoorvogel, 2002). A third approach is to run the simulation model at every point across a grid that encapsulates the desired spatial resolution. Link et al., (2006) documented such on a single field divided into 30 grid cells (each cell measuring 15m X 27.5m or 22.5m X 27.5m). Modelling across a grid is an appealing approach as high resolution model output is produced. However, this process is the most information and computer power intensive of the different approaches. For example to simulate yield information at a resolution similar to yield monitor data (10m X 10m grid) across a typical Australian field, the number of points would be in the order of thousands.

An attempt to deal with a lack of spatial processes encapsulated in a point-based model has been to develop spatially coupled water balance models. Ferreya et al., (2006) compared limitations to yield predictions for both a coupled and an uncoupled model. They found that data requirements for the coupled model is more intense and as a result undermines the improved yield prediction potential.

These areas of research demonstrate that there is scope to continue development of simulation modelling that is specifically suited to PA. The capacity to acquire enough
information for model population at the required spatial resolution is one challenge. It follows that simulating crop growth at such resolutions is definitely at the high end of computer capacity. It is equally important that these simulations capture the spatial processes impacting yield variation. This implies further development of the ‘best’ conceptual model is required.

Some future directions for PA research are quantification of spatio-temporal yield variation with explicit reference to the value of SSCM; whole-farm studies that integrate PA information into systems approaches to farm management with an environmental focus and; studies that enhance the suitability of simulation modelling for spatial and temporal variability relevant to PA. This thesis will address quantification and understanding of spatio-temporal crop yield variation, modelling crop yield variation and the management benefits of this for whole-farms.
References:


Conference on Precision Agriculture" (G. Grenier and S. Blackmore, eds.), pp. 545-550. agro Montpellier, Montpellier.


Research aims

This thesis involves four broad research aims to improve understanding about the management value of Precision agriculture (PA) at a farm level using simulation modelling and spatially dense soil and crop information. Within some of these aims, a number of practical subsidiary aims are outlined:

1. To review the literature in order to understand how whole farms are managed for economic and environmental goals; how simulation modelling impacts management decisions and; how PA impacts management decisions.

2. To quantify spatial crop yield variability, temporal crop yield variability and the spatio-temporal relationship using real yield data.

3. To model crop yield variability across farms at a resolution useful for PA.
   3.1 To quantitatively evaluate the potential of the Agricultural Production Systems Simulator (APSIM) to predict realistic amounts of spatial and temporal yield variation.
   3.2 To identify the importance of soil available water capacity (AWC) as an input into APSIM.
   3.3 To use APSIM to inversely model hydraulic properties onto a ten metre grid across farms.
   3.4 To validate the inversely modelled hydraulic properties for model population to predict yield across farms.
   3.5 To incorporate a spatial component into APSIM yield predictions using terrain attributes derived from a DEM.

4. To apply long-term modelling scenarios across some farms and consider management benefits from a whole-farm planning perspective.
   - To discuss the role of SSCM across whole farms for management of multiple environmental outcomes such as yield, soil carbon and nitrogen leaching.