Precision agriculture and whole-farm planning for sustainability

Summary
This project involves a PhD study of precision agriculture (PA) and whole-farm planning for sustainability using crop growth simulation modelling and high resolution soil and crop information.

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Conclusions
Certainly, using PA or site-specific crop management (SSCM) to manage whole farms requires a comprehensive understanding of spatio-temporal crop yield variability. Consideration of outcomes beyond crop yield is also valuable. The work presented in this report demonstrates that combining crop growth simulation modelling with spatially dense soil and crop information is a way forward.

With regards to spatio-temporal variation of crop yield, conclusions of the research include:
- The magnitude of temporal variation of crop yield is often large relative to spatial variation.
- Considering ‘space-time variation equivalents’ is a useful conceptual approach for comparing spatial variation with temporal variation. This is also a useful contribution for the determination of how spatio-temporal crop yield variation impacts suitability for SSCM.

With regards to crop growth simulation modelling and PA, conclusions of the research include:
- If landscape conditions are such that lateral flow of water is occurring within a system, valid predictions about spatial variability of crop yield using point-based crop growth simulation models are not possible without consideration of spatial hydraulic processes.
- Simplifications of current crop growth simulation models to include a few essential processes that impact crop yield variation proved better than using a current (complex) crop growth simulation model.
- Inverse meta-modelling is a useful strategy to overcome the practical modelling challenge of efficiently obtaining spatially dense soil information to populate models.
- Spatially dense and temporally vast data resulting from successful simulation modelling is extremely useful for quantification of spatio-temporal crop yield variation and evaluation of SSCM.

With regard to whole-farm planning, conclusions include:
- Simultaneous consideration of multiple farm outcomes, such as crop yield, soil carbon and nitrogen leaching, enhances understanding about management outcomes.
- Over the long term, from an environmental and a financial perspective, the value of SSCM across whole farms is highly field-specific.
- Spatially dense and temporally vast data about environmental and production performance potential is extremely useful for alternative land-use design.

Recommendations
Recommendations stemming from this work are related to future work because the possibilities are plentiful. This is an exciting prospect for researchers involved with PA, spatial data analysis and crop growth simulation modelling. Some specific research issues that the PhD thesis has brought to light are outlined below.

First, there is scope to continue developing approaches for quantification of spatio-temporal variation. Impetus for continuing this research is multi-faceted. There is the conceptual challenge of how to comprehend comparisons between a spatial dimension and a temporal dimension. There is the methodological challenge of how to physically make such comparisons. There is the practical challenge of requiring this type of analysis to optimise the application of SSCM.
Second, striving towards a modelling framework that is useful for PA highlights a number of avenues for research. The basis for much of the necessary future work is ensuring that scientists involved with crop growth simulation modelling are asking rigorous questions about the numerous hypotheses that crop growth simulation models are based upon rather than continuing to tweak parameters for calibration and validation.

From a PA perspective, there is scope to challenge the conceptual basis of crop growth simulation models in terms of the scale of applicability. More specifically, to examine and identify processes included within models that might not physically be able to capture spatial variation at a within-field scale. It is important to ascertain which processes within current crop growth simulation models, such as the Agricultural Production Systems Simulator (APSIM), are not designed for the scale of application required for PA, such as modelling spatial variation within heterogeneous fields.

Continuing to search for the most useful balance between complexity and simplicity of crop growth simulation models for PA is an important future research pursuit. Identifying vital processes within current models as well as considering excluded processes such as lateral water movement must be featured within this type of research. Relevant also to the simplicity or complexity of models are practical considerations about the cost (computer and human effort) of the modelling exercise in the context of PA. This is particularly pertinent for PA across farms where vast numbers of points in space require modelling. Also, emphasis on greater exchange between crop modelling skills and skills in spatial statistics is important.

A further practical research issue that requires future work is related to model inputs within the context of PA. As previously mentioned, PA across farms involves many points in space. This means that there is scope to continue the development of strategies that efficiently capture information required for modelling exercises.

**Achievements/Benefits**

The PhD thesis as a result of this project involved four broad research aims to improve understanding of the management value of 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:

- 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.
- To quantify spatial crop yield variability, temporal crop yield variability and the spatio-temporal relationship using real yield data.
- To model crop yield variability across farms at a resolution useful for PA.
- To quantitatively evaluate the potential of APSIM to predict realistic amounts of spatial and temporal yield variation.
- To identify the importance of soil available water capacity (AWC) as an input into APSIM.
- To use APSIM to inversely model hydraulic properties onto a 10-metre grid across farms.
- To validate the inversely modelled hydraulic properties for model population to predict yield across farms.
- To incorporate a spatial component into APSIM yield predictions using terrain attributes derived from a digital elevation model.
- 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.

This project was designed to address the challenge of using PA for a combination of environmental and production outcomes. Upon starting this project, the most pertinent challenge was using crop growth simulation models at a spatial resolution relevant to PA.

**Additional information**

This research has contributed to understanding of this challenge. The most significant impact is through the academic realm and this work has been communicated via a number of means:

- The PhD was completed at the University of Sydney. It has been submitted, three reviewers have read it thoroughly and suggested mostly minor emendations. The suggested changes have been made and the degree will be rewarded on May 2, 2008.
- Two papers have been submitted to the international journals – European Journal of Agronomy and Agricultural Systems.
and a paper has been drafted for the Journal of Sustainable Agriculture.

- The research has been presented at two international conferences – European Conference for Precision Agriculture in 2005 and High Resolution Digital Soil Sensing and Mapping Workshop in 2007.
- The work has been presented at Australian symposiums and conferences – Precision Agriculture Symposium in 2005 and Environmental Research Event in 2005.

