A CRITICAL EXAMINATION OF THE ROLE OF OVERSEER® IN MODELLING NITRATE LOSSES FROM ARABLE CROPS

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Abstract
Loss of nitrate from farmland to freshwater can harm the environment and diminish drinking water quality. In response to this, and the National Policy Statement for Freshwater Management (2011), regional authorities across New Zealand are developing plans to manage water quality. Many of these plans include use of OVERSEER®, a computer model originally designed to assist farmers and their advisors with on-farm nutrient use, for estimating nitrate losses from individual pastoral farms.

Given this emerging and new regulatory role for OVERSEER®, and the relatively recent addition of crop modelling to the programme, the Foundation for Arable Research (FAR) commissioned a review of the arable cropping model of OVERSEER®. The purpose of the review was to assess the strengths, weaknesses and further developments that would improve the usefulness and usability of the cropping model of OVERSEER®.

To do this FAR assembled an expert panel to review the available information regarding development and testing of the OVERSEER® crop model and compare this to other plant/soil interaction models.

The review concluded that OVERSEER® is the best tool currently available for estimating nitrate leaching losses from the root zone across the diversity and complexity of farming systems in New Zealand. More specific findings included:

- OVERSEER's® crop model has been developed using simplifications that are consistent with the approach taken in modelling pastoral systems but that contrast with other crop-soil interaction models. Whilst the crop model has been tested to a limited extent, further testing is needed to determine whether these simplifications impair its ability to predict long-term average nitrate leaching losses from arable systems.

- OVERSEER's® user interface for crops is relatively under-developed compared to the pastoral model and in need of further attention before it will be able to deal effectively with complex crop rotations.

- The application of OVERSEER® in regional authority water policy requires greater transparency regarding the scientific basis of the model and in the software development and validation processes.

- Uncertainty regarding the absolute accuracy of predictions from models like OVERSEER® means that such models are generally better able to predict relative changes than absolute values. All model users need to recognise this aspect of model application.

Introduction

Worldwide there is increasing concern about nutrient losses from agriculture. Nitrate (N) leaching in particular is a problem in many agricultural areas including many parts of Europe (Oenema *et al.*, 2003), the Mississippi Basin in the USA (Goolsby *et al.*, 2001), and even tropical agricultural areas such as the north eastern coast of Australia (Thorburn *et al.*, 2003). In response, considerable effort is being put into reducing nitrate leaching in an effort to improve surface and ground water quality in many countries. Internationally, computer models of the dynamics of N leaching are playing a crucial role in both understanding and managing the nitrate leaching problem. In New Zealand, OVERSEER® (Anon, 2013a) is one such model for use at farm scale.

In accordance with New Zealand's National Policy Statement for Freshwater Management (Anon, 2011), which came into effect on 1 July 2011, regional authorities are developing regional plans aimed at reducing agriculturally-derived nitrate and other nutrient levels in surface and ground water. The favoured approach is regulation of nutrient losses from farmland rather than capping nutrient inputs *per se*. This output-based approach has the potential to offer more flexibility for farmers to use nutrients efficiently and maintain or improve productivity than input limits. However, determining nutrient losses is more difficult than monitoring inputs. As measurement of losses is impractical at present, a modelling approach is needed and OVERSEER® is set to be the model of choice. At present, Environment Canterbury, Otago Regional Council, Environment Southland, Waikato Regional Council, and Environment Bay of Plenty specify use of OVERSEER® for recording estimated nutrient discharges from individual properties. Other regional authorities are also looking at using OVERSEER® in this way.

However, OVERSEER® was originally developed to guide nutrient management in pastoral farms and has subsequently been modified to model a wide range of farming systems, including arable cropping, and to deliver a wide range of outputs, including estimates of nutrient and greenhouse gas losses (Anon, 2013a). Its application in the context of informing water quality policy is a relatively recent development, especially in relation to cropping systems.

Given the emerging role for OVERSEER® in influencing nutrient management across farming sectors and throughout New Zealand, the relatively recent addition of crop modelling to OVERSEER®, and the limited verification of the outputs of this functionality, the Board of the Foundation for Arable Research (FAR) commissioned an expert peer review of the arable cropping model of OVERSEER®. This paper outlines the review process, summarises the development of OVERSEER® and the challenges of its use in a water quality policy context, and gives recommendations aimed at improving the model and growing confidence in its use in implementing water quality policy in New Zealand.

Peer review process

To undertake this peer review, FAR assembled an international Expert Working Group (EWG) consisting of the authors of this paper (Dunbier *et al.*, 2012). With specific reference to estimating nutrient efflux in intensive arable cropping systems, including vegetable production and dairy support, the terms of reference for the EWG were: what are the strengths and weaknesses of OVERSEER® 6 and what, if any, further developments of OVERSEER® would significantly and cost-effectively increase its usefulness and usability?

Additionally, FAR assembled a wider group of stakeholder representatives including the owners of OVERSEER® and other industry sectors to ensure a transparent and credible process was used and to facilitate dissemination and implementation of findings of the review.

Valued technical support was provided to the EWG by Mark Shepherd, Team Leader - OVERSEER® Development & Application, AgResearch and David Wheeler, OVERSEER® Development & Application, AgResearch.

Whilst this review specifically addressed functionality of the cropping model of OVERSEER®, some generic issues were also identified and these are reported here. Additionally, due to time constraints, the review focused primarily on nitrogen, although it is accepted that there are other components to water quality including phosphate, sediments and microbial contamination.

The challenge confronting OVERSEER®

The 'evolution' of OVERSEER®

OVERSEER® was originally developed on farm-gate nutrient balance principles, to guide nutrient management in pastoral farms (Anon, 2013b). The model was (and remains) driven by input of actual farm production, so there was no need to include detailed, fully mechanistic plant and animal growth and yield modelling. For loss of nutrients to the environment, this strategy, in essence, means the nutrient surplus is set by the user (as the difference between the inputs of nutrient applications and removals), and the model's role is to partition the losses to the different possible pathways (gaseous losses, runoff or leaching plus net mineralisation/immobilisation, adsorption/slow release (Anon, 2013b)).

Initially, N leaching was estimated based on N surplus, site and climate factors, including rainfall (Anon, 2013c). The model evolved from a block scale to a farm with effluent, then to a full farm model that accounted for nutrient transfers between paddocks, and between farm structures (pads, farm dairy effluent) and blocks in pastoral farms. The model's domain expanded to include arable crops and forage crops (Anon, 2013d). The cropping model was revised following the project on *Nitrogen management for environmental accountability* (Bromley and Catherwood, 2006), although a separate monthly drainage model was used to estimate N leaching. All the cropping models used a 2 year cycle, accounted for both the nutrient uptake and removal by these crops, and estimated the amount of N mineralisation following cultivation. They also focused on the N transformations within a year, not a crop rotation.

The application of OVERSEER® to arable systems

OVERSEER® has been 'given the challenge' of predicting long-term average N leaching to assess whether a wide range of New Zealand farming activities and/or management practices meet relevant water quality policies. This requires modelling of the complex processes that lead to, for example, nitrate leaching. However, OVERSEER®'s application as a farm management tool has, quite appropriately, resulted in simplifications of the processes represented (Anon, 2013a), which include:

1. Long-term average data for rainfall, and monthly figures for total irrigation applied, are used to estimate daily time-steps for rainfall and irrigation. These values in turn are used to estimate monthly aggregated drainage values.
2. Soil mineral nitrogen supply and crop N uptake is based on a monthly time step.
3. A single, 1.5m deep soil layer, is used rather than a composite of several discrete horizons.

The challenge is increased by the wide range of agricultural practices in New Zealand (dairy farming, forage cropping, arable cropping, etc.) with contrasting characteristics. Pastures are generally perennial, with ground cover year round (unless overgrazed) and an established root system, making them amenable to a simplified modelling approach i.e. as described above. However, dairy farms are complex management systems, with animals grazing different fields, gathering near milking sheds, having stand-off pads, etc. These features make nutrient budgeting complex as the animals, in effect, transfer nutrients from field to field. Thus, a nutrient balance model for dairy farming needs quite sophisticated representation of the farm management system in contrast to the potentially simple representation of the plant-soil system in pastoral systems. The complexity of nutrient balances in farming systems is recognised by Oenema *et al.* (2003) in the need for farm gate nutrient budgeting. While these simplifications in OVERSEER®'s plant-soil modelling approach have been shown to be appropriate for pastoral systems, it is less clear whether they are appropriate for other agricultural systems.

In cropping systems, nutrients are predominantly applied to a given field through fertilisers, manures, etc., and there are minimal nutrient transfers within the farm. Nutrient exports in harvested product are relatively easily quantified. Thus, soil surface nutrient budgeting approaches are appropriate for cropping systems. However, there is much greater complexity in the plant-soil component of cropping systems. Crop management can result in substantial daily variation in soil N status such as when N fertiliser is applied which may or may not support an actively growing plant, or which may or may not be irrigated immediately afterward. Different crops can have different rooting depths, and the soil can be bare during fallows.

Further complexity in arable systems comes through crop rotations and the timing of management interventions. Capturing N dynamics in these situations has generally been achieved through daily (or sub-daily) time step models. Sometimes the aim of these models has been to capture daily N dynamics and N leaching from the system. Furthermore the spatial complexity of a cropping farm can be much greater than many pastoral farms, with each paddock potentially having a unique crop rotation and management history.

Thus, the challenge for OVERSEER® is how to develop from a model focused on the relative soil-plant simplicity but management complexity of pastoral systems to one also dealing with the soil-plant complexity of arable systems. Further, the context of OVERSEER®'s application in all agricultural systems is in predicting long-term average, rather than daily N dynamics and leaching. Given that some of the complexity in modelling the soil-plant dynamics in cropping systems is driven by the requirement to provide short-term predictions, it is valid to ask: what simplification can be made in the model for predicting long-term average values in arable systems?

The application of the current and earlier versions of OVERSEER® to arable systems can therefore be framed as a hypothesis about the simplifications that can be made, with the null hypothesis being that the simplifications appropriate for a pastoral system are also appropriate for arable systems. Testing this hypothesis is complicated by the difficulty in obtaining data on long-term average N leaching. N leaching is difficult to measure due to spatial and temporal variation (as discussed by Cichota and Snow, 2009), and long-term data are scarce.

Findings

Testing the crop model in OVERSEER®

OVERSEER® has been designed to predict long-term leaching losses on an annualised basis and this approach has been adopted in developing the cropping model. It uses long term, average annual climatic data, a monthly time step and a single soil layer. In contrast, other research-focused crop models designed to predict the dynamics of N leaching use short-term (days to weeks) climatic data, daily time steps and multiple soil layers. Whilst the simplifications adopted in OVERSEER® appear to be consistent with the policy requirements for managing water quality, they may mean that the cropping model is unable to model the impacts of crop management interventions which occur on a scale of days, weeks and months e.g. precise timing of fertiliser applications to meet crop growth needs.

Relatively little information is available to evaluate the reliability of the current cropping model in OVERSEER® to predict long-term average N leaching in arable systems. The crop model now in OVERSEER® is a modified version of the model developed by Cichota *et al.* (2010). These authors evaluated their model as follows:

- Testing against field trials data, albeit limited to a small data set: one site (Lincoln) and two rotations with different fertiliser inputs.
- Inter-model testing against the more complex plant-soil dynamics model called LUCI (itself not well tested for predicting N leaching).

Finally, new versions of OVERSEER® have been released since the early testing, and these new versions have some substantial changes (e.g. a move to quasi-daily water balance calculations) that may affect predictions of N leaching.

For all these reasons it is essential that the OVERSEER® cropping model undergoes further testing to provide users with sound information on the accuracy or otherwise of the predicted N leaching losses.

Usability issues

A fundamental principle of the OVERSEER® model is that it is developed in a way that is easy to use and that it provides output that is relevant and useful. Rahn (2004) discussed several of the barriers to use for decision support models.

Significant software issues with the user interface of the current version of the cropping model of OVERSEER® result in slow and tedious performance. In particular, implementation of the "Crop Rotations" input screen is troublesome. This needs to be addressed as soon as possible.

The cropping model is currently structured such that there is a 'lead-in' year followed by an assessment year. This is satisfactory if only a few paddocks are to be modelled, but for a large arable farm with many paddocks at different stages in a five to seven year rotation, the current structure can result in a situation where every paddock has to be modelled independently. Hence data entry can become very onerous, with double entry of data for every rotation stage. Further, the complete rotation may not be represented in a single year, meaning that the result will not reflect a long term average for the whole rotation. It is essential that a software improvement to the cropping model is implemented so that it is a simple task to carry over data from one year to the next.

The primary aim of OVERSEER® is to calculate a long term average nutrient budget for a farm system. Therefore, an alternative structure where the user can enter typical crop rotations over a number of years and OVERSEER® models the nutrient loss for every year entered would potentially be more efficient. Because there may be a variety of soil types on the farm, a modelling structure where an area-weighted average over a combination of soils and rotations may be required. Both individual crop and long term average nutrient losses could be reported. While not precisely representing actual management in a particular year, this would achieve the major aim of identifying problem areas where mitigation strategies would have the greatest benefit. It would also allow the modification of crop rotations to be explored as a mitigation strategy.

However, it is acknowledged that a trade-off exists between ease of use and flexibility to customise inputs to represent actual management. For example, if a farm has a mix of light and heavy soils, some of the details of the rotation (timing of sowing, fertiliser application, irrigation) may vary from paddock to paddock. Moving to a 'typical rotation' structure would lose these subtleties of management which can be important in managing N loss. Therefore further consideration is needed to deliver a simple interface with sufficient flexibility to closely match OVERSEER® management with actual farm practice.

Transparency in the science underpinning OVERSEER®

It is likely that OVERSEER® is going to be used in a public policy context to facilitate the reduction of diffuse nitrate (and phosphate) pollution in agriculture. Thus, the extent to which it is fit-for-purpose will be questioned by an increasingly wide range of stakeholders and the model will be under increasing scrutiny as it develops into this role. Therefore, open and independent review of the science underpinning OVERSEER®, the assumptions made in its application, and the operational aspects of the model will be essential to build confidence in its integrity and use.

Uncertainty associated with model outputs

OVERSEER® has evolved from a decision support system designed for on-farm fertiliser and nutrient management advice to a tool being used to implement regional policy and regulations in relation to nutrient losses from agriculture. Therefore, all users of OVERSEER® must appreciate its limitations and must have a good understanding of the uncertainties in OVERSEER® estimates.

Differences between measured and modelled values, for example N leaching, are an expression of the certainty/uncertainty arising from attempting to model complex biological processes with a minimum set of readily available farm data inputs. The uncertainty in N leaching (from the root zone) in the pastoral model has been estimated to be ± 20% (Ledgard and Waller, 2001). There is currently no estimate of the uncertainty in N leaching in the cropping model and no estimate of the uncertainty in predicted phosphate runoff in either model.

Further uncertainty is associated with the accuracy and appropriateness of data inputs. OVERSEER® users must have access to good quality farm data that accurately reflect management practices on farm. Clear protocols for data entry are also needed to ensure a consistent and fair approach is taken across farm systems.

Although input errors may be a significant source of uncertainty in OVERSEER® N leaching estimates between farms, this is probably relatively minor within a farm where the user is examining the effects of changes in on-farm practices because many of the parameters (e.g. site factors such as area, soil, slope, rainfall) remain constant under any comparative scenario. Again, this emphasises that a good understanding of the model and training in its use are important for the use of OVERSEER®.

In a regulatory context, the impact of OVERSEER®-related uncertainties are lessened when the model is used to examine "what-if-scenarios" (as it is in part of the proposed Canterbury Land & Water Regional Plan (Anon, 2013e)) and when assessing relative N loss changes within a farm (as in the Regional Plan Variation 5 – Lake Taupo Catchment (Anon, 2013f)).

It is therefore clear that a good understanding of the principles and practice of OVERSEER® modelling in the context of regulation is essential for a wide range of stakeholders including central government, regional authorities, farmers, farm groups and industry groups. Different approaches are likely to be required for the different stakeholder groups. However, fostering opportunities for shared learning between stakeholder groups will be advantageous.

Governance of OVERSEER®

The evolution of OVERSEER® from a decision support system for research and advisory purposes to a primary tool for nutrient management, including setting regulatory limits by regional authorities, is remarkable. The obligations placed on the owners in terms of the strategic direction and resourcing of the model and of managing risks have, as a consequence, increased substantially and are likely to continue to increase.

Implementing the recommendations of this review without slowing development at this key stage in the model's history will require a significant expansion in the current OVERSEER® team. Such an expansion however will greatly improve the capability of the team to deliver a useful tool to meet the ever-increasing challenge of reducing diffuse pollution in agriculture.

Concluding remark

It is the opinion of the authors that addressing the issues identified in this review will help to increase the usefulness of OVERSEER® and to grow confidence in its application to water quality policy, especially in relation to cropping systems.

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