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EVALUATION OF IRRIGATION STRATEGIES FOR ARABLE FARMS TO MITIGATE NITROGEN LOSS USING THE OVERSEER MODEL

JJ Drewry, AK Manderson, and CB Hedley

Manaaki Whenua – Landcare Research, Private Bag 11052, Palmerston North

Abstract

The aim of this study was to use OVERSEER to investigate how irrigation strategy choice, and climate parameterisation, influence predicted water use, drainage and nitrogen leaching for irrigated arable-farming operations.

The study was undertaken to evaluate the irrigation module component of OVERSEER Nutrient Budgets, using a case study approach. OVERSEER is a farm nutrient cycling model now used by many regulatory authorities and others for estimating farm nitrogen losses. It is important for farmers with irrigated systems, especially those subject to regional council nitrogen (N) loss restrictions, to be aware of the implications of choosing the most appropriate OVERSEER irrigation scheduling strategy. The OVERSEER irrigation module was upgraded in 2015, allowing users to investigate irrigation scheduling options (e.g. precision irrigation), which was not previously possible.

Irrigation scenarios were evaluated for each of three case study arable farms located in Hawke's Bay. The farms had a wide variety of arable crops, mixed sheep and cattle grazing, and a range of soils with low, moderate, and high profile available water. Scenarios were based on OVERSEER's irrigation strategies, and parameterisation using OVERSEER defaults. Scenarios using fixed-fixed (fixed application depths and fixed return periods) produced the highest N losses, irrigation consumption, and drainage losses. Scenarios using variable-variable (variable application depths and variable return periods) generally produced the lowest N losses, irrigation consumption, and drainage losses.

Where possible, we recommend the wider uptake of irrigation practice that includes a variable component to ensure depth applied is adequate but not excessive, and also applied at an appropriate time. As demonstrated by the case studies, compared with fixed methods, considerable efficiencies were available for minimising N loss, water use, and deep drainage through the use of variable depths and/or returns. We also recommend that OVERSEER users undertake a simple check by comparing modelled irrigation water supply during a season with actual irrigation water use.

Introduction

Precision agriculture technologies, such as variable rate application of irrigation water or fertiliser, use of management zones for spatial variability, coupled with good farm practices can help reduce farm inputs, improve nutrient use and profit, and help minimise nutrient losses from farms (Hedley et al. 2009; Rab et al. 2009; McCarthy et al. 2010; Mackenzie 2013).

Variable rate irrigation (VRI) systems have been shown to reduce drainage and nutrient losses compared with uniformly applied irrigation water on dairy and cropping farms (Hedley et al.

2009; Hedley 2015; McDowell 2017). This study was undertaken as part of the ‘Maximising the Value of Irrigation’ programme. A component was to evaluate the recent irrigation module, which includes variable rate irrigation, of the OVERSEER Nutrient Budget model.

OVERSEER is a long-term average farm-scale nutrient cycle model (Wheeler et al. 2006; Wheeler 2016a) used for estimating farm-scale nutrient losses and cycling processes. The model is used for research of nitrate leaching, nitrous oxide emission, nutrient loss and transfer, and farm mitigations, among other research purposes (Monaghan & De Klein 2014). The model is regularly used by industry bodies for individual farm nutrient management, and increasingly for planning and farm resource consenting, and by regional and unitary councils in a regulatory context for resource management. OVERSEER is now also used in work commissioned by some regulatory authorities for modelling farm nitrogen losses, for regional plan policy initiatives (e.g. Lilburne et al. 2013; Muirhead et al. 2016; Blyth et al. 2018). A recent overview of OVERSEER within a regulatory context was provided by the Parliamentary Commissioner for the Environment (2018).

OVERSEER models a wide variety of farm systems and components, including irrigation. Before 2015, the OVERSEER irrigation sub-model was subject to scrutiny and challenge over its inadequacy for representing actual irrigation practice, with few irrigation management options for model end-users, and for its use of mean annual climate data inputs (Curtis 2013; Davoren 2013; Wheeler & Bright 2015b). The OVERSEER irrigation module was upgraded in 2015 (Wheeler 2015; Wheeler & Bright 2015a), allowing users to investigate irrigation scheduling options (e.g. precision irrigation), which was not possible previously.

It is important for farmers with irrigated systems, especially those subject to regional council nitrogen loss restrictions, to be aware of the implications of choosing the most appropriate OVERSEER model irrigation scheduling strategy.

This paper reports on a study developed to evaluate the irrigation module component of OVERSEER. The objective was to evaluate how choice of irrigation strategy influences water use, drainage and nitrogen leaching for irrigated arable-farming, using a case study approach. The aim was to compare irrigation scenarios within case studies. Another aim was to compare OVERSEER N loss estimates based on long-term annual averaged climate data, and N losses calculated using multiple year or monthly data.

Methods

Overview of approach - irrigation

Irrigation scenarios were modelled for each of three case study arable farms located in Hawke’s Bay. A brief description of the method is provided in this paper, and further details are available in Manderson (2017). The farms had a wide variety of arable crops, mixed sheep and cattle grazing, and a range of soils with low, moderate and high profile available water. Scenarios were based on OVERSEER’s four irrigation strategies (described in the next section), and parameterisation using OVERSEER defaults, with version 6.2.0.

Overview of OVERSEER irrigation module

The release of OVERSEER 6.2.0 in 2015 included a substantial upgrade of the irrigation sub-model to include a variety of irrigation system types such as linear, pivot and drip irrigation, and a suite of irrigation scheduling options based on the IrriCalc model (Wheeler 2015; Wheeler & Bright 2015a).

In summary, five irrigation scheduling methods are available. The simplest is by *application depth*, where users specify an irrigation depth only. The other four methods are based on IrriCalc strategies, and represent possible *fixed* and *variable* combinations of application depth and return period (e.g. FV = fixed depth; variable return period). For each strategy, users can accept application depths and return periods calculated automatically from Profile Available Water (PAW) to 60 cm, or have the option for user defined inputs. For further detail, see Wheeler (2015).

PAW is a term devised in New Zealand, particularly for describing soil water characteristics in the New Zealand soil mapping system, S-map (Manaaki Whenua-Landcare Research 2018). The soil depth specified, for example PAW60, is the amount of water stored in the 0–60 cm depth of soil.

Case study farms

All case study farms were commercial operations in central Hawke's Bay. OVERSEER files were constructed and supplied by Diana Mathers, Foundation for Arable Research.

Case study 1

The farm is an irrigated mixed cropping block of 252 hectares (250 ha effective), part of a larger, 1,009-ha cropping and sheep/beef farm. Climate includes 839 mm/yr rainfall, 917 mm/year PET, and a mean annual air temperature of 12.7° C. Soils are dominated by high PAW Hastings silt loam, but with a significant area of low PAW Argyll sandy loam. The supplied nutrient budget for 2014 comprises 16 blocks, most of which are cropped and irrigated using a pivot irrigator (180 ha). Crops include a mix of maize, sweetcorn, annual ryegrass, peas, beans, beets, wheat, and lucerne. Grazed areas are mostly stocked by sheep (18.2 su/ha) and some bull beef (1.8 su/ha).

Case study 2

The farm is a 1960 ha, mixed-cropping farm. Annual rainfall is 800 mm/yr, and soils include a mix of high PAW Hastings soils (PAW = 126), and moderate PAW Ōtāne and Okawa soils (PAW = 88-96). The OVERSEER model is set up for the 2012/2013 season, and contains 16 blocks within the irrigated part (totalling 291 ha). Key crops include squash, peas, beans, wheat, annual ryegrass, ryegrass seed, maize, sweetcorn, barley, and maize silage. All but two of the blocks are irrigated, primarily with a 450-m linear irrigator and a centre pivot, and one block has a travelling irrigator. Sheep grazing is practiced between crops (1,150 revised stock units).

Case study 3

The farm is an arable operation with predominantly commercial and fodder cropping (e.g. ~60% of farm can be in barley, grass seed, sweetcorn, peas, beans, wheat, maize, and lucerne) and livestock grazing. Annual rainfall is 960 mm/yr, and soils are dominated by moderate PAW Takapau and Poporangi soils. The supplied nutrient budget for 2011/2012 represents the cropped portion of the property (total of 147 ha). Approximately 94 ha are irrigated with linear and centre pivot systems. Grazing is practiced between crops and on uncropped proportions with sheep and cattle (20:80 ratio) at a total of 1,682 revised stock units.

Irrigation strategy comparison

The irrigation strategies available within OVERSEER were compared with each other. The comparisons evaluated are listed in Table 1. Most were limited to the use of OVERSEER default parameters and the original parameterised strategies in the OVERSEER files supplied.

The study was conducted using OVERSEER model simulations only. As no measurements were conducted, no statistical comparisons were made.

Table 1 Irrigation scenarios modelled for each case study

Scenario	Description
Baseline	No irrigation applied (crops and cropping rotations remain unchanged)
Fx #1	*Fixed application depth* (mm/month). Data used was supplied from monthly irrigation water supplied as per the VV strategy in the reporting year (average monthly from all irrigated months)
FF #1	*Fixed application depth and fixed return period* using OVERSEER defaults
FF #2	*Fixed application depth and fixed return period* using a common rule of thumb: 15 mm every 3 days
FF #3	*Fixed application depth and fixed return period* using a design value of 50 mm per 7 days for linear irrigation systems
FV #1	*Fixed application depth with variable return period according to trigger point* (irrigation is applied at the specified depth when soil water content decreases below the trigger point) using OVERSEER defaults
VF #1	*Variable depth according to target with a fixed return period* using OVERSEER defaults
VV #1	*Variable depth and variable return period* according to OVERSEER defaults
VV #2	*Variable depth and variable return period* according to actual user inputs (i.e. original settings in the models supplied)

Overview of climate input evaluation

This section presents an overview, as detailed methodology undertaken evaluating climate inputs is reported elsewhere (Manderson 2017). This study evaluates OVERSEER estimates of N leaching loss to water using long-term annual averaged climate data, and N losses calculated using multiple year data. The farm for case study 1 was used. Four climate parameterisation scenarios were developed (Table 2). Changes in estimated N loss are reported. For scenarios with multiple N loss estimates, these were averaged for comparison against single model-run N estimates. Irrigation was set to use a variable depth and variable return strategy (model adjusts irrigation in response to soil water conditions).

Table 2 Climate parameterisation scenarios tested

Scenario code	Scenario description	Description	OVERSEER runs	What was averaged
LTA	Long-term annual means (default)	Annual means of all years (OVERSEER default).	1	Averaged input
LTMM	Long-term monthly means	Monthly means of all years (i.e. monthly average by year, then a secondary average by month Jan–Dec).	1	Averaged input
AAnn	Annual summaries	Summed annual rainfall & PET for individual years (total of 40 years). Average annual temperature for each of the 40 years. N losses averaged to a single value.	40	Averaged output
M40	Monthly summaries	Monthly averages for each year. N losses averaged to a single value	40	Averaged output

Climate data were obtained from the NIWA Virtual Climate Network (VCN; Agent #29472). This provided daily rainfall, air temperature, and PET for the period 1972 to 2014 (+40 years). Data were averaged by year to obtain annual averages. Daily temperature minimums and maximums were averaged to provide a single value for mean daily temperature. Data were also averaged by month to generate two types of monthly averages. For the first method, the 40-year average for each month was calculated. One monthly input dataset was generated. For the second method, monthly averages were calculated for each month within each year. Further details are presented in Table 2. More complex evaluations were beyond the project scope.

Monthly averages (Table 2) are included to demonstrate the implications of using monthly data. We also acknowledge that different methods exist for calculating representative climate inputs, but we limit the study to the use of averages (Table 2) to maintain consistency with OVERSEER.

Results

Irrigation scenarios

Predicted nitrogen leaching losses (kg N/ha/y; described as N loss to water), annual irrigation applied (ML/y; i.e. megalitres/y), and annual drainage volume (ML/y), are presented for the nine irrigation scenarios (Table 3), all reported on a whole-farm basis. The N losses to water are presented in Figure 1. The outputs are for a whole year, and therefore include any N leaching related to crop management that occurs after irrigation ceases.

Patterns are similar between the case study farms, but at different magnitudes (Figure 1). Note that the aim of this study was to compare scenarios within each case study, not between farms because there are varying proportions of the farms that are irrigated, and different years. Case study 1 has 25% of the farm irrigated. Case study 2 has 15% of the farm irrigated. Case study 3 has 64% of the farm irrigated.

The VV#1 scenario results are used as the basis for comparison between strategies, as the combination of variable *application depth* and variable *return period* offer the greatest opportunity for optimal irrigation water use (referred to as the *optimal scenario*). The ‘base’ scenario has no irrigation supplied, and is included to demonstrate the use of irrigation in OVERSEER can result in a N loss increase irrespective of how efficient the strategies are (Table 3).

Fx#1 is the simplest scenario to parameterise, as users are only required to specify an application depth per month, but there a high risk of both under- and over-estimating irrigation requirements. It is unclear how OVERSEER calculates the return period.

All three FF scenarios produced the highest N losses, used the most irrigation water applied, and produced the highest volumes of drainage (Table 3). FF#1 and FF#2 (15 mm/3 days vs OVERSEER FF defaults) showed little comparative difference between the three outputs evaluated, while FF#3 (50 mm/7 days) had the greatest N loss, irrigation water applied, and drainage of all nine strategies. Irrigation volumes applied were 3, 5, and 11 times higher than the volume used in the optimal (VV#1) scenario, for case studies 1, 2, and 3, respectively. Similarly, drainage losses were 2–3 times higher than the optimal scenario. Nitrogen losses for the FF scenarios were approximately 2–4 times higher than the optimal (VV#1) scenario (Table 3).

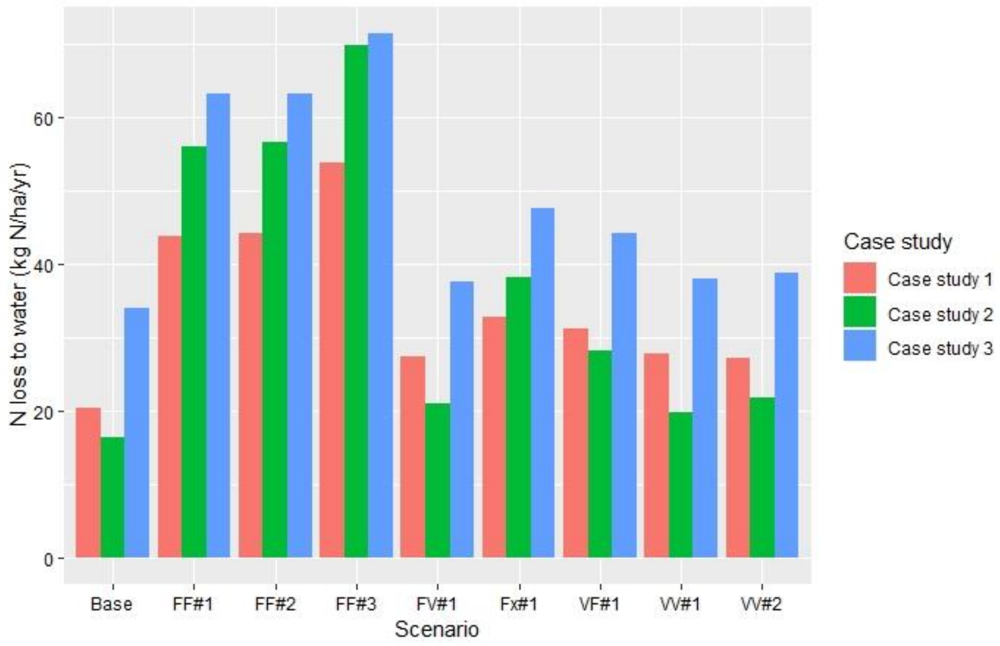

Figure 1 Modelled nitrogen losses to water (kg N/ha/yr) for nine irrigation scenarios.

Note: The first letter in the scenario code indicates the type of *application depth* (Fixed or Variable) and the second letter indicates the irrigator *return period* (Fixed or Variable).

Table 3 Summary of results for irrigation scenarios from the OVERSEER predictions. 'Base' includes no irrigation, VV#1 is the *optimal* scenario used for comparisons within case studies. N loss data are presented per hectare per year; the outputs are for a whole year, reported on a whole farm basis. Scenario comparisons should be made within case studies

	Case study 1			Case study 2			Case study 3		
Scenario	N loss	Irrig applied	Drainage	N loss	Irrig applied	Drainage	N loss	Irrig applied	Drainage
	kg/ha/y	ML/y	ML/y	kg/ha/y	ML/y	ML/y	kg/ha/y	ML/y	ML/y
Base	20.4		672	16.3		767	33.9		586
Fx #1	32.8	475	987	38.1	614	1321	47.5	385	1105
FF #1	43.7	819	1195	56	1491	1862	63.1	1304	1767
FF #2	44.1	817	1214	56.5	1472	1895	63.1	1287	1788
FF #3	53.8	1183	1549	69.8	2171	2517	71.4	1867	2306
FV #1	27.3	381	796	20.9	453	925	37.6	177	690
VF #1	31.2	518	906	28.1	692	1093	44.1	446	935
VV #1	**27.8**	**402**	**820**	**19.7**	**438**	**919**	**38**	**174**	**691**
VV #2	27.2	398	813	21.8	507	958	38.8	227	725

Note: The table reports irrigation applied and drainage as megalitres/y (ML/y) for the whole farm (although only part of the farm is under irrigation). N loss is predicted N leaching loss to water. 'Irrig applied' is predicted irrigation water applied. Drainage is predicted drainage

In contrast, those strategies with a variable component produced the lowest N losses, irrigation water applied and drainage (see Table 3). FV#1 (fixed depth; variable return) generally produced the lowest net differences overall, other than one or two instances where the VV#1 strategy was slightly lower again. VF#1 was not quite as efficient as the optimal scenario (VV#1). However, overall the strategy produced lower N losses, water used and drainage than any of the fixed-fixed scenarios.

Theoretically, VV#1 is the optimal scenario as it adjusts both application depth and irrigation timing according to soil water needs. This is reflected in the modelled results, where the VV#1 produces the lowest average (i.e. average of all three case studies) N losses, irrigation water applied, and drainage volume of all scenarios, other than FV#1.

However, we also note that VV#2 had slightly less N loss, water used, and drainage than VV#1 for case study 1 (VV#2 has user-specified trigger and target values). The VV#2 trigger and target values were the same for all three case studies as supplied in the original OVERSEER files. We suspect that farm-specific tuning of trigger and target values has the potential to produce more optimal results for case studies 2 and 3. However, while fine tuning may allow for slight improvements, in general we found that the OVERSEER default values appeared to produce good results because they adjusted for a wide range of situations according to differences in PAW, as demonstrated in the performance of the FF scenarios.

In summary, irrigation strategies with a variable irrigation component are more efficient than those strategies with a fixed component.

Climate comparison

Annual

As would be expected, for the 40-year annual losses there was considerable variation in N loss between years. Both (LTA and AAnn) climate scenarios produced an average N loss of 31 kg N/ha/y (Figure 2, Table 4).

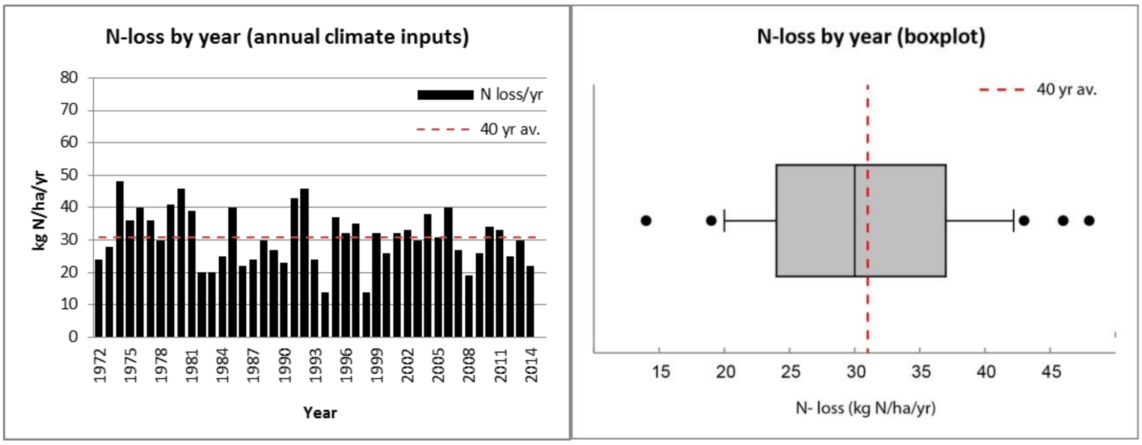

Figure 2 Nitrogen loss for individual year modelling (40 years, scenario AAnn). Red dotted line is the long-term N loss mean (i.e. average of 40 years of N loss, scenario LTA).

Monthly

For the monthly scenarios (LTMM and M40) there was considerable N loss variation between years. However, in this case study, N loss from the averaged input method (LTMM) was 28 kg N/ha/yr, and N loss from the averaged output method (M40) was 31.5 kg N/ha/yr (Table 4).

Table 4 Climate parameterisation scenarios and N loss for case study 1

Scenario code	Scenario description	What was averaged	Nitrogen loss (kg N/ha/y)
LTA	Long-term annual means (OVERSEER default)	Averaged input	31
LTMM	Long-term monthly means	Averaged input	28
AAnn	Annual summaries	Averaged output	31
M40	Monthly summaries	Averaged output	31.5

The averaged output method (M40) had similar N loss (31.5 kg N/ha/yr) as the estimates made using annual means (31 kg N/ha/yr; AAnn). This is despite differences evident between annual and monthly-derived losses. However, a loss of 28 kg N/ha/yr from the averaged input method (LTMM) suggests that the long-term average monthly profile was less representative. We reiterate others' recommendation (e.g. Wheeler 2016b) that the monthly climate parameterisation option be used with caution.

Discussion

OVERSEER has been upgraded on a regular basis as new research becomes available. For arable cropping, Dunbier et al. (2013) noted that spatial complexity of cropping systems is often greater than for pastoral farms. A challenge with OVERSEER, is to provide sufficient simplification for the end user but provide adequate representation of complex processes, especially in arable cropping systems, such as N leaching (Dunbier et al. 2013). Dunbier et al. (2013) recommended improvements to the arable components and overall development process of OVERSEER. A variety of recommendations for the OVERSEER modelling, in a regulation context, were provided in a recent review (Parliamentary Commissioner for the Environment 2018).

The aim of the study was to compare irrigation scenarios within each case study, as modelled by OVERSEER. More complex analyses were beyond the project scope. The irrigation strategies with the lowest N leaching, irrigation water applied, and drainage, were those with a variable component, especially the variable-variable strategy. The fixed-fixed strategies had the greatest N leaching, irrigation water applied, and drainage.

There have been few other studies on the effects of variable component irrigation on nutrient loss. For furrow irrigation, the use of 'variable alternate furrow irrigation' and 'fixed alternate furrow irrigation' both reduced N leaching and drainage compared with 'ordinary furrow irrigation' (Tafteh & Sepaskhah 2012). N leaching was lowest in the variable furrow treatment. However, both fixed and variable furrow irrigation are considered partial root drying irrigations, and therefore can contribute to water stress, compared with ordinary furrow irrigation (Tafteh & Sepaskhah 2012).

Under spray pivot irrigation on dairy pasture, N and P annual loads were about 80–85% less under variable rate irrigation compared with uniformly applied irrigation water (McDowell 2017). The flow of drainage water was one third less under variable rate irrigation than uniform rate irrigation (McDowell 2017). The use of new sensor technology, potentially coupled with technology for frequent assessment of crop or pasture water and nutrient requirements, may also reduce nutrient loss, but further research is required (McDowell 2017; Ekanayake & Hedley 2018). User adjustments, such as the use of different trigger levels of the percentage of available water capacity, from which to irrigate, can improve dairy farm irrigation management resulting in a reduction in modelled N loss to water (Bright et al. 2018). However, several conditions needed to be met, including monitoring soil moisture content, a short (e.g. 3 day) return period, and a reliable irrigation water supply.

In terms of on-farm practice, some pivot irrigators take several days for a full rotation. Farm practice should be considered when parameterising the model, such as with default values. Where possible, we recommend users undertake a simple check of comparing modelled irrigation water supply with actual irrigation water use. Irrigation supply values are available under 'block reports' and can be converted to a volume by multiplying irrigated area (ha) by irrigation supplied (mm/yr) by 10. Resulting units will be m^3/yr. Actual water use should be the average from at least several years.

Wheeler (2016b) reported that the monthly data option has been provided for research trials and where climate profiles do not conform to the default annual average profiles, but that the monthly option should be used with caution. Our analysis for the climate input and output data is based on one case study only, so should be used with some caution. Based on the case study, we recommend that climate variables be parameterised using long-term annual means. The additional work to gain knowledge of between-year variation may provide useful context for some users.

Conclusions

From this study, we conclude:

- As demonstrated in the case studies, considerable efficiencies are available for minimising N leaching loss, irrigation water applied, and drainage, through the use of variable depths and/or return periods, compared with fixed options.
- The OVERSEER irrigation strategies with the lowest N loss, irrigation water applied and drainage are those with a variable component, especially the variable-variable (VV) strategy that allows for optimal irrigation depth and return period according to soil properties and climate.
- Fixed-fixed (FF) strategies, especially those based on rule-of-thumb application depths and returns, are least efficient.
- OVERSEER defaults (which adjust according to soil properties) performed quite well. Default parameters produced the most efficient FF scenario, and not-unreasonable results for the VV scenario. With fine tuning, user parameterisation of the VV strategy should produce meaningful improvements.
- For climate data, the annual comparison of averaged inputs vs averaged outputs produced the same long-term nitrogen loss estimate. The monthly option should be used with caution.
- There are few published studies on the effect of variable rate sprinkler irrigation on nutrient loss, so further studies are required.

Recommendations

From this study, we recommend:

- Where appropriate, that the wider uptake of irrigation practice be adopted that includes a variable component for application depth, and/or interval.
- Where possible, that OVERSEER users undertake a simple check of comparing modelled irrigation water supply with actual irrigation water use.
- That the monthly climate parameterisation option be avoided.
- That climate variables be parameterised using long-term annual means.

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