Extending "SafeGauge for Nutrients" to high rainfall cropping in Australia

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Abstract
As agricultural systems continue to intensify there is a need for farmers and farm advisors to understand how soil, climate and management interact to affect nitrogen (N) losses at the paddock scale. Computer-based decision support tools have been widely used to build farm advisors' capacity to understand the risks of N losses to the environment. However, existing tools often only provide an average annual risk of nitrogen loss from a paddock, even though nitrogen export is dependent on daily interactions between soil water content, water movement through deep drainage and runoff pathways and N availability. In this paper we present the design of a decision support tool for high rainfall cropping systems building on SafeGauge for Nutrients (developed for the sugarcane industry in Queensland, Australia). This tool (SG_Grains), allows users to define the system including location, cropping season, soil type and management decisions (e.g. fertiliser rate and timing, cultivation, stubble management). Information on management practices is combined with relevant modelled daily crop growth, soil water, drainage and runoff sourced from a library of simulation runs for various soil types and climates. Taking account of N uptake and cycling, the daily nitrogen balance and risks of nitrogen losses via the various pathways are calculated. The risks are then modified to account for differences in slope and paddock position in the landscape. The results are presented as a risk gauge for all three loss pathways (runoff, leaching and denitrification), as well as a summary report on nitrogen input/output balance for the selected paddock. SG_Grains will be used as part of the training for advisors within the Fertcare Program, allowing the investigation of how management affects the risk of N export through various pathways.

Key Words
Nitrogen, Decision Support System (DSS), water quality

Introduction
The agronomic efficiency of nitrogen (N) fertiliser in Australian cropping systems is highly variable (McDonald 1989), dependent on a range of factors including timing and quantity of fertiliser application, soils and climate. While fertiliser efficiency has an economic impact on crop production, off-site N losses from cropping systems (eg. runoff, deep drainage and nitrous oxide emissions) also have significant environmental impacts.

There are a range of tools which can be used to inform and develop our understanding of N export from cropping systems. These range from annual nitrogen calculators such as the Generic Yield and N Calculator (Baldock 2015) to biophysical models such as APSIM (Probert *et al.* 1998) which integrate complex biological and physical processes, to investigate how N management on farms interact with soil and climate to effect N utilization. Generally these tools are either too general (e.g. annual budget which doesn't capture the temporal sensitivity), or too complex (e.g. biophysical models) for regular use by farmers or farm advisors. In order to build farm advisors' and farmers' capacity in identifying high/low risk N loss environmental conditions and management practices, easy to use tools which account for the short temporal sensitivity to management and environmental conditions are required. SafeGauge (SG) for Nutrients, developed for the sugarcane industry is a user-friendly package that uses site-specific soil and rainfall information together with user-entered fertiliser management details to display visually the risk of off-site N and phosphorus (P) movement to surface water (by runoff), groundwater (by drainage) and the atmosphere (by denitrification) over the crop cycle (Moody *et al.* 2009; DEHP 2012).

In this paper we present the design of a decision support system for high rainfall cropping (canola and wheat) in Australia. SG for Nutrients was used as a basis for developing a tool which defines nutrient inputs, flows and losses from high rainfall cropping systems (SG_Grains). SG_Grains is intended to be used as part of the training for advisors within the Fertcare Program, which aims to lift the skills and knowledge of farm advisors and fertiliser suppliers through training. The tool will assist in "calibrating" advisors' ability to identify high risk N loss situations in cropping systems and develop an understanding of nutrient loss and management on a daily time scale for a user selected paddock and time period. The underlying equations and assumptions used in developing SG_Grains are investigated in this paper using a case study from South West Victoria.

SafeGauge_Grains

SG_Grains qualitatively assess the potential risk for off-site N losses by runoff, drainage and denitrification as a result of on-farm N use and management on a daily time scale. The risk rating is based on a daily N and soil water balance. In SG_Grains the user defines the site details, crop and N management (Figure 1) through a user interface. Most of the inputs are pre-defined and use drop down lists (e.g. year, location, crop type, cultivation management), however the N management inputs are more detailed. SG_Grains is underpinned by a database of daily crop growth (dry matter yield), runoff, drainage and soil water for a range of climate stations and soil types. This database contains the results of a 1D crop growth model (wheat and canola) run in CAT (Christy *et al.* 2013). The CAT model was run for selected combinations of soils and climate stations . Daily average crop growth, runoff, drainage and soil moisture were calculated for wet, dry and average years based on the categorization of 50 years of annual rainfall into wet (top 20th percentile), dry (bottom 20th percentile) and average, as well as individual years from 2000-2015.

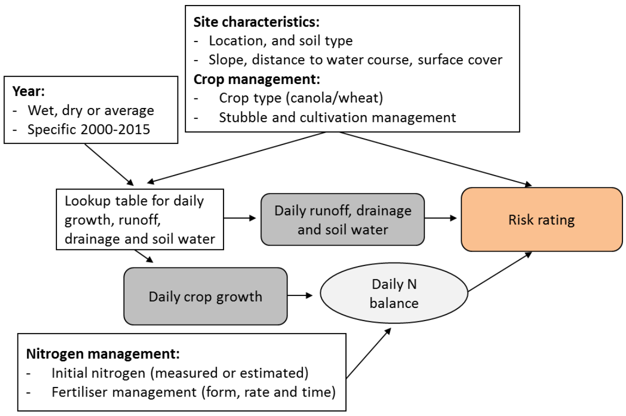

Figure 1. Flow chart of inputs and the risk estimation processes in SG_grains: inputs (rectangles), calculations (oval) and outputs (rounded rectangles).

Soil N is calculated for a 60cm deep soil profile based on the recommended sampling depth for N in crops (to take account of the mobility of N and rooting depth of crops). We have assumed a distribution of 10% in the surface 0-2cm and 30% in the 0-10cm layer with the remainder distributed evenly through the profile. The initial soil N at the start of the season is either calculated directly from soil tests or it is calculated based on an estimate of soil profile mineral N from organic carbon (DEHP 2012) and further pre-sowing mineralisation of 0.69 kg N/ha.day (1st January to sowing) which is adjusted based on stubble management and cultivation (Angus *et al.* 2006). The daily N balance for the paddock begins with either the date of sowing or the date of N fertiliser application, depending on which is first. The daily N balance is calculated for nitrate and ammonium N, based on the initial conditions defined by the user, the database and the embedded functional relationships for nitrate [NO_3^-] and ammonium [NH_4^+] which include:

- Nitrification based on Michaelis-Menton kinetics with average daily temperature (T_{avg}) used to reduce the rate of nitrification at sub-optimal temperatures.
  Daily Nitrification = 10 x [NH_4^+]/([NH_4^+] + 90) x (0.33 x T_{avg}),
- Net mineralisation rates were based on Angus et al. (2006) and were also varied to account for optimal temperature ranges:
  Daily Mineralisation = 0.0 (T_{avg} <5); = 0.037 (T_{avg}>15); = 0.037 x ((T_{avg}-5)/10)
- Plant N uptake was calculated as a function of daily biomass growth and N concentration based on the critical nitrogen concentrations from APSIM, set at: [N] = 0.045 (sowing to 45 days pre-anthesis); = 0.005 + 0.035/45 × number days pre-anthesis (45 days pre-anthesis to anthesis); = 0.005 (anthesis to harvest).

Nitrogen losses were also calculated to complete the daily soil N balance and to calculate N export risk.

Nitrogen losses

The daily available N combined with the soil water (mm) provides a N concentration which is used to calculate N movement to surface and ground water. The calculation of runoff assumed that only 10% of the soil N was available at the soil surface to interact with runoff water, while drainage assumed an average N concentration throughout the profile, and these proportions were multiplied by the runoff and drainage (mm/day) from the lookup tables to give a net export (kg N/ha.day). Denitrification was assumed to occur when the percent water filled pore space (WFPS) was greater than 60%, with an assumed denitrification rate of 0.02% of the available soil NO_3, consistent with the original SG. These quantitative estimates of N export were then used to calculate a qualitative N Loss Rating (Table 1). The daily N loss ratings are then modified to account for differences in slope, paddock position, water table depth and distance to water course. Finally, risks are reported for the selected season, in the form of seasonal risk gauges, daily risk index and a seasonal N budget.

Table 1. Daily N Loss Rating table.

Rating	Runoff or Drainage kg N/ha	Denitrification kg N/ha
0	<0.05	<0.02
1	0.05-0.10	0.02-0.10
2	0.11 - 0.5	0.11 - 0.5
4	0.51 - 1.0	0.51 - 1.0
8	>1.0	>1.0

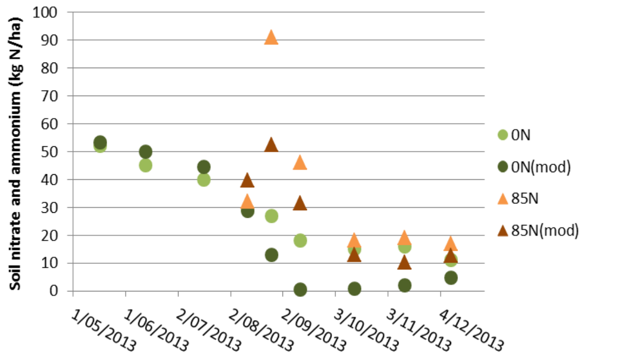

Figure 2. Measured Soil N$_{(NO3- \text{ and } NH4+)}$ (kg/ha) for the surface soil (0-10cm) at Tarrington and the modelled (mod) results from SG_Grains (30% of total soil available N).

Application

SG_Grains is designed to describe the frequency and magnitude of off-farm N risk in relation to soils, climate and management factors, and not to be used to accurately predict off-site N losses. However, to assess the underlying equations and relationships within SG_Grains this paper compares the calculated results with a case study from South West Victoria: where a recent study of nitrogen fertiliser management and the influence on nitrous oxide losses from high rainfall cropping was undertaken (Harris *et al.* 2016). In 2013 a wheat crop was grown in Tarrington, sown on the 9th May on a Eutrophic Brown Chromosol (10-20% clay top soil, 60-70% clay sub soil). Two fertiliser regimes were used for comparison, 0N (no fertiliser) and 85N (15 kg N/ha as DAP at sowing and 85 kg N/ha as Urea 19th August). The measured soil N, crop N uptake, surface soil water and N_2O losses were compared with the results of SG_Grains. The SG_Grains used the BoM Climate Station at Hamilton and a soil with similar clay percentages and matching fertiliser management.

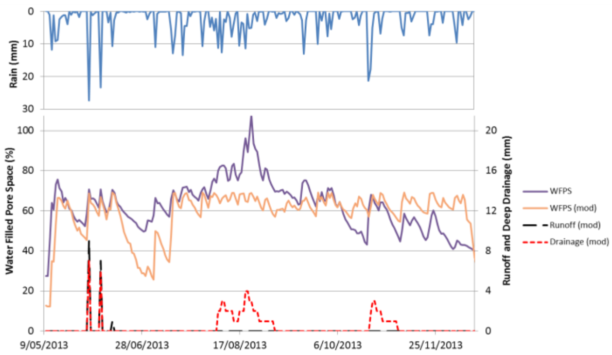

Figure 3. Measured Water Filled Pore Space (WFPS) at Tarrington and the modelled (mod) WFPS, runoff and drainage from SG_Grains.

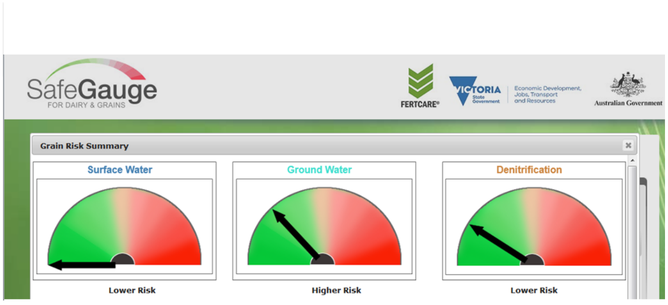

Figure 4. Grain risk summary gauges for the 85N treatment estimated in SG_Grains

Measured nitrate and ammonium (0-10cm) at Tarrington was compared to the available N calculated by SG_Grains using the estimated 30% of available N in the surface 0-10cm (Figure 2). While, the exact values in the comparison may vary depending on the estimated N distribution (eg. 48% N in top 40cm, Harris *et al.* 2016), the results follow similar trends over time. As expected, the greatest variation was in the 85N treatment where the measured surface N was notably higher in mid-August after fertiliser application compared to the modelled value where fertiliser inputs were averaged across the soil profile. Nitrogen uptake

by the crop's above ground biomass was 139 and 176 kg N/ha at Tarrington for the 0N and 85N treatments respectively, which were slightly lower than the 161 and 207 kg N/ha estimated by SG.
Trends for WFPS are similar between the measured Tarrington surface soil and the WFPS of the model (Figure 3). While the wetting and drying trends over the season are similar, the WFPS from the look-up table in SG_Grains does not exceed field capacity due to the movement of water beyond the first soil layer, suggesting greater drainage in the modelled soil than the site at Tarrington which was prone to water logging. This was probably due to a subsoil throttle that was not taken account in the soil water model simulation. Runoff and drainage from SG_Grains appear reasonable in the context of measured soil water, coinciding with periods of high soil water and rainfall (Figure 4), although there was no measured data for comparison.

Finally, in terms of risk and magnitude of nitrous oxide emissions SG_grains overestimated the emissions compared to the cumulative N flux measured at Tarrington (Harris *et al.* 2016) of less than 0.7 and 1.0 kg N/ha for the 0N and 85N treatments. This was largely due to emissions at Tarrington occurring when the saturated topsoil began to dry in late winter-early spring, while SG_Grains had WFPS greater than 60% for a significant period of autumn and winter that triggered assumed denitrification losses. The mismatch in timing of emissions between measured and SG_Grains simulated emissions needs to be addressed in future versions.

Conclusion

While SG_Grains does not provide a quantitative assessment N export (Figure 4), it is important that simulated soil N and water dynamics were consistent with field data. In this paper the predicted results were compared with measured data reported by Harris et al. (2016). In general SG_Grains and the measured data were reasonably consistent. The one exception was the nitrous oxide emissions which were overestimated and weren't consistent in terms of the timing of emissions. Refining the rules used to estimate nitrous oxide emissions will need to be addressed in future versions of SG_Grains. Despite some discrepancies between simulated and actual data, SG_Grains is a decision support tool which provides reasonable predictions of the frequency and magnitude of N export risk. It allows users to identify high risk N loss situations in cropping systems and develop an understanding of nutrient loss and management on a daily time scale for a user selected paddock, climate and management. In developing SG_Grains, minimal changes were made to the original structure of SG, highlighting that the tool can be further developed for a range of industries.

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References

Angus J, Bolger T, Kirkegaard J, Peoples M (2006) Nitrogen mineralisation in relation to previous crops and pastures. *Soil Research* **44**(4), 355-365.

Baldock J (2015) Generic Yield and N Calculator. http://www.clw.csiro.au/products. Accessed Feb 2015.

Christy B, O'Leary G, Riffkin P, Acuna T, Potter T, Clough A (2013) Long-season canola (Brassica napus L.) cultivars offer potential to substantially increase grain yield production in south-eastern Australia compared with current spring cultivars. *Crop and Pasture Science* **64**(9), 901-913.

DEHP (2012) 'SG for Nutrients Sugercane. User Manual.' (Queensland Government.)

Harris R, Armstrong R, Wallace A, Belyaeva O (2016) The effect of nitrogen (N) fertiliser management on soil mineral N, nitrous oxide (N2O) losses, yield and N uptake of wheat growing in waterlogged prone soils of South Eastern Australia. *Soil Research* **54**(5), 619-633.

McDonald G (1989) The contribution of nitrogen fertiliser to the nitrogen nutrition of rainfed wheat crops in Australia: a review. *Animal Production Science* **29**(3), 455-481.

Moody P, Legrand J, Schroeder B, Wood A (2009) 'SCAMP'and'SG for nutrients': two new decision support tools for minimising off-site movement of nutrients. *Sugar Cane International* **27**(1), 12-16, 29.

Probert M, Dimes J, Keating B, Dalal R, Strong W (1998) APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agricultural Systems* **56**(1), 1-28.