# Nitrate leaching under sugarcane: interactions between crop yield, soil type and management strategies

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## Abstract

Comprehensive agricultural systems simulation tools such as APSIM (Agricultural Production Systems Simulator) can be effectively used in studying the behaviour of agricultural systems in response to alternative management strategies. This is illustrated using hypothetical long-term simulations for a sugarcane system in Bundaberg. The simulations, which focus on nitrate leaching, show that there are significant year-to-year carry-over effects and suggest some management principles that could potentially reduce the risk of groundwater contamination by nitrate leaching.

*Key words: Nitrate leaching, sugarcane, modelling, systems analysis, SWIM, APSIM, nitrogen management.*

The study of alternative management strategies poses major challenges due to the complex behaviour of the agricultural system. Factorial field trials give import-ant insights into that behaviour, but these are often site specific and determined by the weather and management conditions during the limited length of the experiments. ?There is, therefore, a need to extrapolate these experimental results to include the temporal effect of weather and account for different management or soil type. The agricultural systems model APSIM provides a frame-work for such analyses. It has a modular structure in which crops and major processes are encapsulated in separate modules. These modules can be plugged into and out of the model and so a configuration can be chosen that best reflects the system to be simulated (3).

One of the modules, APSIM-SWIM, is based on the SWIMv2 model (Soil Water Infiltration and Movement version 2, (5)), which provides a detailed description of the water balance and solute transport. We have used APSIM-SWIM to simulate and analyse two sugarcane trials located near Bundaberg, Qld. These trials high-lighted the effect of water stress on yield and the non-responsiveness of the system to nitrogen if there was a carry-over from a preceding crop or fallow period. Here we present an extrapolation of the field results in the form of long-term hypothetical simulations. The parameterisation and testing of the model is a crucial preliminary step to provide confidence in model perform- ance. These aspects are reported elsewhere (6).

The simulations discussed here focus on the nitrate leaching component of the N-balance. This is an import-ant issue in the context of groundwater contamination, but is a difficult component to measure in the field. The combination of field experiments and modelling present opportunities for its study.

## Materials and methods

For the simulations APSIM was configured with the APSIM-SWIM module (5), a sugarcane crop module (2), a surface residue module (4), and a soil nitrogen module (4). This combination was parameterised with data obtained from two experimental sites near Bunda-berg, Qld. The model and its parameterisation were tested against data from two 2-year cropping trials which included different fertiliser rates. The first study (1) was on an imperfectly drained red-yellow podzolic soil. It also included two different irrigation regimes. A similar experiment was set up on a well-drained red earth site.

The simulations of these experimental data were generally very good, except for the zero N fertiliser treat-ments in which yield and N uptake was under predicted in the second year (6). This gave confidence that the model was satisfactorily simulating the dynamics of the sugarcane cropping system, especially when some fertiliser-N was applied, and that it could be used to analyse hypothetical scenarios.

Anumber of hypothetical scenarios were analysed in this study. They were all based on long-term simulations of a sugarcane cropping system with the following characteristics:

• A 14-month plant crop (cv. CP51) followed by four 13-month ratoon crops and a 6-month fallow;

• A "cool" burning regime at harvest time which removed 70% of the trash and incorporation of the remainder into the soil;

• Automatic irrigation either in response to soil water status (eg. below a certain soil water fraction) or at set times (eg. at sowing); and,

• Planting and harvest windows consistent with local practice.

Soil properties were those of the two experimental sites (red-yellow podzolic soil and red earth). The soil profile was assumed to be 150 cm deep, with roots extending to 120 cm. Any nitrate leaching below 150 cm was assumed to be lost to the crop. N fertiliser was applied as urea buried below the surface as in the two trials. The application was made once at sowing or ratooning, or split with the second application made 90 days later. Nine rates between 0 and 320 kg N/ha were studied. Irrigation was applied in 25 mm amounts to avoid confounding effects of runoff. The applications were made at sowing or ratooning and whenever the fraction of plant available water was less than 0.5 ("wetter" regime) or 0.25 ("drier" regime). The total water allocation for the crop season was 600 mm in the "wetter" regime and 200 mm in the "drier" regime. These two irrigation criteria caused some water stress to the crop in the "drier" regime, whereas this was avoided in the "wetter" regime. The simulations used the 1888-1995 weather record from Bundaberg, which contained a combination of measured (rainfall, temperature, radiation) and generated (temperature and radiation) data. Data from the first cropping cycle were discarded in the analyses to avoid any artificial initialisation effects.

Results and discussion

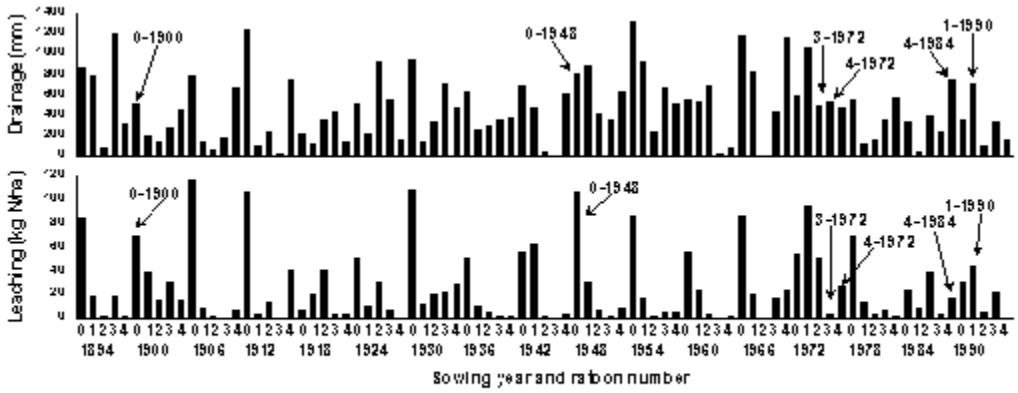


Fig. 1: Variability in predicted drainage and nitrate leaching for the red earth soil for different cropping seasons indicated by their sowing year and ratoon number (0 = plant crop).

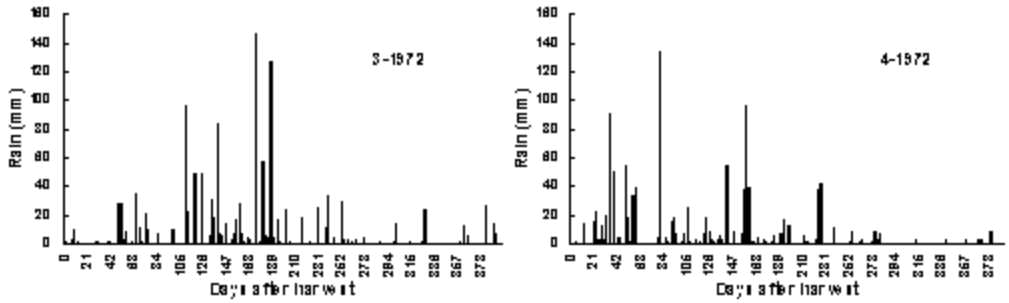


Fig. 2: Rainfall patterns of the 3-1972 and 4-1972 cropping seasons.

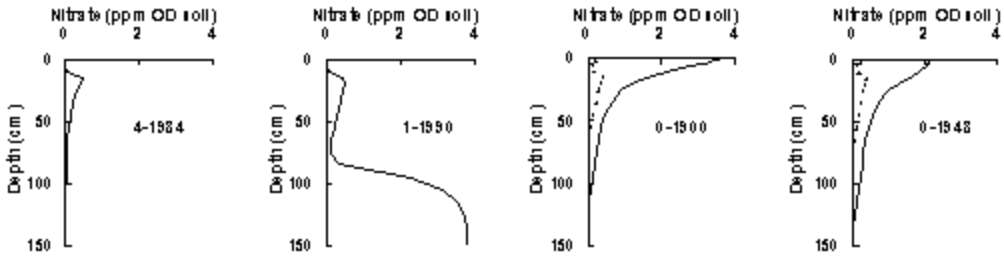


Fig. 3: Initial nitrate profiles for the 4-1984, 1-1990, 0-1900, and 0-1948 cropping seasons; dashed curves for plant crops (0-1900, 0-1948) indicate nitrate profiles at the beginning of the preceding fallows.

The results of the "drier" irrigation regime with single 160 kg N/ha fertiliser applications on the well-drained red earth soil (Fig. 1) show that season to season variability in drainage and nitrate leaching is large. The nitrate leaching pattern exhibits some similarities with the drainage pattern, but can be quite different. Consider, for example, the third (3-1972) and fourth (4-1972) ratoons of a crop sown in 1972. While the drainage in these cropping seasons was quite similar, nitrate leaching was very different (4 vs 27 kg N/ha). ?Detailed analysis of the weather records indicated that the rainfall patterns were quite different for the two cropping seasons (Fig. 2). During 3-1972 the rain fell later than in 4-1972, at a time when most N fertiliser had already been taken up by the crop.

Two other cropping seasons that differed in the amount of nitrate leached, but had similar drainage, were the fourth ratoon of a crop sown in 1984 (4-1984) and the first ratoon of a crop sown in 1990 (1-1990). In this case, ?rainfall patterns were similar, but the initial nitrate profiles were very different (Fig. 3). On average plant crops lost more N due to leaching than ratoon crops (Fig. 1). This is due to the extra N mineralised during the preceding fallow (Fig. 3), as well as the higher drainage (Fig. 1) in response to a higher initial water content from water stored in the profile during the same period.

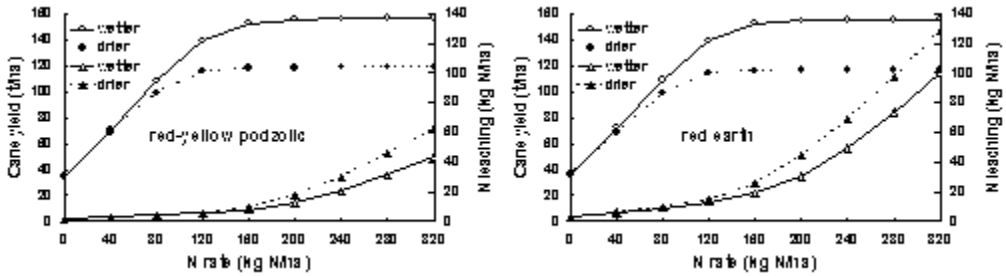

Figure 4

The average effect of N fertiliser rate on cane yield is characterised by a plateau (Fig. 4). Once a threshold rate is reached, any further increase in N applied does not ?increase yield, but it does lead to increased nitrate leaching. The yield plateau is affected by the irrigation regime. In the well-watered "wetter" scenario, the crop yield plateau is higher and reached at a higher N rate, while at the same time nitrate leaching is smaller. While somewhat counter intuitive, this is due to the greater crop growth and N demand compared with the water-stressed "drier" scenario, where unused N accumulates in the profile and is subject to leaching upon big rainfall events. It should be noted that this finding is particular to efficient irrigation regimes, where the main impact on nitrate leaching results from differences in crop uptake. Frequent inefficient irrigation could increase deep drainage, thereby adding to the risk of nitrate leaching.

The effect of soil type becomes clear by comparing the results of the red-yellow podzolic soil with that of the red earth (Fig. 4). The "drier" irrigation regime resulted in the same average total irrigation per cropping season (156 mm at maximum yield), but more nitrate was leached in the red earth, due to its higher permeability. In the "wetter" irrigation regimes the analysis is confounded by the higher average total irrigation amount for the red earth than for the red-yellow podzolic soil (475 vs 429 mm).

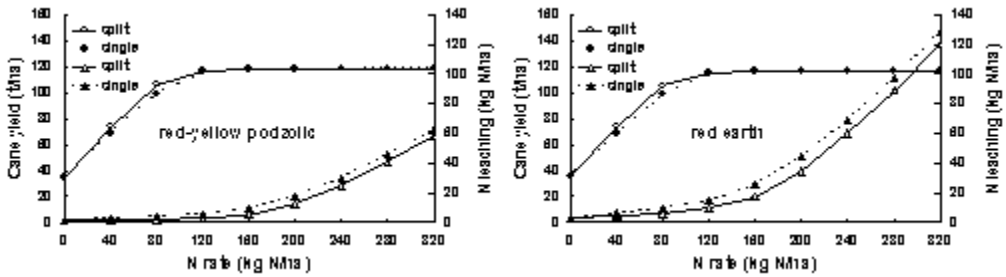


Figure 5

Split application of N fertiliser was expected to decrease the amount of nitrate leached, as it would reduce the amount of nitrate in the soil during the 90-day period between the two applications. The effect was, however, surprisingly small (Fig. 5). The main reason for this is the carry-over effect from one year to the next. Split application only reduces the amount of nitrate leached if it leads to higher N uptake than in a compar-able scenario of a single N fertiliser application. Otherwise its effect will be limited to a delay in leaching. Factors that influence this differential N uptake are the timing of the 90-day period relative to events of heavy rainfall and the depth of the root zone. The latter factor is another example of crop-soil interactions. If a soil is highly permeable and the root zone shallow the chance that rain during the 90-day period leaches N below the root zone is larger than in a less permeable soil with a deep root zone, hence increasing the potential of split application to lead to increased N uptake. As sugarcane is a fairly deep rooted crop, the effects of split application may be limited, especially in a climate like that of Bundaberg. Larger effects could be expected in high rainfall areas like around Innisfail, north Qld.

Concluding remarks

This study highlights the complex interactions between crop yield, soil type, weather, and nitrate leach-ing, and hence the importance of considering the whole system when examining management scenarios. The illustrated season to season variability in nitrate leaching and the limited effect of split N fertiliser application show that significant carry-over effects from previous years need to be taken into account. This finding applies not only to simulations, but also to experiments, as often confirmed by the absence of N response observed in the first year of cropping trials. The results also suggest that if N-fertiliser rates are matched to plant requirements and fertility status (lower rates for water stressed or plant crops) nitrate leaching could be reduced.

Acknowledgments

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