Computer simulation of the effects of cropping rotations and fallow management on solute movement

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Summary. Profile distributions of nitrate and chloride measured on a black earth near Warwick Qld, indicated that over 20 years of continuous winter cropping, nitrate losses by leaching represented up to 30% of applied fertiliser and were greatest where annual summer fallows were zero tilled. The APSIM system model was used to simulate the observed chloride movement patterns and then investigate the influence of alternative cropping rotations with both conventionally tilled and zero tilled fallows. Simulation results demonstrated that within the period 1969 to 1992, there were only three periods of rapid leaching. Those cropping systems which kept the soil dry, reduced drainage and chloride movement during these periods. Zero tillage combined with long fallows moved the most chloride whereas conventional tillage combined with shorter fallows and more intensive cropping moved the least.

INTRODUCTION

The Hermitage long-term fallow management trial was established in 1969 to study the influence of four fallow management strategies (combinations of zero tillage and conventional tillage with stubble burning and stubble retention) on nitrogen supply to a continuous winter cereal system (4). Analysis of the Hermitage soil (0-5.4 m) in 1989 for nitrate and chloride (7) provided information on rates of nitrate leaching losses (nitrate moved below the crop root zone) and solute movement under the trial's four fallow management treatments. Nitrate profiles indicated that nitrogen losses by leaching were greatest from fertilised zero tilled treatments (both stubble burnt and stubble retained), constituting up to 30% of applied fertiliser. Chloride profiles showed that drainage through the profile was greatest where fallows were zero tilled and stubble retained (ZTSR), with the chloride profile peak 2m deeper on ZTSR than any other management treatment. Analysis of two farm sites with similar soils to the Hermitage site, but growing wheat and sorghum in rotation with long fallows, indicated negligible nitrate losses. The possible reasons for the lack of nitrate movement on farm sites, include: 1. use of cropping rotations which include summer and winter crops, reducing number of summer fallows, 2. summer crops drying the soil more effectively, and 3. cropping rotations reduce the infestation of root lesion nematodes which restrict nitrate and water uptake by wheat roots (6).

The APSIM modelling framework (3) has the capability to simulate soil water, soil nitrate and crop growth and a range of summer and winter cultivars. Soil pathology issues like nematode infestations are, however, not simulated by the model. While it was possible to simulate nitrate leaching using this model, results may be unreliable, due to limited knowledge of the rates of some cycling processes, such as denitrification. We choose instead to simulate chloride movement at the site and explore the effects of alternative cropping rotations on the rate of solute leaching, to provide insight into why there was little nitrate leaching on the farm sites.

MATERIALS AND METHODS

To simulate 24 years of cropping at Hermitage (1969 - 1992), using APSIM's SOILWAT, SOILN and NWHEAT modules, required parameters describing the soil's water holding capacity and conductivity, the size and rate of turnover of organic pools and parameters defining crop growth. Probert *et al*.(5) used APSIM to simulate yield response to fertiliser and fallow management on the Hermitage trial. This work provided already tested parameters for the soil water, soil organic matter models and the six wheat and barley varieties grown between 1969 and 1989. Turpin (7) simulated chloride movement for the trial using the NEWHEAT model (unpub.), a predecessor to APSIM. This involved analyses of the sensitivity of soil water and chloride predictions to changes in soil water parameters. The 'best fit' values for these parameters have been used in this current study. As chloride was not measured at trial establishment in

1989, there was no accurate way of setting chloride at the start of the simulation. However, chloride was measured to 90cm in 1973 (2), and these values plus estimates of the chloride distribution in 1973 for deeper layers (based on chloride concentrations measured in poorly drained treatments in 1981(1) and 1989 (7)) were used to initialise chloride in 1973. Fig. 1 compares predicted and observed chloride distributions in 1989 for zero tillage with stubble retention (ZTSR) and conventional tillage with stubble burning (CTSB). These two treatments were chosen for simulation as they represent the extremes of stubble management. The only differences in model setup and parameters between these two treatments were: 1.the slightly different initial chloride profiles (Fig. 1), 2.greater conductivity in the surface layers of ZTSR and 3.the stubble burning and tillage events in CTSB. The burning and tillage events play an important role in decreasing the drainage rate in CTSB through reducing surface residues and thereby increasing simulated runoff and evaporation.

APSIM was then configured to grow two hypothetical wheat-sorghum rotations at the Hermitage site (using the CS_SAT sorghum model), for comparison with the continuous winter cereal rotation. The first rotation was a pattern of alternating sorghum and wheat separated by long fallows of 9 to 14 months (more if the sequence was interrupted by a missed crop). This sequence is commonly used by farmers on the Darling Downs to reduce risk of crop failure by maximising stored soil moisture. The second strategy was an intensive opportunistic cropping system where either crop (or even both) could be planted in any year, as long as there was 120?mm of available water and 30 mm of rain over 5 days within the specified planting window. Fertiliser was applied at planting in both systems at a rate of 69 kg/ha (the same rate as the Hermitage continuous wheat received), and cultivars grown were Hartog wheat and Dekalb-DK55 sorghum.

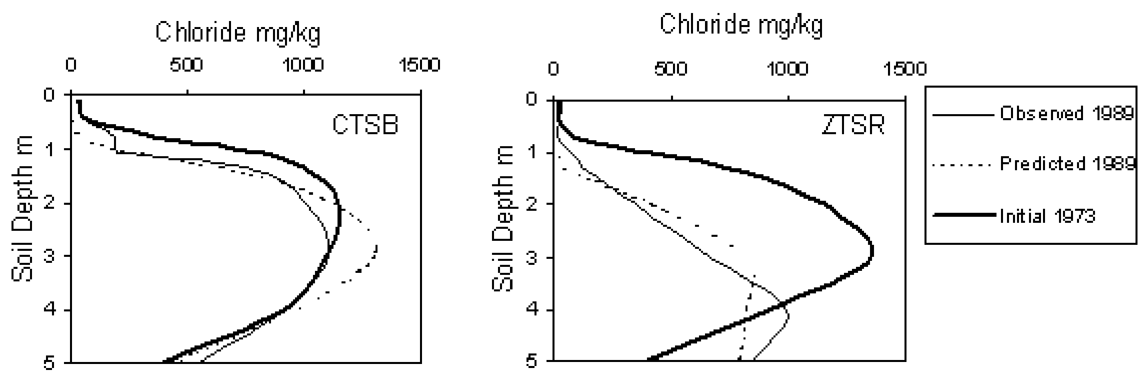

Figure 1: Observed soil chloride in 1989 compared with ‘best fit’ simulated chloride distributions for conventionally tilled, stubble burnt and zero tilled, stubble retained treatments on the Hermitage fallow management trial.

RESULTS AND DISCUSSION

Fig. 2 shows simulated total soil water for continuous winter cereals and the two hypothetical wheat/sorghum rotations, for both conventional and zero tilled fallows. The three wettest periods in this sequence were the mid 1970’s, 1983 and 1988 and each of these correspond to periods of rapid chloride movement (Fig. 3). The ZTSR systems were generally wetter than CTSB systems, particularly during the first ten years of the simulation. This meant there were not large differences in moisture contents between the three ZTSR rotations, whereas the difference in soil water between the CTSB long fallow rotation and the other CTSB rotations was very pronounced during the 1970’s. The long-fallow rotation (both CTSB and ZTSR) moved the most chloride out of the 90-120cm layer and into the 500-550cm layer during the simulated period because the profile was very wet during the 1970’s and the late 1980’s, as the strict rotational sequence did not provide for more intensive cropping during these wet periods. However this system did have a sorghum crop growing in 1982-83 and prevented leaching during this very wet period.

Whereas, the *cont winter* and the conventionally tilled *opportunistic rotation* had been fallow since the previous summer and therefore moved chloride during this period.

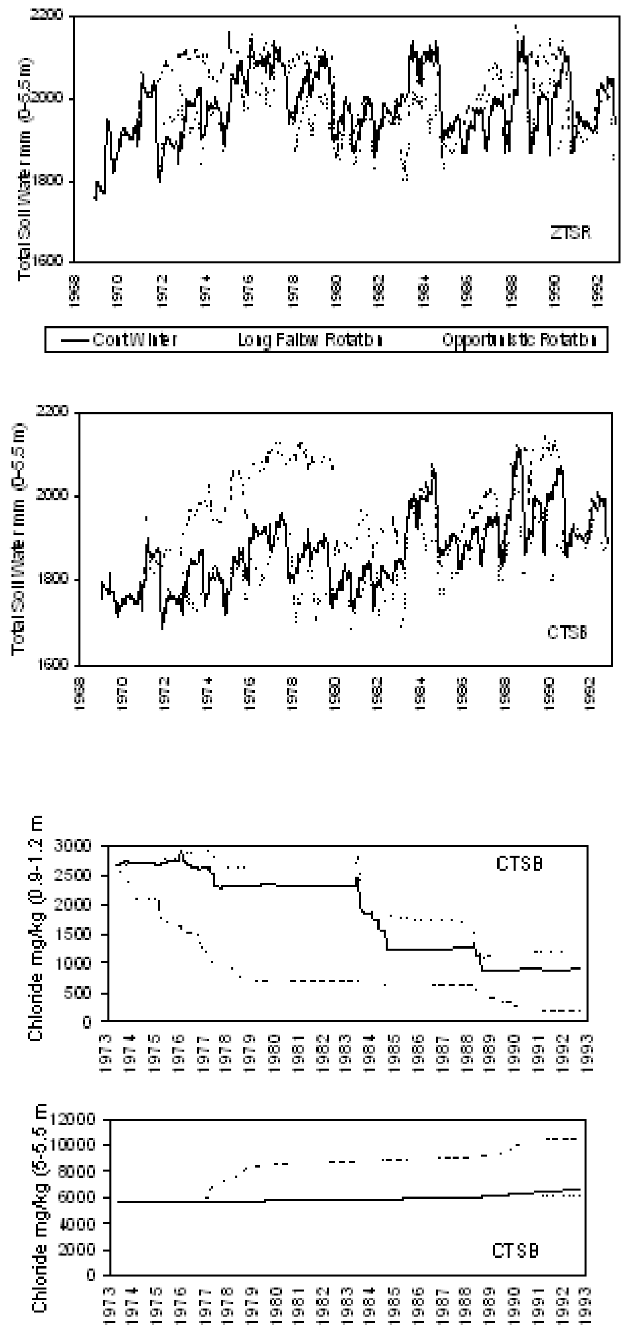

Figure 2: Simulated total soil water (0-5.5 m) for continuous winter cereal, long-fallow rotations and opportunistic rotations with both CTSB and ZTSR.

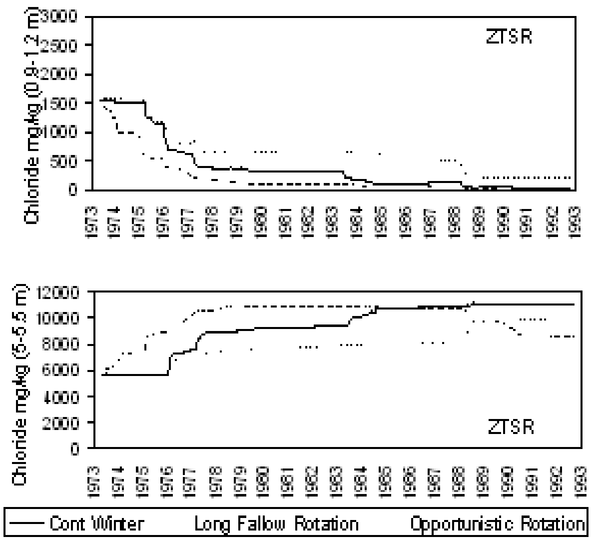

Figure 3. Simulated chloride concentrations in the 90-120 cm and 500-550 cm soil layers for each cropping systems for both CTSB and ZTSR.

Chloride distributions at the end of the simulated period (1989) are compared for the three cropping systems and two fallow management treatments in Fig. 4. Where fallows are conventionally tilled and the stubble burnt, the continuous winter cereal and opportunistic systems did not move chloride far from the initial (1973) distribution, but the long-fallow system moved much more chloride. Where fallows were zero tilled, chloride movement from the initial values was more rapid and chloride movement was markedly decreased with intensive opportunistic cropping and increased with use of long-fallows. Average annual drainage from the root zone (0-150 cm) for the six simulated systems were 5 mm (CTSB) and 20 mm (ZTSR) for continuous winter cereals, 15 mm and 42 mm for the long-fallow rotation and 3 mm and 11 mm for the opportunistic rotation. This indicates that the lack of observed nitrate leaching losses on our long fallow farm sites was not a result of reduced drainage, but perhaps decreased available nitrate-N because of better crop uptake through reduced nematode damage to roots or less fallow mineralisation.

The fact that there were only three periods of rapid drainage during the 24 years simulated illustrates the episodic nature of leaching. While the simulation results show clear and consistent differences between the rotations, a longer simulation period would cover a greater number of leaching events and thus give a more accurate picture of the risk of leaching losses in each of the systems studied.

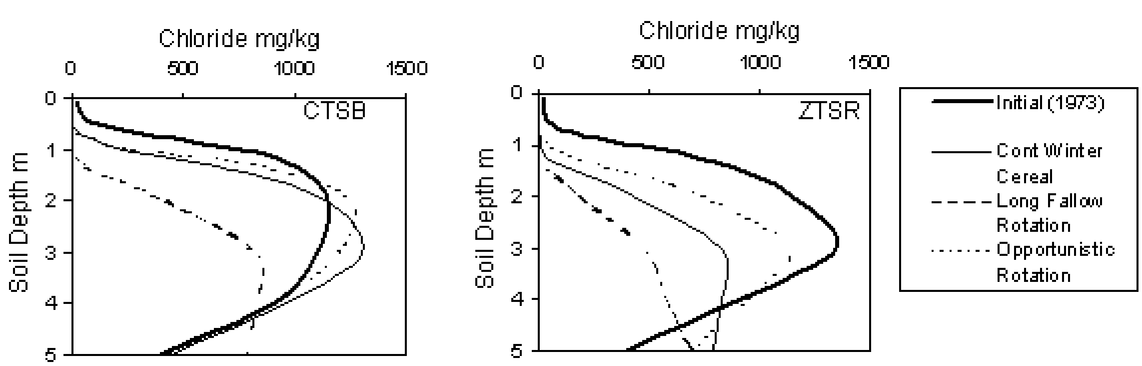

Figure 4. Simulated chloride distributions in 1989 for the three cropping systems with both CTSB and ZTSR, compared with initialisation values (1973).

CONCLUSIONS

Results suggest that, while fixed long-fallow rotations may decrease the risk of crop failure, they are generally increasing the risk of nitrogen leaching by increasing the severity of drainage events. As the heavy clay soils of the eastern downs do not represent an environment with a high frequency of leaching events, minimising leaching loss is probably not very important. However, the simulations of opportunistic cropping demonstrate the advantages of using soil water monitoring and flexible rotations to increase cropping frequency and decrease water and nitrogen wastage, particularly in zero tilled systems where infiltration rates are higher.

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