Australian Society of Soil Science Inc.
(WA Branch)

Soils '97

Advances in Soil Science for Sustainable Land Use

Proceedings of the Fourth Triennial Western Australian Soil Science Conference

CSBP

Helping to care for our Land, through more productive crops & pastures

African Reef Resort, Geraldton, Western Australia
30 September - 2 October 1997

Compiled by David R. Williamson

ISBN 095 865 9540

USE OF THE MACRO MODEL TO PREDICT EFFECTIVE LEACHING OF CHLORIDE BY RAINFALL IN A DEGRADED DUPLEX SOIL PROFILE

P.L. Bourgault du Coudray[1], D.R. Williamson[2], W.D. Scott[3]

[1]BOWMAN BISHAW GORHAM, Environmental Management Consultants, 1298 Hay Street, West Perth, Western Australia, 6005.

[2]CSIRO, Division of Water Resources, Private Bag PO Wembley, Western Australia, 6014.

[3]Murdoch University, Division of Environmental Science, South Street, Murdoch, Western Australia, 6150.

ABSTRACT

The determination of the time period for the rehabilitation of degraded salinised soil under natural rainfall conditions requires an appropriate simulation model of a macroporous soil system. MACRO (Jarvis, 1994) is a one-dimensional, mechanistic solute transport model which simulates the movement of reactive and non-reactive solutes through a macroporous soil profile containing up to 15 soil layers. The soil profile is treated as a two-domain flow system. The first domain is the soil matrix or micropore region where the transport of water is dominated by capillary forces. The second domain characterises the macropores within which water and solute flow is solely induced by gravity, with capillarity assumed negligible. The relative saturation of each domain determines the extent of the water and solute interaction between each region.

The model was applied to an investigation of chloride leaching from a de-watered saline duplex soil in the non-irrigated Wheatbelt region of south-west Australia. Hydraulic parameters obtained by monitoring a soil pedon over a two-year period provided input data for the calibration of the model. Within 250mm of the surface of the soil profile there was a dispersed layer acting as a hydraulic throttle.

MACRO model simulations were conducted for three management Treatments: I. Do nothing; II. Continually rip the soil surface to remove the throttle; III. Periodically rip the soil surface to remove the effect of sealing resulting from the dispersion of soil aggregates. The time period required to effectively leach the chloride from the profile, to a depth of 1.5m, was predicted. Effective leaching would take at least 400 years and possibly in excess of 200,000 years for Treatment I, 5 years for Treatment II and 90 years for Treatment III.

INTRODUCTION

In the past 50 years, agricultural production from dryland regions in south-west Australia has been significantly affected by salinisation. Surface soil salinity has developed as a result of over-clearing native deep-rooted vegetation (Peck, 1978; Williamson *et al*, 1987). The salinisation process involves the increase in discharge of groundwater, often saline, as seepage at the soil surface where water saturation and salinity combine to affect plant growth. To restore saline land for agricultural uses, both short and long term de-watering practices are required. Short term practices include artificial pumping or siphoning (Salama *et al*, 1994) while long term practices include revegetation in recharge areas, to more effectively utilise the rainfall in the whole catchment (Bell *et al*, 1990) and control the source of increased seepage. The objective of the project reported in part here has been to determine the physical processes of salt removal from salinised soils under natural rainfall conditions once the elevated groundwater level has been lowered.

Many saline seepage areas are associated with catchments dominated by duplex soils derived from in-situ weathering of granitic rock. Nulsen (1980) presented evidence that pathways for preferred flow exist within these soils. Therefore, the conceptual model for the leaching of these soils required the incorporation of the effects of preferred pathway flow.

This paper describes the use of the MACRO model (Jarvis, 1994) in understanding the leaching process in a heterogeneous pore system and examines the contribution of preferred pathways in the leaching process. The model accurately simulates field-measured values of runoff, soil water chloride concentration and soil water tension (Bourgault du Coudray, 1996). The model has been applied to predict the time period required to effectively leach chloride from a de-watered soil profile given three soil management scenarios.

MATERIALS AND METHODS

The study was undertaken using a three stage approach:

1. A pedon scale field study;
2. A laboratory simulation of leaching in a macroporous system;
3. Modelling of the system using the MACRO model.

The groundwater at a salinised field site called "Wimmera", within the Wallatin Creek Catchment near Kellerberrin, was artificially lowered below 2m by aquifer pumping with a windmill (Salama *et al*, 1994). A pedon of area $6m^2$ and 2m deep was established at the field site and instrumented with tensiometers, soil solution samplers and leachate interceptor trays (Bourgault du Coudray, 1996). The interceptor trays were installed at a depth of 1.8m to measure flow in preferred pathways. The stratigraphic features and soil physical parameters of the site were determined and detailed hydrological measurements of the pedon were made for nearly two years. The soil at the site was salinised and devoid of vegetation. The observation of active preferred pathways confirmed the importance of using MACRO.

A dispersed and compacted layer, acting as a throttle to vertical infiltration, was identified at a depth of 100mm. This layer was ripped to a depth of 250mm on Day 518, in the second year of the field study. Following rainfall, it was observed that dispersion of soil aggregates occurred resulting in the partial sealing of the rip fractures. As a consequence the soil surface was re-ripped during each site visit.

Field data including soil water tension and soil solution chloride concentration were collected. The data was used to calibrate the MACRO model to enable the predictive modelling of chloride leaching.

Description of the MACRO Model

The existence of cylindrical macropores (root channels of the native vegetation) and planar macropores (weathered quartz veins) required a model which could simulate the solute flow in a heterogeneous system. The MACRO model (Jarvis, 1994) is a one-dimensional, mechanistic model for water and solute flow through soil containing macropores. The model can be used for both conservative and non-conservative solutes and in its simplest form provides a numeric solution of the Richard's and convection-dispersion equations. The change in chloride concentration of the soil solution was used as the indicator of leaching. Driving variables for the model were field-measured values of rainfall and potential evaporation. The basic features of the MACRO model include:

1. The water balance in the profile, including movement between macropores and micropores, runoff, evapotranspiration, seepage (percolation) and drainage;
2. The interactions occurring at the soil surface;
3. The interactions occurring within the soil profile.

The soil profile is treated as a two-domain flow system. The first domain is the soil matrix (or micropore region) where capillary forces within the pore space are assumed to be dominant and solute transport occurs by both convection and diffusion. The second domain characterises the macropores within which water and solute flow is induced solely by gravity (convective flow) with capillarity assumed negligible. The relative saturation of each domain determines the extent of the water and solute interaction between each region. Macropore flow is generated when the water content in the soil is at or close to saturation and the rainfall intensity is larger than the saturated soil matrix hydraulic conductivity. When fully saturated layers exist within the simulated soil profile it is assumed that micropores will not drain or empty until the macropores have drained. It is assumed in the model that the hydraulic head of groundwater is maintained at a depth of 1.5m below the ground surface.

Calibration and Parameterisation

The input parameters were obtained from field-measured values wherever possible. Those parameters that could not be directly measured were obtained from relevant literature sources. The model was calibrated to accurately simulate field conditions both before and after surface ripping. Calibration involved initially adjusting the hydraulic parameters within the model until the simulated runoff quantity matched the field-measured runoff. Parameters estimated from literature sources were then adjusted until simulated values of chloride concentration were within one standard deviation of the field-measured values. Further parameter tuning was made to match the simulated and field-measured values of soil water tension. To simulate changes occurring in the field after ripping, only the parameters likely to be affected as a result of the ripping process, such as the degree of macroporosity, were adjusted.

Predictive Modelling

Predictive modelling was carried out for three management treatments, as follows:
Treatment I Do nothing;

Treatment II Continually rip the soil surface to remove the throttle;
Treatment III Periodically rip the soil surface to remove the effect of sealing resulting from the dispersion of soil aggregates.

The treatments were simulated by varying the saturated hydraulic conductivity of the surface layers to 250mm depth. For Treatment II, it was assumed that the physical properties of the soil aggregates remained unchanged with only the degree of porosity increasing to accommodate greater water infiltration. With Treatment III, the surface sealing was simulated by lowering the hydraulic conductivity of the surface layers in two stages until the soil had the same hydraulic properties as the non-ripped soil surface. Eleven years of rainfall and potential evaporation data collected from the nearby town of Merredin were used in the simulations. For simulations over periods longer than 11 years this climatic data set was replicated. Key outputs were plotted to determine the leaching response in each treatment. Linear, exponential and logarithmic regression curves were fitted to the simulated profile chloride storage values for Treatments I and III and extrapolated in order to establish the time required to achieve effective leaching. The soil profile to a depth of 1.5m was considered to be effectively leached when a chloride storage of 250g m^{-2} was attained. The original chloride storage for the pedon was 7200g m^{-2}.

RESULTS AND DISCUSSION

Calibration and Parameterisation

Figure 1 shows a good visual match between plots of field-measured and simulated runoff. The simulated chloride concentrations at 0.35m are shown in Figure 2 to be within one standard deviation of the field-measured values. This was the case for most depths, with the exception of the 1.1 to 1.5m interval of soil profile after ripping. Figure 3 shows that at a depth of 0.36m, simulated values of soil water tension compared favourably with field-measured values. The processes in the pedon were found to be well simulated by the MACRO model. The selected parameters were accepted as appropriate for predictive modelling.

The field results collected prior to surface ripping showed that there was no leaching occurring in either the micropores or the macropores. This was attributed to the hydraulic characteristics of the "throttle" layer within the top 0.25m of the profile. Because of the short-term nature of the field pedon study, the model was used to establish the relative importance of the two pore domains on the movement of chloride and water within the soil profile. Following ripping of the top 250mm, most water and chloride movement below the rip fractures occurred in the micropore domain. Macropore flow contributed to the movement of water but did not significantly affect the degree of leaching (Bourgault du Coudray, 1996).

Predictive Modelling

Figure 4 shows the relative quantity of chloride stored within the 1.5m of soil profile for all three soil management Treatments. The profile chloride storage decreased to almost zero after 2500 days (6.8years) for Treatment II. At 2500 days, the salt storage was still 6200g m^{-2} and 5200g m^{-2} for Treatments I and III, respectively.

For statistically acceptable prediction beyond 50 years, an exponential regression curve was most appropriate for Treatment III (Figure 5), whilst a logarithmic fit (Figure 6) was best for

Treatment I. The r^2 values were 0.98 and 0.96, respectively. Using an exponential extrapolation effect leaching was approximately 400 years for Treatment I (r^2 = 0.91) and 90 years for Treatment III. Using a logarithmic curve as best fit for Treatment I the time required to leach the top 1.5m of profile was approximately 200,000 years.

CONCLUSIONS

Natural chloride leaching of saline agricultural soils in a non-irrigated, low rainfall environment can be well simulated by the MACRO model, when groundwater levels have been stabilised. The model was run without modifications to any of the source code. Predictive modelling for three surface treatments showed that leaching would not occur unless appropriate soil treatment occurred to prevent runoff and increase water infiltration. By comparison, effective leaching of the top 1.5m of soil was achievable within 10 years if the dispersed and compacted soil layers remained in a ripped non-dispersed condition. However, field observations showed that after rainfall the ripped soil aggregates slaked, dispersed and sealed. When the effect of surface sealing following rainfall was periodically removed by ripping to re-establish water infiltration, effective leaching of top 1.5m of soil would take up to 100 years. This is about five times as long as the time it has taken for some duplex soils in the W.A. Wheatbelt to become saline. The application of these results to the real world of farming practice requires improved soil and groundwater management. This involves the use of chemical soil amendments to prevent the dispersion of soil aggregates following the removal of the hydraulic throttle by ripping. Given this, the time period to effectively leach the soil profile could be expected to be in the order of 10 years.

ACKNOWLEDGMENTS

This research was supported by the CSIRO, Division of Water Resources. We are grateful to Ms Sarah Palmer for editing the document.

REFERENCES

Bell, R.W., Schofield, N.J., Loh, I.C., and M.A. Bari (1990) Groundwater Response to Reforestation in the Darling Range of Western Australia, *Journal of Hydrology*, **115**, 297-317.

Bourgault du Coudray, P.L., (1996) Chloride Leaching of a De-Watered, Saline, Non-Irrigated Soil Profile, PhD Thesis, Murdoch University, Perth, Western Australia.

Jarvis, N.J. (1994) The MACRO Model (Version 3.1) Technical Description and Sample Simulations, Swedish University of Agricultural Sciences, Department of Soil Sciences, Reports and Dissertations 19, Uppsala, Sweden.

Nulsen, R.A., (1980) Preferred Pathway Leakage of Saline Water from Semi-Confined Aquifers. Proceedings International Symposium on Salt Affected Soils, Karnal, India, 227-232.

Peck, A.J., (1978) Salinization of Non-Irrigated Soils and Associated Streams: A Review, *Australian Journal of Soil Research*, **16**, 157-168.

Salama, R.B., Otto, C.J., Bartle, G.A., and G.D. Watson (1994) Management of Saline Groundwater Discharge by Long-Term Pumping in the Wheatbelt, Western Australia, *Applied Hydrogeology*, **2**, 19-33.

Williamson, D.R., Stokes, R.A., and Ruprecht, J.K. (1987) Response of Input and Output of Water and Chloride to Clearing for Agriculture. *Journal of Hydrology*, **94**, 1-28.

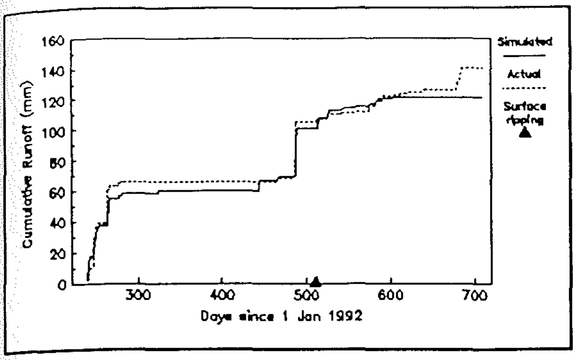

Figure 1 MACRO simulated and field measured values of runoff.

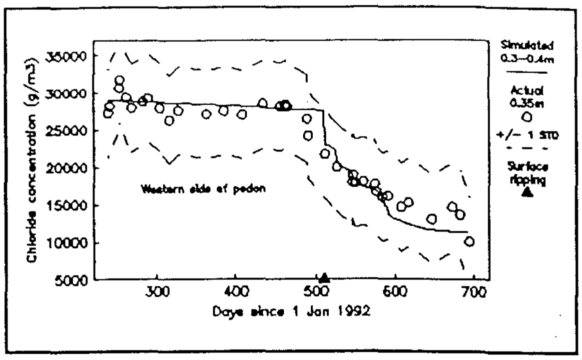

Figure 2 MACRO simulated and field-measured values of chloride concentration within the B horizon of the soil profile.

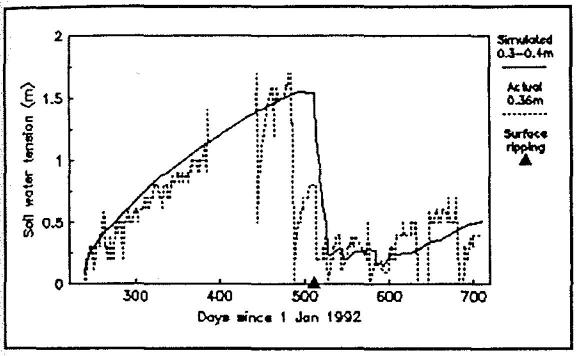

Figure 3 MACRO simulated and field measured values of soil water tension.

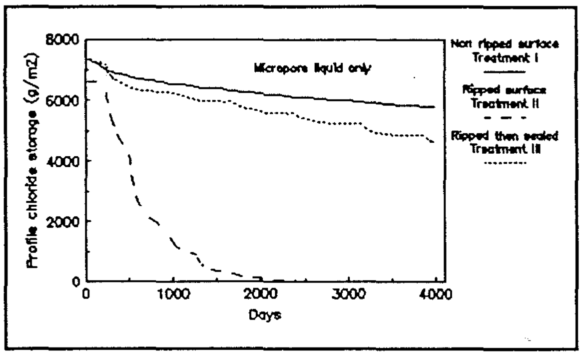

Figure 4 Predicted chloride storage in the micropore domain from the three surface treatment scenarios.

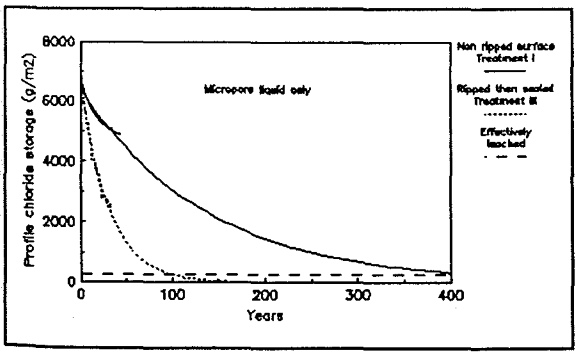

Figure 5 Exponential extrapolation of the profile micropore chloride storage for surface treatments I and III.

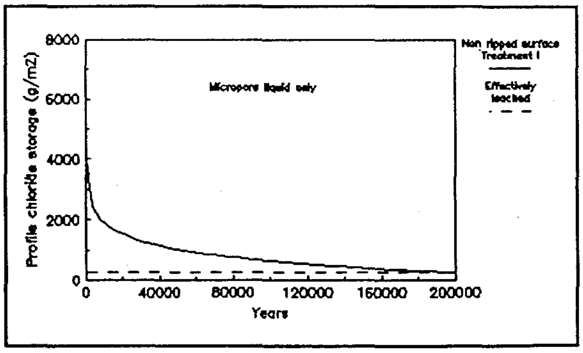

Figure 6 Logarithmic extrapolation of the profile micropore chloride storage for surface treatment I.