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Development, testing and application of a crop nitrogen and phosphorus model to investigate leaching losses at the local scale

by

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Submitted in partial fulfilment of the requirements for the degree PhD (Agronomy) in the faculty of Natural and Agricultural Sciences
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DECLARATION

I, Michael van der Laan, hereby declare that this dissertation for the degree PhD (Agronomy) at the University of Pretoria is my own work and has never been submitted by myself at any other University. The research work reported is the result of my own investigation, except where acknowledged.

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ABSTRACT

The leaching of nitrogen (N) and phosphorus (P) from the rootzone of cropping systems is a major contributor of non-point source pollution resulting in deterioration of fresh water supplies. An escalating world population is forcing further intensification of agricultural production practices and the identification of suitable and effective management practices to reduce N and P leaching losses is becoming ever more important. Such leaching losses are, however, extremely challenging to measure and quantify due to uncertainties associated with the estimation of deep drainage and N and P concentrations in this drainage water. SWB-Sci is a locally developed, mechanistic crop model to which N and P subroutines have been added to enable analysis of leaching losses at the local scale. This involved novel approaches to estimate the effects of N deficiencies on yield; to simulate crop P demand, uptake and stress effects; to simulate banded P fertilizer applications; and to estimate incomplete solute mixing. New equations to estimate the size of the *Labile P* pool from soil P tests commonly used in South Africa, and guidelines on the classification of South African soils as calcareous, slightly weathered or highly weathered which is required to simulate P, were also developed. The upgraded more versatile model was tested using historical datasets from the Netherlands, Kenya and South Africa, and performed well in simulating N and P dynamics in maize and wheat cropping systems. Variables tested included aboveground dry matter production, yield, leaf area index, aboveground crop N and P mass, grain N and P mass, soil water content and soil inorganic N levels. A study was also conducted on a large drainage lysimeter into which suction cups and wetting front detectors were installed, and data from this experiment together with the SWB-Sci model was used to study vertical solute movement more closely. As hypothesized, wetting front detector nitrate (NO_3^-) and P concentrations were observed to align closely with simulated mobile phase concentrations, and suction cup NO_3^- concentrations were observed to align closely with simulated immobile phase concentrations. These results confirm that monitoring and modelling can be used together to improve understanding and obtain more accurate estimates of N and P leaching losses, and further work on this approach is recommended for a wide range of soils and cropping systems. Finally, long-term modelling with the SWB-Sci model was used to analyse and compare N and P leaching losses from a dryland versus an irrigated monoculture maize production system. Over a 30 year simulation period, irrigated maize was estimated to leach considerably higher loads of N and P (~ 4-fold higher). For dryland production, zero leaching was observed for consecutive years on several occasions, with major leaching losses associated with high rainfall events. A 'room for rain' irrigation scheduling management practice was estimated to reduce N leaching by 12% and P leaching by 14%, while a crop rotation system which incorporated wheat grown over the winter months was estimated to reduce N leaching by 23% and P leaching by 24%. From this study, long-term modelling was confirmed as an effective approach to investigate N and P leaching losses, to assist with the planning and design of field trials, and to assess the effectiveness of best management practices. It is envisaged that SWB-Sci will continue to evolve as a valuable tool for analysing and reducing N and P leaching losses from cropping systems to further reduce non-point source pollution.