Modelling Nitrogen Dynamics in Cotton Cropping Systems

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Introduction

Nitrogen management plays a key role in cotton production. It is the nutrient required in greatest quantity by the crop and it is the nutrient most often deficient. Despite a large investment in fertilizer N in cotton cropping systems, the efficiency with which it is used by the crop can often be very low. This efficiency can vary greatly from season to season, between different forms of management and between cotton cropping systems. Much of this variation can be attributed to variations in the amount of N lost from the cotton cropping system.

The N that is not recovered by the crop may be lost to the atmosphere through volatilization of ammonia or as the gaseous products of denitrification. It may also be lost from the rooting zone via the leaching of nitrates and it can be made unavailable to the plant through immobilization in the soil. In dryland cropping systems it may also become inaccessible to the plant through lack of water. The relative importance of each of these various transformations which affect the use of N is influenced by climatic, soil and crop management practices. The many transformation pathways and the number of factors affecting each makes N one of the most complex plant nutrients to study. The difficulty of quantifying these factors and their interactions makes the task of prescribing fertilizer rates and management practices a difficult task. The N which is lost from the cropping system is of considerable concern. Some of the N lost via denitrification is an atmospheric pollutant and a significant contributor to the greenhouse effect and ozone depletion. Some of the N lost via leaching can pollute groundwater and N lost from the surface of soils, either directly from the fertilizer or with soil loss can be a significant source of stream pollution. In some regions of the world these negative aspects of N fertilizer use have precipitated legislation aimed at restricting levels of fertilizer application.

Simulation Models

Computer simulation models that predict the effects of weather, soil properties, and crop management on nutrient dynamics and crop growth processes can contribute to our understanding of fertilizer management in cropping systems. Such models, with the capability of readily simulating various crop and fertilizer management strategies, should lead to an improvement in the efficacy of fertilizer decision making. Optimizing fertilization strategies, given the uncertainties of climate, is generally difficult and can become more difficult when issues of soil trafficability and compaction associated with the passage of heavy machinery are considered.

A comprehensive simulation model of the cotton crop incorporating procedures to describe the growth and development aspects of the crop and the balance of water and nitrogen in the soil is needed to address these issues of fertilizer management. The OZCOT model (Hearn 1990; Wells and Hearn 1992) developed at the CSIRO Cotton Research Unit is a model which simulates the daily growth and development of cotton fruit, leaves and stems. The model incorporates a soil water balance procedure enabling the simulation of the effect of water deficits on growth, development and the components of yield. The model is driven by daily weather data and is thus sensitive to prevailing temperatures, rainfall conditions and solar radiation inputs. The simulations produced by this model provide the basic crop data for decision support packages used in pest management and irrigation scheduling.

In cereal cropping systems the CERES (Ritchie 1991) family of simulation models have been widely used to address several issues of fertilizer management. The CERES models simulate water balance, growth and development of the crop as well as the balance and transformations of nitrogen in the soil. The models have been widely tested (Otter-Nacke et al. 1985) and have proved reliable in a diversity of cropping systems. Work is currently in progress at the CSIRO Cotton Research Unit to combine the water and nitrogen simulation routines of CERES to the crop growth, development and yield components of the OZCOT simulation model.

Description of the CERES nitrogen simulation model

A technical description of the nitrogen component of the model may be found in Godwin and Jones (1991) and thus only an overview is presented here.

The nitrogen component of the CERES model describes the breakdown of crop residues and root material and the associated mineralization or immobilization of nitrogen. The mineralization of the soil organic matter or "humus" is also simulated. The pools and pathways considered in the model are depicted in Figure 1. The model can simulate losses of nitrate through leaching and through the process of denitrification and it also simulates the conversion of ammonium to nitrate (nitrification). Ammonia volatilization is depicted in Figure 1 with a dotted line to indicate that this process is not explicitly described in the model. Under most circumstances in cotton cultivation fertilizer is placed below the soil surface and significant N losses through this process are not likely to occur. Exceptions to this can occur if broadcast or water run applications of urea or anhydrous ammonia are made. Ammonia volatilization is included in a special version of the model for rice cropping systems where ammonia loss from the floodwater can form a substantial portion of the nitrogen lost from the system.

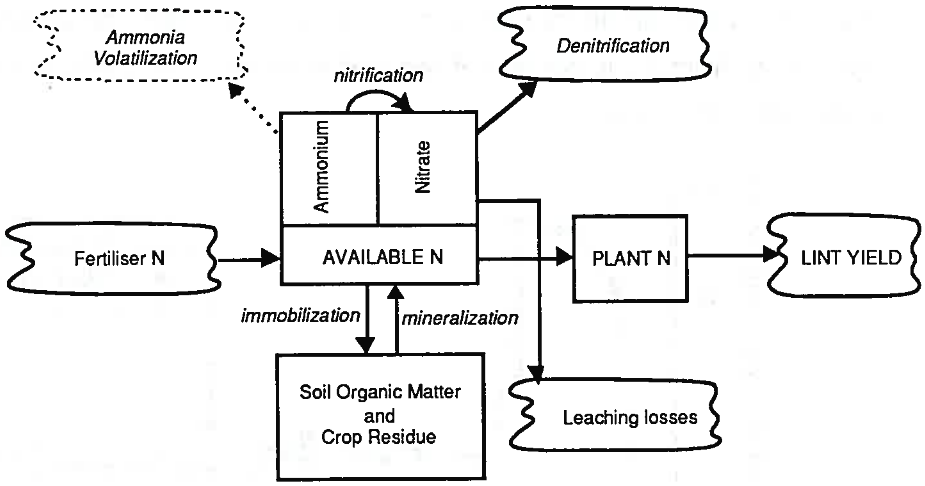

Figure 1: Systems diagram of nitrogen in the cotton cropping system.

The model is sensitive to the type of fertilizer used and to the placement of fertilizer. It addition to the inputs required by the crop and water balance parts of the model the N component requires data on the amount of mineral N in the profile at the start of simulation, the concentration of soil organic carbon, soil pH , and an estimate of the amount and type of crop residue present. The fertilizer data required by the model are the date, type of fertilizer, placement depth and amount for each fertilizer application. The model maintains pools of nitrate, ammonium and urea in each soil layer. When fertilizer applications are made , the fertilizer nitrogen is partitioned into these pools according to the type and depth of placement.

Testing of the Model

Considerable testing of the nitrogen components of the CERES model has been reported elsewhere (Otter-Nacke et al. 1985), and this has shown the model to be quite reliable over a diverse range of data sets. To date only limited testing has been performed under cotton. A priori there is no reason to suspect differences in simulation of soil nitrogen and nitrogen losses between cereal and cotton cropping systems.

As part of the ongoing work on testing and development of the model, it was run against a field experiment at Myall Vale conducted by Freney and Humphries (unpub). In this experiment 60 kg of N per ha as ^{15}N labelled urea was placed under ridges in each of March June and September 1988. Periodic observations of ^{15}N were made after placement. The simulated time course of mineral N and the corresponding observations in the top 30 cm of soil in this experiment are depicted in Figure 2. Here the spike following fertilizer application can be seen and the subsequent run-down in mineral N as N is lost from the system and as some movement from the upper part of the profile occurs. The model is simulating these conditions effectively

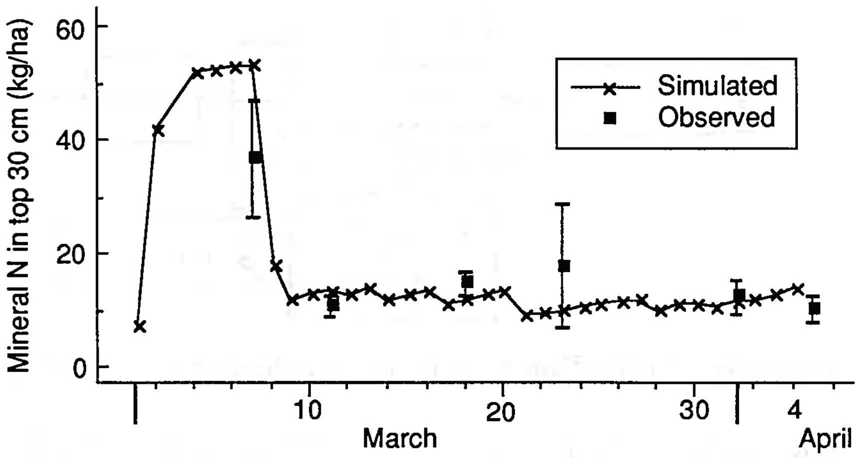

Figure 2: Comparison of simulated and observed mineral nitrogen levels in the top 30 cm of soil after a March nitrogen application.

Applications of the Model in N Management

It is envisaged the model could be used for the following:

- evaluation of the risks of losses attached to early applications of fertilizer;
- examination of the probability of response to split applications;
- determination of the magnitude and frequency of N losses;
- evaluation of fertilizer management options.

When the work on coupling the soil N model to the plant routines of OZCOT is complete the model will be used to examine the consequences of differing fertilizer management strategies on crop growth and performance. Broader applications of the complete model in risk studies on dryland cotton, irrigation management and agronomic and environmental studies are envisaged.

N Risk Study

The N model at this stage of development is suitable for examination of the fate of N in fallows as shown by the testing described above. A study to examine the risks associated with early applications of N fertilizer has been conducted. The aim of this study was to find out how often large losses of N from early pre-plant applications of fertilizer occur. In this study soil physical and chemical data representative of a typical Namoi cotton soil were used. Simulations were run examining the fate of applications of fertilizer made in each month from January to September. In each case 100 kg of N as urea was applied at a depth of 10 cm. The simulations were run with weather data for each of the 16 years from 1976 to 1990. In each year of simulation the same initial soil conditions were deemed to exist on January 1. Cumulative losses to the end of September were compared. Losses in most years were primarily due to denitrification although some leaching did occur. Losses were in general greatest from the January applications. Losses varied greatly from year to year and from the January application varied from 8 to 70 kg N/ha. The range of these losses and the mean loss is indicated in Figure 3. In this Figure the upper bound indicates that N losses would be less than this amount in 80% of years. Losses in excess of 48 kg N /ha can be expected less frequently than 1 year in five. The lower bound indicates that losses would be less than 14 kg N/ha in 20% of years. In 60% of years losses are between this two bounds.

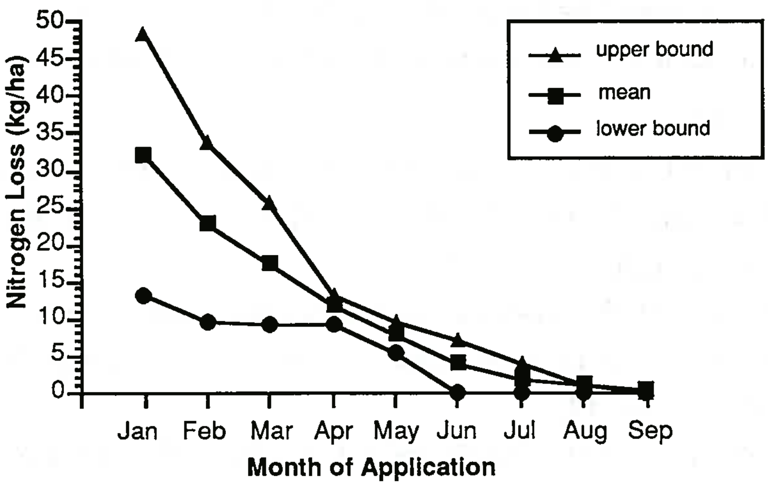

Figure 3: Simulated effect of time of nitrogen application on the likelihood of nitrogen loss.

From a practical point of view the Figure indicates there is considerable risk associated with a January pre-plant application of N and the chances of substantial losses of N from applications made after June are small.

Further Work

Work is continuing on the merger of the CERES and OZCOT models. Additional procedures are required in this model to accommodate such practices as water run fertilizer and to overcome some small anomalies associated with N movement in the ridge and furrow system. Simulation of water movement and the associated movement of N in cracking clay soils has long been a problem with all models. An examination of alternative approaches is underway. The status of N in the tissues of a cotton plant is an important determinant of crop growth and formation of yield. Procedures for simulating the response of plant N to soil N and the corresponding response of the plant to a changing N regime are undergoing development. These procedures will be fundamental to achieving a reliable prediction of cotton crop response to nitrogen.

Summary

The CERES simulation model described here can reliably describe the fate of nitrogen in cotton fallows. When this model has been successfully merged with the OZCOT cotton model, detailed studies of N dynamics under cotton crops can proceed. Simulation modelling of N dynamics in cotton cropping systems has the potential to become an important adjunct to field experimentation. Because simulation modelling has the ability to rapidly evaluate a range of crop management alternatives it will have an important role in decision support systems of the future.

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