SIMULATION OF NITROGEN DYNAMICS IN WHEAT CROPPING SYSTEMS

by

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ERRATA

Page 10, line 24--Various loss processes.

Page 22--Equation dy/dx should read dY/dX.

Page 23--Equations should have X rather than x.

Page 28--Replace last sentence with:

> "Since crop yield is an input to these models, they cannot be used to describe response to fertilizer but they can be used to provide a prescription for fertilizer amount."

Page 31--Last sentence, which is continued on page 32, replace with:

> "Since these models are driven by daily weather data they should, in principle, have the capacity to account for yield and response variations from year to year."

Page 32--Equation:

> Replace w with W on left hand side of equation and in sentence above equation.

Page 32, line 22--.... as a ratio of an actual ....

Page 34--Delete second sentence.

Page 35, line 23--(Hanks and Ritchie, 1988).

Page 36, line 16--.... a function of soil nutrient ....

Page 42--Delete last sentence, paragraph 2.

Page 42, line 23--.... theory and/or solution of systems of simultaneous ....

Page 43, line 22--.... The minimum data set (MDS) for rice ....

Page 44, paragraph 1--Add the following sentences at end of the paragraph:

> "Most of the models listed in Table 2.3 have been subjected to limited testing while some have had no testing. Those which had limited testing are indicated by an "L" under the testing heading and those with no reported testing are indicated by "0"."

Page 45, table 2.4--Caption should read $y = ax+b$.

Page 45, line 2--Model with the simulated mass of nitrate for the upper 60 cm.

Page 49, line 11--Insert reference as follows:

> The original version of the model (Ritchie and Otter, 1985) had no nitrogen component.

Page 51, paragraph 2--Should appear as paragraph 1, page 53 immediately prior to section 3.2.

Page 56, figure 3.2c--Add an arrowhead coming into the WATBAL box from the Water Balance decision diamond.

Page 88, paragraph 1--Add the following sentence at the end:

> "For a more detailed description of the temperature model, the reader is referred to Williams et al, (1984)."

Page 89, line 18--The original CERES-WHEAT model (Ritchie and Otter, 1985) was developed ....

Page 93--At the end of the first paragraph, add the following sentence:

> "Critical N concentration refers to N concentration in the above-ground vegetative parts of the plant."

Page 178, line 10--.... data with statistical properties .....

Page 235, line 11--.... by the CERES-WHEAT model without the nitrogen components was the ....

Page 276--Delete the first paragraph.

Bibliography--Add Richardson, C. W., and Wright, D. A. (1984). WGEN: A model for generating daily weather variables. U. S. Department of Agriculture, Agricultural Research Service, ARS-8, 83 p.

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Appendices

Acknowledgments

When undertaking a project such as this, spanning several disciplines and working in three quite different research institutes, one accrues many debts.

Before specifically nominating those due for special thanks I would like to mention that my initial interest in crop modelling and the potential it held as a new science was originally kindled in 1974 as an agronomy undergraduate in a series of lectures provided by Dr. R.C.G. Smith, now of CSIRO Griffith. My interest was later developed further during postgraduate study in agricultural economics with Professor Jock Anderson of the University of New England. I wish to thank these two excellent teachers for providing the initial motivation for launching my career in the direction it has taken.

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Abstract

Some 8 million tonnes of fertilizer N are applied annually to the world's wheat crop. The efficiency with which this is used is very variable but in general poor. Much of this variability in fertilizer efficiency and hence crop response to N is due to differences in climate. Soil physical and chemical properties, crop residues, crop variety, and management practices also influence crop response to fertilizer and efficiency. A tool which is able to reliably predict crop response to N and determine the causes and magnitude of poor fertilizer recovery could greatly assist crop and fertilizer management. Various approaches to describing the response to N and their ability to capture the effects noted above are reviewed in the thesis. The shortcomings of traditional response research are highlighted and dynamic computer simulation modelling is advanced as an appropriate methodology. A review of modelling methodologies and models of N dynamics in cropping systems is presented. The review indicated that one comprehensive model with a management or user focus and which is able to accommodate the effects of the factors listed above is lacking.

This thesis describes the CERES-WHEAT model and the development of an N component for it. This model utilizes a daily time step and is designed to be able to simulate the growth, yield, and response to N of a wheat crop grown anywhere in the world. The model requires daily climatic data as well as data describing soil water storage characteristics and data pertaining to soil factors which influence the supply of N to the crop. The model utilizes several genotype specific coefficients to characterize a cultivar's response to environment. Management data defining the time of planting, plant population, fertilizer rate, source, and time of application are also required. The CERES-WHEAT model describes the processes of evapotranspiration, soil water balance, crop ontogeny as affected by temperature, photoperiod, and vernalization, and the growth of leaves, stems, roots, ears, and grain. The nitrogen component of the model adds to this the description of mineralization and/or immobilization of N associated with the decay of crop residues, mineralization of "stable" organic matter, movement of nitrate in the profile, nitrification, denitrification, uptake of N by the plant, plant N effects on growth processes, and redistribution of N within the plant associated with grain filling. The derivation of the functions for each of these processes and their relationship to published information is described.

To validate the model, data sets from field experiments on wheat from various locations in the world were assembled. These data sets encompassed a broad range of climatic environments, crop cultivars, soil conditions, fertilizer rates, and management practices. Simulated yield, biomass, total N uptake, grain N uptake, and N balance compared favorably with observations. The statistical techniques available for simulation model validation were reviewed and validations compared using various techniques.

Weather simulation techniques were reviewed and as a prelude to long-term simulations the WGEN stochastic weather simulator program

was evaluated. Long-term daily rainfall and temperature data for many sites in the Australian wheat belt were assembled and used to calculate coefficients for the WGEN weather simulator. Long sequences of daily weather data for each location were synthesized using these coefficients and the WGEN simulator. Rainfall synthesis performance aspects of WGEN were assessed by comparing predicted and observed values of several parameters. These parameters were daily and monthly rainfall amount, rainfall frequency, wet spell length, dry spell length, and the frequency of large rainfall events. Similarly the validity of synthesized temperature data were examined by comparing predicted and observed mean maximum and minimum temperatures, temperatures on wet and dry days, and the occurrence of temperature extremes. WGEN was able to produce sequences of daily weather data statistically similar to observed sequences at most locations. Exceptions to this occurred when the length of run used to characterize the parameters was short.

Several sensitivity analyses of the CERES-WHEAT model were performed. The first of these involved running the model coupled to WGEN at Rothamsted (UK), Wichita (Kansas, U.S.A.), and Wongan Hills (W.A., Australia). In this analysis key variables were perturbed up and down 5%, 10% or 20% and the model run with 20 years of simulated climatic data. Results from a run with a variable perturbed were compared to a standard run with no variables perturbed. Runs were made both with a moderate fertilizer rate and with no fertilizer applied. Differences in simulated grain yields, biomass, and N uptake

were used as indices of sensitivity. The analysis showed daily rainfall to be the most sensitive parameter. Other sensitive parameters were temperature, solar radiation, variables affecting soil moisture availability, and when no fertilizer was applied certain variables which affect the supply of N to the crop were sensitive. Sensitivity varied among the three sites. Other sensitivity analyses were conducted to examine the model's sensitivity to fertilizer rate, timing, placement, and to nitrification inhibition. To examine sensitivity to fertilizer rate and timing, data from a fertilizer timing experiment on a coarse sand in Western Australia were used as the basis for a reference simulation. Combinations of fertilizer rates, split-application patterns, and times of application illustrated sensitivity to these management options and enabled identification of treatments where losses were minimized and grain yields were maximized. Sensitivity to depth of placement was investigated using 20 years of simulated climatic data for Jondaryan (QLD, Australia) and Waite Institute (SA, Australia). The range of responses in simulated grain yield to deep placement of fertilizer compared to surface incorporation of fertilizer was much greater at Jondaryan than at the Waite Institute. The nature and magnitude of the response to simulated deep placement was very seasonally dependent. Sensitivity to nitrification inhibition was examined using a sequence of simulated weather data for Rothamsted and comparing a simulation run with nitrification blocked for 30 days following a fertilizer application with a control run with nitrification not inhibited. In most years the simulated inhibition reduced simulated leaching and denitrification losses but the resulting savings contributed only slightly to improved fertilizer recovery and had little impact on grain yield.

The simulated growth of wheat crops and the response to various fertilizer strategies was examined in three locations forming a north-south transect and three locations forming an east-west transect of the eastern Australian wheat belt. Each fertilizer strategy was compared to a reference simulation using 50 years of simulated daily weather data. Risk analysis procedures incorporating the principles of stochastic dominance were used to evaluate the strategies. Simulated losses at each location were usually small and the response to N determined by the availability of water. With the given initial conditions, the analysis determined appropriate N rates and also suggested that possibilities for improving N fertilizer efficiency in these locations via changes in fertilizer management were usually limited.

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