Prediction of effects of nitrogen management on barley quality for malting

J.M. de Ruiter

New Zealand Institute for Crop & Food Research Ltd., Private Bag 4704, Christchurch, New Zealand

Abstract

Consistent high quality barley (*Hordeum vulgare* L.) for malting is difficult to achieve in high fertility sites and on soils with low water holding capacity. Poor quality grain may result from excessive nitrogen (N) uptake and consequently high amounts of N translocated to the grain, or incomplete filling of kernels in drought situations, especially on light soils. A mechanistic model which has the capacity to predict grain quality variables such as grain N concentration and grain size was validated with a field experiment. The validation crop was grown in the North Island of New Zealand under four N management treatments without irrigation and compared with a simulated crop for growth responses. Dry matter (total and grain) yield and crop N uptake agreed closely with the simulation results. There was also close agreement between the simulated and the observed variables for grain characteristics, although prediction of grain N concentration was higher than the observed values across the range of N treatments. The model sensitivity for grain N and grain size was evaluated over an extended range of N applications and for variable soil moisture conditions simulated by calculated deviations from long term mean rainfall. These simulations provided guidelines for improved N management during the growing season to achieve more consistent grain quality.

Additional key words: *grain protein, yield, crop monitoring, crop simulation, decision support*

Introduction

Simulation models which operate at the process level and which predict grain quality can potentially be used to assist growers in management of crops to achieve desired grain quality. This is especially useful in situations where the climate, soil water and soil nitrogen (N) are variable, as these all have a strong influence on the pattern of crop growth. Yield and quality stability in variable environments must be considered in attempts to optimise the management of crops. Desired characteristics of barley grain for malting are grain N concentrations of less than 2% and mean grain size in excess of 35 mg. A compromise must be reached to optimise quality while not sacrificing grain yield by limiting the crop N uptake. An earlier study (de Ruiter *et al.*, 1993) has demonstrated the capabilities of a process level model which accounts for nitrogen and water effects and their interactions. The objectives of this study were to (a) validate a model for predicting growth and yield of malting barley with data from a field experiment with treatments differing in timing of N fertiliser application and (b) examine the sensitivity of grain size and grain N concentration in situations of variable soil water and N fertiliser application.

The Model

A barley simulation model was adapted from a spring wheat model (van Keulen and Seligman, 1987) and preliminary calibrations were described in an earlier study (de Ruiter *et al.*, 1993). This model provides a mechanistic simulation of the dynamics of water and nitrogen in the soil and their availability to the crop, while disregarding limiting factors such as weed competition, pests and diseases. The crop accumulates dry matter and nitrogen in the roots and above ground organs of leaves, sheath and stem, and grain. Dynamics of crop growth are based on functions for photosynthetic performance, organ formation, and distribution of assimilate and nitrogen among the various plant organs in relation to a linear developmental scale. Most functions in the model are formulated to account for moisture and N stress at any point in crop development.

Starting values for soil and plant variables as well as daily meteorological data (maximum and minimum temperature, solar radiation, and rainfall) are required. Characterisation of the soil environment is imperative for reliable simulation of the water and nitrogen balance. The model runs under a FORTRAN-77 Simulation Environment allowing flexibility for input of weather data, and input of soil and plant variables (van Kraalingen, 1991).

Model Validation

A validation trial was conducted in the 1993/94 season on a Manawatu fine sandy loam with a low pre-season inorganic N level. Barley (cv. Triumph) crops were sown on 1 October with four nitrogen fertiliser treatments arranged in a randomised complete block design. Nitrogen was applied in the form of urea at a rate of 50 kg N/ha per application. The 'N application' treatments were at sowing, at sowing + tillering, and at sowing + tillering + anthesis. Significant rainfall events occurred at 26 days (80 m) and 10 days (25 m) before anthesis. In addition, 26 m fell in early grain filling. Soil moisture was therefore not limiting during grain filling, but near physiological maturity the soil had dried to levels typical of long term mean levels.

Simulated total yield and grain yields were within 10% of the observed values (Fig. 1). Similarly, leaf area development, tiller numbers, total N uptake, harvest index and N harvest index all agreed closely with the simulated treatments (data not shown). There were significant effects due to added N fertiliser in the validation crops for grain N concentration, grain number per unit area and grain size (Table 1). Grain N concentrations were 0.20 - 0.35 % N lower than in the simulated crop. This was unexpected, but could be explained as the season was particularly wet, therefore causing lower soil N concentrations through downward leaching of inorganic N. In addition, optimal conditions for grain growth enabled maximum 'dilution' of the protein in the grain. At the same site in previous years, grain N was closer to 2% (de Ruiter and Brooking, 1994). Simulated leaf area and tiller development are particularly sensitive to the level of available N for plant uptake and therefore it was not surprising that deviations from observed responses were noted. Inadequate simulation of the levels of soil inorganic N or the rates of mineralisation during growth may also account for deviations from observed crop responses.

Simulations with Variable Rain and N

A series of simulations were performed to show the extent of changes in grain quality if seasonal or management options were varied. Simulations using climatic data for the 1993/94 season were compared with simulations with long term mean weather data and calculated deviations (-50% to +50%) from the long term mean rainfall. These served as a realistic test of the sensitivity of grain quality variables to environmental variation.

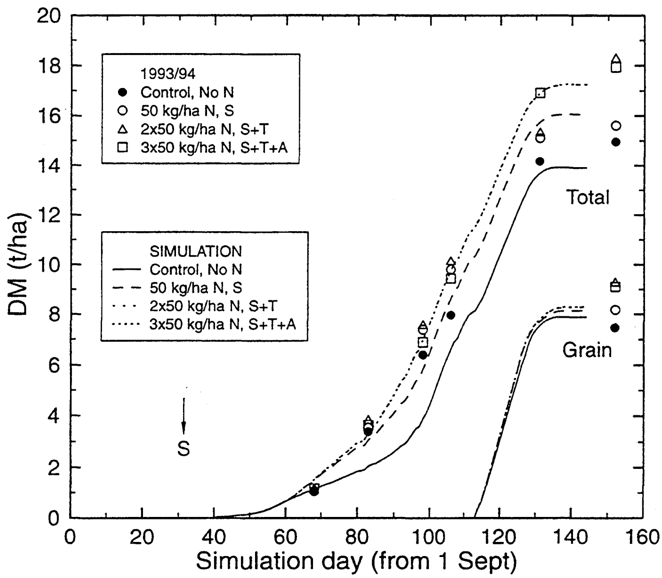

Figure 1. Simulation of total above-ground yield and grain yield compared with field observations of barley (cv. Triumph) sown on 1 October 1993.

Table 1. **Grain characteristics of field trial data for the 1993/94 season and simulated values (Sim) for four nitrogen (N) treatments (control, 0 N applied; 50 kg N/ha at sowing (50); 50 kgN/ha at sowing and 50kgN/ha at tillering (2x50); 50kgN/ha at sowing, tillering and anthesis (3x50)).**

Variable	Observed or Simulated	Treatment Control	50	2x50	3x50	$LSD_{(0.05)}$
Grain N (%)	1993/94	1.40	1.47	1.68	1.71	0.12
	Sim	1.60	1.83	2.00	2.00	-
Grain size (mg)	1993/94	39.5	40.7	38.7	36.3	1.89
	Sim	35.8	34.5	34.9	35.0	-
Grains per m^2	1993/94	19240	20487	22735	25123	4404
	Sim	22030	23593	23712	23712	-
Grains per ear	1993/94	23.3	24.0	23.4	24.3	1.65
	Sim	23.2	20.3	20.0	20.0	-

Grain nitrogen concentration

Linear increases in grain N concentration up to the 2% level occurred for the range of 0-100 kg N/ha total N irrespective of the timing of application (Fig. 2). Probabilities for achieving excessive grain N were increased by 20% if supplemental N was applied at tillering (Fig. 3). The pattern of response was dependent on the soil moisture (Fig. 4). There was a 50% chance of exceeding 2% grain N in an average rainfall year with total N applications up to 200 kg N/ha applied prior to tillering. In drier seasons, there was an increased probability of high grain N concentration at harvest. If

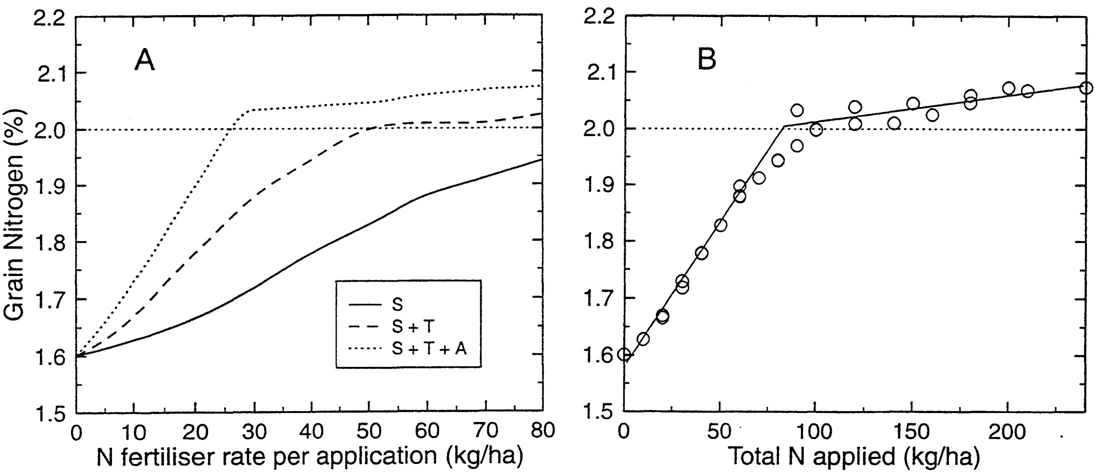

Figure 2. Simulation of the effect of N fertiliser application rate and timing on grain N concentration. Long term mean climatic data for the Manawatu were used in the simulation. A, effect of application rate at sowing (S), tillering (T) and anthesis (A); B, relationship with the total N applied irrespective of the timing.

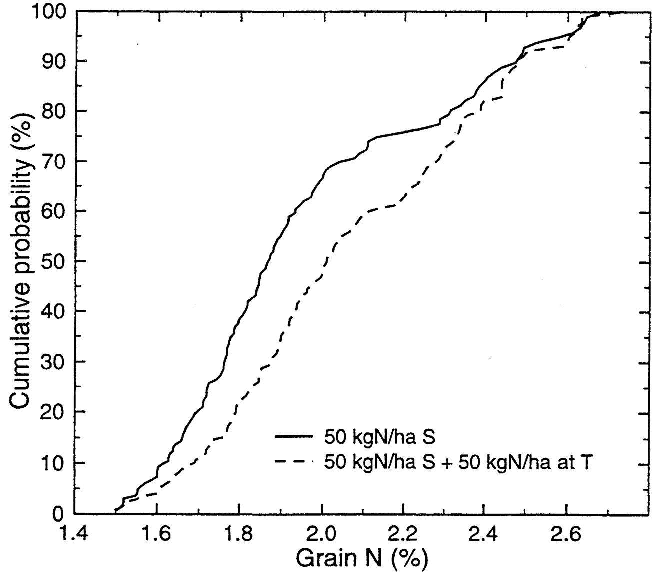

Figure 3. Cumulative probability function for simulated grain N concentration for low and high N management options given rainfall deviations of +50% to -50% from the long term means.

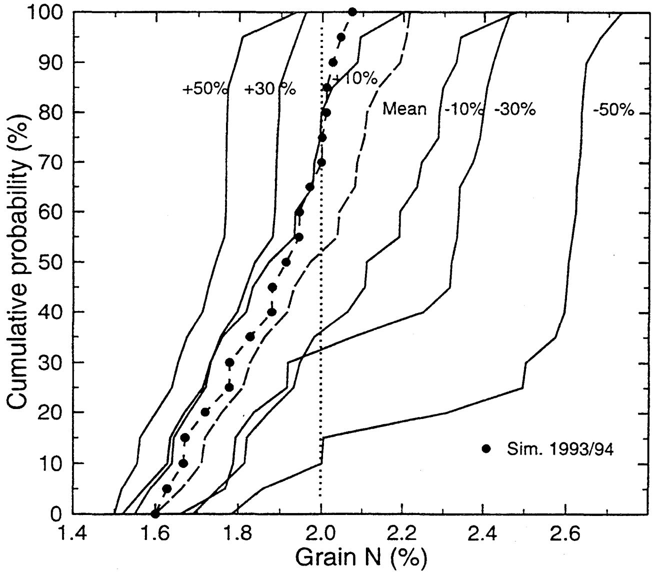

Figure 4. Cumulative probability function for grain N concentration generated by simulations of rainfall deviation of +50% to -50% of the long term mean for the Manawatu.

the rainfall was 10% less than average the chance of grain exceeding 2% N increased to 65%. However, if rainfall was 10% more than average the probability was reduced to 25%.

Grain size

Simulated grain size was unaffected by the level or timing of N application. However, the size variation was strongly influenced by soil moisture (Fig. 5). A grain size of 35 mg/grain can be expected if rainfall is close to the long term mean. However there is a 90% chance of achieving mean grain size less than 22 mg with 50% less rain. Alternatively, there is a 90% chance of achieving in excess of 40 mg mean size if rainfall is 40% above average. Irrigation scheduling to match a 40% increase in the mean rainfall for the duration of crop growth would therefore result in high quality grain on both size and N concentration criteria.

Conclusions

The model can be used as an aid for crop risk assessment and evaluation of crop performance in water and N-limiting environments. The model supports field data which shows that improved grain will be achieved if soil moisture is managed to reduce soil water deficits. The benefits of N application for yield and quality enhancement should be evaluated within the context of simulated (or measured) soil moisture information and data on site N fertility. The likelihood of excessive grain N concentrations will be reduced if the crops are managed to achieve grain yields close to their potential.

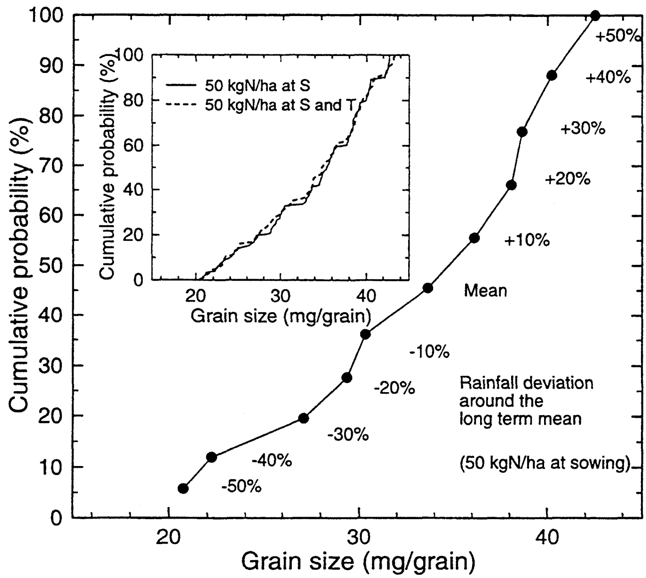

Figure 5. Cumulative probability functions for simulated mean grain size with variable rainfall and N management options (insert).

References

de Ruiter, J.M. and Brooking, I.R. 1994. Nitrogen and dry matter partitioning of barley grown in a dryland environment. *New Zealand Journal of Crop and Horticultural Science 22*, 45-55.

de Ruiter, J.M., Stol, W. and van Keulen, H. 1993. Simulation of yield and quality of malting barley. *Proceedings Agronomy Society of New Zealand 23*, 11-19.

van Keulen, H. and Seligman, N.G. 1987. Simulation of water use, nitrogen nutrition and growth of a spring wheat crop. Pudoc, Wageningen. 310 pp.

van Kraalingen, D.W.G. 1991. The FSE system for crop simulation. Simulation Report CABO-TT nr. 23. Centre for Agrobiological Research and Department of Theoretical Production Ecology, Wageningen, Netherlands. 77 pp.