CHAPTER 5

SIMULATING WATER AND NITROGEN BALANCES OF ANNUAL RYEGRASS WITH THE SWB-SCI MODEL

5.1 INTRODUCTION

The increasing food production target requires intensive use of fertilisers and water in agriculture which leads to a higher cost of production and greater risk of environmental pollution. Irrigated pasture production in the dairy industry of South Africa represents one of the most intensive agricultural activities in terms of water and fertiliser inputs, especially N (Theron *et al.*, 2002; Eckard *et al.,* 1995). Despite the latest N and irrigation application equipment and scientifically based fertilisation and water application guidelines, N and water use efficiency are generally still very low (Monaghan *et al.,* 2007).

Sustainable pasture production requires optimal fertiliser and water management practices in order to attain high biomass yield with minimum inputs to maximise profit. As a result, a basic understanding of the effects of N and water stress in pasture production are a prerequisite for the development of sound N and water management strategies. However, pasture systems are highly complex involving interactions between crop growth, soil and plant nutrient dynamics, and animal and pasture management systems. Considering temporal and spatial complexity, it is difficult to evaluate the whole system with short-term monitoring experiments. Development of site specific optimal N and irrigation management practices requires costly long-term trials. Since it is expensive and impractical to test multiple irrigation and N application strategies, the use of models can provide great insight and better understanding of the behaviour of the pasture system. Models can also be helpful in selecting best management practices for specific sites and environmental conditions.

Over the last few decades many mathematical computer models have been developed with varying levels of complexity, ranging from simple empirical models to mechanistic process based models (Godwin and Jones, 1991). The Soil Water Balance (SWB-Sci) model is a mechanistic, real time, generic, crop growth, soil water, nutrient and salt balance model (Annandale *et al.,* 1999; Van der Laan *et al.,* 2011) which can be used for irrigation, nutrient and salt management. The Soil Water Balance model was parameterised and tested for a wide range of crops including cereals, vegetables and pasture (Annandale *et al.,* 2000; Jovanovic and Annandale, 2000; Beletse *et al.*, 2008). The simple water balance model (without the nutrient sub-module) was intensively tested under different pasture management practices using annual ryegrass in Chapter 4. The N sub-module was validated for a range of sludge loading rates for dry land and irrigated agronomic crops as well as for dry land pasture (Tesfamariam, 2009), and a range of inorganic N fertiliser treatments under agronomic cropping systems (Van der Laan, 2009; Van der Laan *et al.,* 2011). Performance of the model for irrigated pasture with different N management strategies had not previously been tested. Therefore, the objectives of this study were to parameterise, calibrate and evaluate the performance the SWB-Sci model under varying N levels and irrigation regimes for annual ryegrass pasture.

5.2 MODEL DESCRIPTION

The simple irrigation scheduling version of the model is called SWB-Pro and was described in Chapter 4. The scientific version of the SWB model (SWB-Sci) includes salt balance, 2-D above-ground radiation interception and finite difference water balance routines (Singels *et al.,* 2010). Recently, N and P modelling subroutines have been incorporated into the SWB-Sci model (Van der Laan, 2009). Weather, soil and crop parameters are the same for both versions (SWB-Pro and SWB-Sci) and are described in Chapter 4. Hence, in this Chapter, the focus will be only on the N sub-module.

The main N processes (Figure 5.1) of the N sub-model including N transformations (mineralisation, nitrification, denitrification and ammonium volatilisation), N fixation, crop N demand and crop N uptake (Van der Laan, 2009) are presented below briefly:

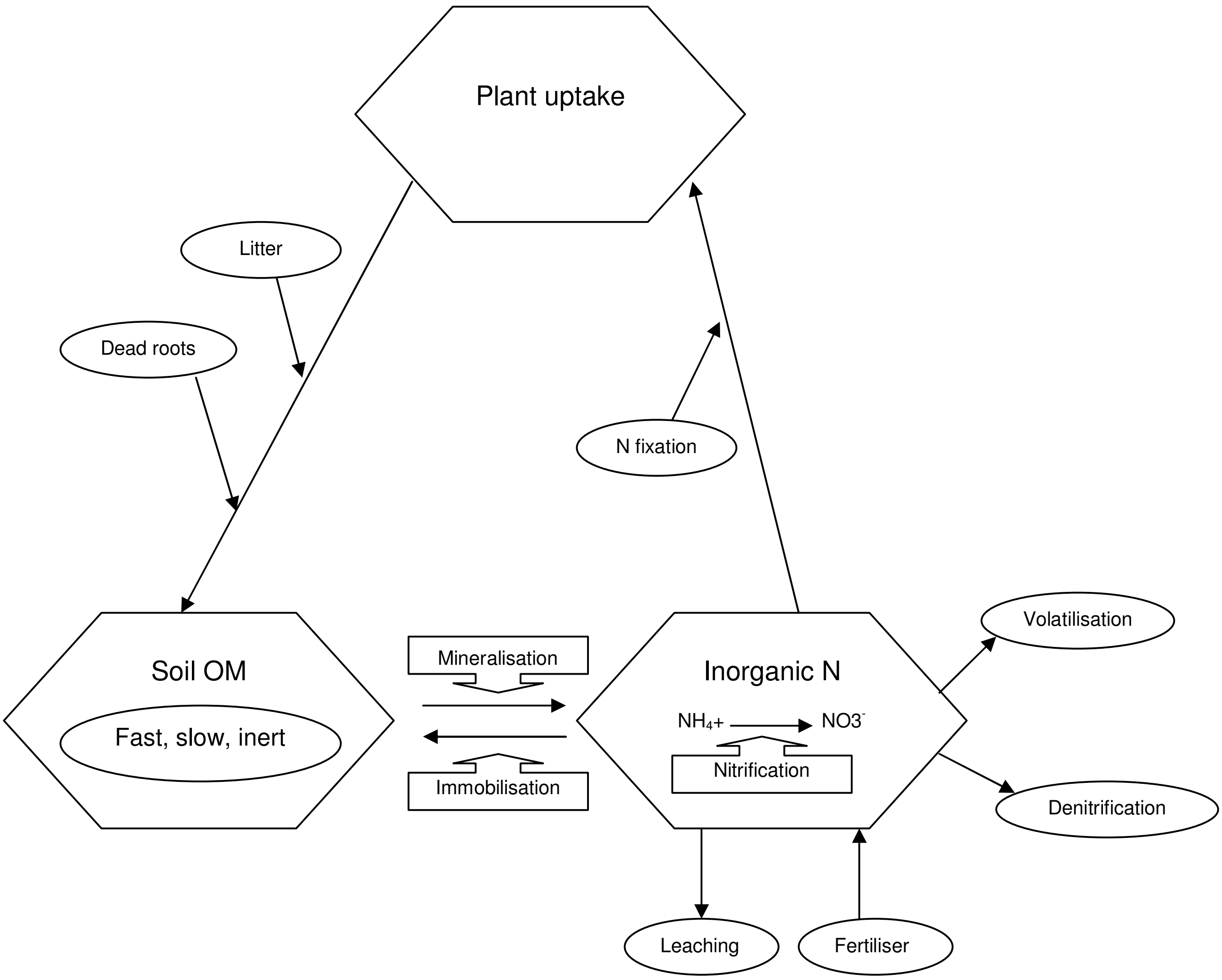

Figure 5.1 Schematic representation of the organic matter and inorganic N dynamics

5.2.1 Crop nitrogen uptake

For estimating N demand and potential uptake, SWB-Sci follows similar approach to that of CropSyst (Godwin and Jones, 1991; Stöckle *et al.*, 2003). Crop N demand is calculated from crop input parameters of plant N concentration. While it is known that N concentrations of crops are different, the dilution curves are grouped only for C3 and C4 plants. Therefore, plant N concentrations for critical, minimum and optimum crop growth for C3 or C4 plants are available in the model. N limited growth is estimated to occur when above ground biomass N concentration is between the critical and minimum concentration (Stöckle *et al.*, 2003). Below the minimum N concentration crop growth stops, although there may be translocation of resources between plant organs.

5.2.2 Organic matter turnover

Both mineralisation of soil organic matter and turnover of crop residues modelling follow similar principles as the CropSyst (Stöckle *et al.*, 2003). Residues need to be parameterised for the fraction and half-life of the three pools (active, slow and inert) (Figure 5.1). It is also important to determine the C:N ratio of the residues (Van der Laan, 2009; Tesfamariam, 2009). The C:N ratio is a key parameter that is used in the estimation of N mineralisation or immobilisation. The model first calculates net N mineralisation, while immobilisation is considered if the net mineralisation is less than zero (Van der Laan, 2009; Tesfamariam, 2009).

5.2.3 Inorganic nitrogen transformations

Ammonia volatilisation is simulated from inorganic and organic fertilisers as a function of weather, method of N application (broadcasted or incorporated), soil pH and cation exchange capacity (CEC). The value is further modified by a turbulent transfer coefficient estimated from wind speed and leaf area index. Nitrification is influenced by soil water and texture (indirectly estimate of soil aeration), soil temperature and soil pH and usually it takes place when the climatic and soil conditions are favourable. In the model, denitrification is the conversion of nitrate to nitrous oxide, and N gas to the atmosphere is simulated. Denitrification is simulated as function of soil temperature, soil water and soil porosity (Van der Laan, 2009; Tesfamariam, 2009).

The movement of solutes in the soil profile is based on incomplete solute mixing (Corwin *et al.*, 1991) using the coefficient of mobility which represents the percentage of solute to be displaced and cascaded to the next layer (Van der Laan *et al.,* 2010). The water and N budgets interact to produce a simulation of N transport within the soil profile (Van der Laan *et al.,* 2010). Crop growth can be limited by water, radiation and/or nitrogen. A N nutrition index is used to account for N deficiency and accumulation of biomass (Van der Laan 2009; Van der Laan *et al.,* 2010).

5.3 MATERIALS AND METHODS

5.3.1 Site description and crop management

Data sets for model evaluation were collected from experiments carried-out under a rainout shelter (Hatfield) and in an open field (Cedara) in the 2007 and 2008 growing seasons. The open field experiment was conducted at the Cedara Experimental Farm of the Department of Agriculture (1076 m asl, 29°32'S; 30°17'E) in the Midlands of KwaZulu-Natal. The rainout shelter experiment was conducted at the Hatfield Experimental Farm (1327 m asl, 25°45'S; 28°16'E) of the University of Pretoria, Pretoria. At both sites, Italian ryegrass (*Lolium multiflorum*) cultivar 'Agriton' was planted at a seeding rate of 30 kg ha^{-1} with a row spacing of 0.15 m.

5.3.2 Treatments

A factorial design of irrigation levels and N rate treatment combinations were assigned in a completely randomized block design, with three replications (Table 5.1).

Table 5.1 Irrigation and N application rate treatments used for SWB-Sci model calibration and validation of annual ryegrass during 2007 and 2008 growing seasons

Site	Year	Growth cycles	Irrigation treatments	N Treatments (kg N ha^{-1}) Growth cycle^{-1}	N Treatments (kg N ha^{-1}) Total
Cedara	2007	8	Non-stressed (W1) Mild-stress (W2)	N_0	0
				N_{30}	240
				N_{60}	480
	2008	7§	Non-stressed (W1) Serve-stress (W2)	N_0	0
				N_{20}	120
				N_{40}	240
				N_{60}	360^{β}
Hatfield	2007-08	8	Non-stressed (W1)	N_0	0
			Mild-stress (W2)	N_{30}	120
			Serve-stress (W3)	N_{60}	240

§No N fertiliser was applied for all treatments for the first growth cycle.

5.3.2.1 Cedara

In 2007, the experiment included three different N rate applications of 0, 30 or 60 kg N ha^{-1} (N_0, N_{30} and N_{60}) over eight harvests applied at the beginning of each growth cycle. In 2008, treatments included four fixed N rates of 0, 20, 40 and 60 kg N ha^{-1} (N_0, N_{20}, N_{40} and N_{60}) applied after each cut (Chapter 2). In 2007, deficit (growth cycle one to three) and frequency (growth cycle four to eight) irrigation scheduling strategies were used. For the first three growth cycles, plots were irrigated to field capacity (**W1**) or 60% of W1 (**W2**) weekly. For the next five (four to eight) growth cycles, plots were irrigated every 7 days (**W1**) or 14 days (**W2**) to field capacity. In 2008, well watered treatment plots were irrigated once to field capacity weekly during autumn, spring and summer; and once every two weeks in winter (**W1**). Water stressed plots in 2008 were irrigated only at the start of growth cycles when N fertiliser was applied (**W2**).

5.3.2.2 Hatfield

In both years, N rates of 0 kg N ha^{-1}(N_0), 30 kg N ha^{-1} (N_{30}) and 60 kg N ha^{-1} (N_{60}) were applied for each growth cycle. Plots were irrigated to field capacity twice a week (**W1**); once a week (**W2**) or twice a month (**W3**).

5.3.3 Data collection

5.3.3.1 Weather

Meteorological data were recorded daily at both experimental sites. Fully automated weather stations were installed to measure solar radiation, minimum and maximum temperatures, wind speed and direction, rainfall and minimum and maximum relative humidities. Irrigation was recorded using water meters in Hatfield and manual raingauges at Cedara.

5.3.3.2 Soil analysis

Soil texture was determined to a depth of 1.0 m at the commencement of the trial in 2007. The sites have a deep, Hutton soil with a clay loam texture at Cedara and a sandy loam soil type at Hatfield (Soil Classification Working Group, 1991). Soil fertility was analysed in both years prior to planting by taking samples down to 1 m. These were analysed for N, P, K, pH, CEC, Mg, Ca and micro elements. Ammonium acetate was used for macro (K, Mg and Ca) and micro elements extraction (Table 2.2). Organic carbon and N were estimated by mid-infrared spectroscopy (Ben-Dor and Banin) and P was measured with the Bray I method. Nitrate and ammonium N were determined with an auto-analyzer after extraction using 1M KCl. To ensure maximum N utilization other elements were kept at optimum levels. Based on soil fertility analysis, no lime was required. K and P were applied based on South African Department of Agriculture recommendations of soil test analysis results by the Department of Agriculture. 20 kg P ha^{-1} was incorporated with the soil at the time of planting. The seasonal recommended K was divided into the number of expected regrowth cycles and 25 kg K ha^{-1} was broadcast at the beginning of each cycle.

5.3.3.3 Soil water content

Volumetric soil water content in the top 1.0 m soil profile was measured using a neutron probe (0.20 m intervals) at Hatfield and a Diviner 2000 Capacitance probe (0.10 m intervals) at Cedara. However, only the upper 0.60 m was used to calculate the deficit to field capacity and to use as the refill point during irrigation. This was because the majority of the annual ryegrass roots were in the top 0.60 m.

5.3.2.4 Crop growth, yield and nitrogen uptake

Plant samples were collected at 7 - 10 day intervals by harvesting plant material from an area of 0.0625 m^2 at Cedara and 0.09 m^2 at Hatfield to a height of 50 mm from the soil surface. Leaf area index (LAI) was determined using an LI3100 belt driven leaf area meter (LiCor, Lincoln, Nebraska, USA). For forage yield determination the grass was harvested at about the three leaf stage in Cedara and at 28 day intervals at Hatfield from 1.0 m^2 quadrants using a manual grass mower to 50 mm stubble height. At Cedara, biomass and leaf area index of the residual plant material after cutting (1 m^2) was determined. Forage yield and residual plant material were determined by oven drying the samples at 70 °C to constant mass. Forage N concentration was determined by Kjeldahl analysis (AOAC, 1991) and forage N uptake was calculated as forage DM yield multiplied by N concentration. For the Cedara site, forage yields and N concentrations are reported in Chapter 3.

5.3.3.5 Soil solution nitrate concentration

Wetting front detectors were used to collect soil solution samples for determining the soil nitrate concentration at different soil depths (Stirzaker, 2003). Solution sampling from WFDs was undertaken the day after irrigation or a rainfall event. This was done to standardise the sampling time and to allow redistribution within the profile. For each sample, nitrate content was analysed using a colour test strips (Merck KGaA, Germany).

5.3.4 Model parameterisation and testing

Crop growth parameters of annual ryegrass were generated using data collected from the field experiment (Table 4.2, Chapter 4). Some of the parameters which could not be determined from the collected data were obtained from literature and estimated by calibrating the model against measured field data (Table 5.2). Root N concentration of 0.015 kg N kg^{-1} DM^{-1} and increased root activity biomass of 0.50 were used. For starting the dilution curve for forage biomass and N concentration default values for typical C_3 crops (Van der Laan, 2009) were used. However, the slope of the dilution curve was increased with calibration to -0.40 from of -0.45. By-pass coefficients of 0.5 and 0.7 were used for clay loam (Cedara) and sandy loam (Hatfield) soils, respectively. The values were chosen after several runs of the model for optimally-growing annual ryegrass. Default values of soil initial C fractions for N mineralisation transformations were used. Average above ground measured biomass of (0.75 t ha^{-1}) and a leaf area index of 0.5 m^2 m^{-2} were used to reinitialise the model after each cut.

Table 5.2 Specific crop input parameters of annual ryegrass used for SWB-Sci model for calibration and validation

	Parameter	Value	unit
Crop	N dilution slope	-0.40	-
	Increased root activity biomass	0.50	-
	Root N concentration	0.015	kg N kg^{-1} DM^{-1}
	Residual biomass after cut	0.75	t ha^{-1}
	Residual LAI after cut	0.50	m^{2} m^{-2}
Soil	Initial C fraction to microbial biomass	default	-
	Initial C fraction to active labile SOM	default	-
	Initial C fraction to active metastable SOM	default	-
	Initial C fraction to passive SOM	default	-
	Bypass coefficient	0.5 - 0.7	-

Statistical parameters, including the coefficient of determination (r^2) to assess the degree of association, Wilmott (1982) index of agreement (D) to measure variability, and mean absolute error (MAE) to measure percentage of the relative difference between simulated and observed values were used to evaluate model performance. For accurate model predictions r^2 and D should be greater than 0.8, whilst MAE should be less than 20% (De Jager, 1994).

5.4 RESULTS AND DISCUSSION

5.4.1 Model calibration

Crop growth parameters from the SWB-Sci database (Table 4.2, Chapter 4) were used in conjunction with parameters developed from this study (Table 5.2) to run the model. Measured crop growth (forage yield and LAI), above-ground N uptake, soil water content and mobile soil solute concentrations were used to evaluate model accuracy.

Accuracy evaluation statistical parameters are presented in Table 5.3. The measured versus simulated values for the well-watered, nutrient non-limiting treatment (N_{60}) from Cedara for the 2008 growing season are presented in Figures 5.2 and 5.3. These parameters include forage yield, N uptake, LAI and profile soil water deficit (Figure 5.2) and mobile soil solution nitrate concentrations at four soil depths (Figure 5.3).

Table 5.3 Statistical parameters for SWB-Sci model calibration (r^2: coefficient of determination; D: Willmott index of agreement; MAE: mean absolute error) for optimally growing annual ryegrass

Treatment	r^2	D	MAE (%)
Forage yield (cycles)	0.90	0.97	8.3
Forage yield (cumulative)	0.99	0.99	7.5
LAI	0.84	0.94	13.0
Soil water content	0.78	0.81	19.2
N uptake (cycles)	0.37	0.59	10.4
N uptake (cumulative)	0.99	0.98	13.8
Mobile nitrate	0.64	0.58	58.9

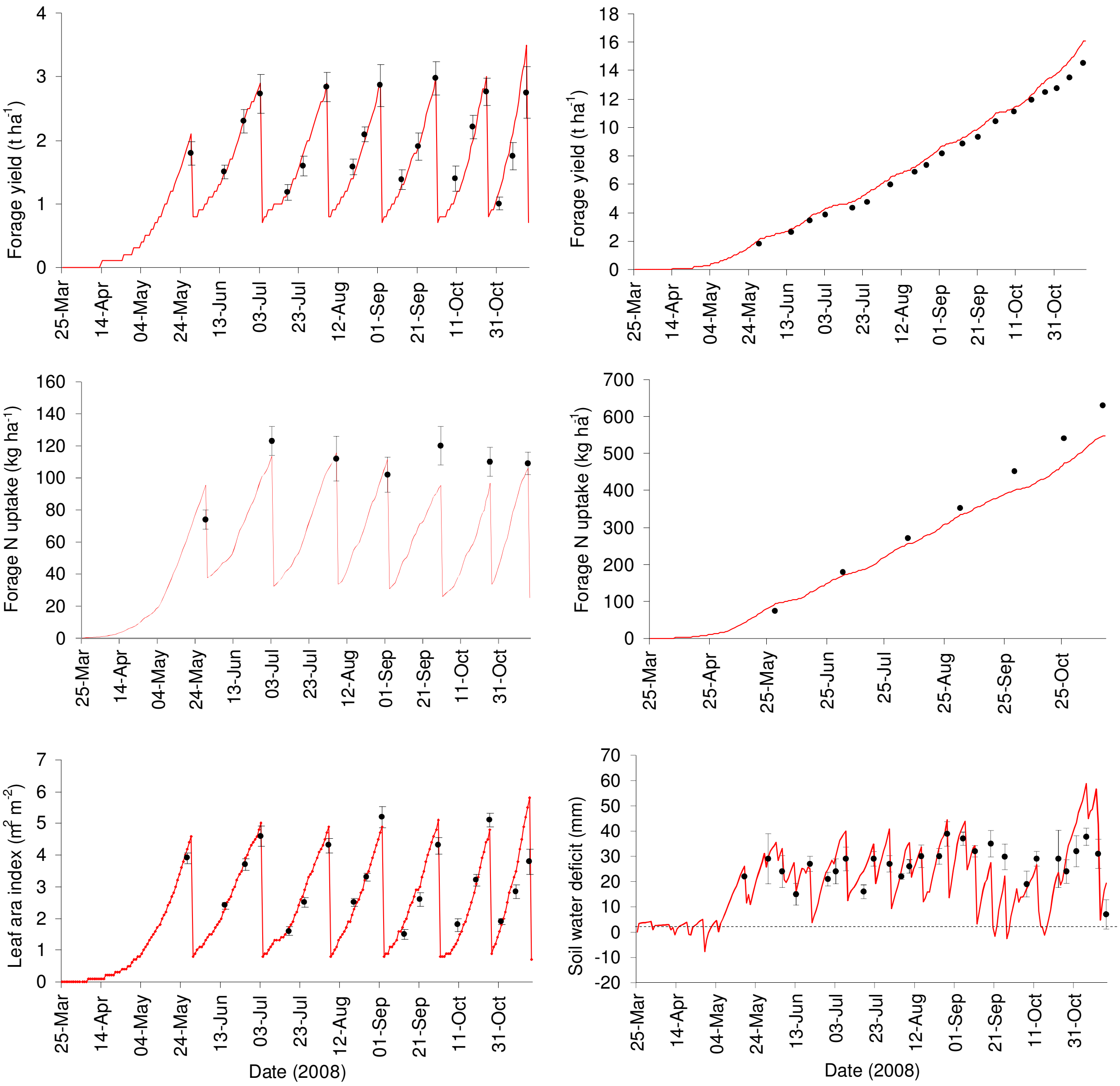

Figure 5.2 Simulated (solid lines) and measured (points) a) above ground forage biomass for growth cycles and b) the whole season, c) above ground forage N uptake for growth cycles and d) the whole season, e) leaf area index and f) soil water deficit to field capacity during model calibration under well watered (W1), N non-limiting (N_{60}) treatment at Cedara during 2008 (Vertical bars represent standard error)

The model predicted forage yield (per cycle and cumulative), LAI, cumulative above ground N uptake and soil water content accurately for all the statistical parameters within the prescribed range of r^2 and D > 0.80 and MAE < 20% (Table 5.3). Unlike cumulative N uptake, above-ground forage N uptake for individual growth cycles was simulated less accurately with r^2 = 0.37 and D = 0.59 (Table 5.3). Mobile nitrate soil solution concentration was, as can be expected, simulated with somehow lower accuracy (r^2 = 0.64 and D = 0.58). However, the model was able to predict trends of soil solution nitrate concentrations well (Figure 5.3). Considering the complexity of the N cycle, soil heterogeneity and the strong influence of water content, the model simulated soil solution nitrate concentration at different soil depths fairly accurate.

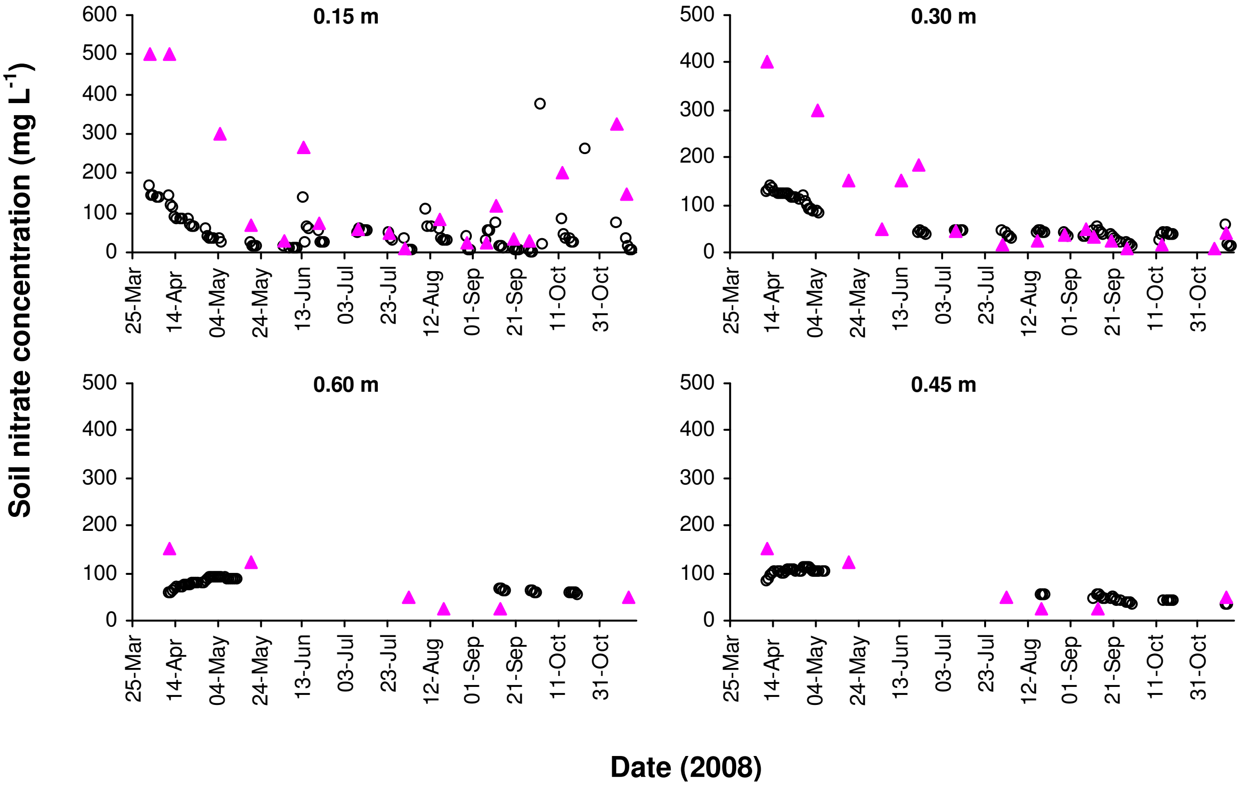

Figure 5.3 Simulated (O) and measured (▲) mobile soil solution nitrate concentrations for the well watered (W1), N non-limiting (N_{60}) treatment at Cedara site during 2008

5.4.2 Model validation

The model was validated using independent data for various irrigation and N treatment combinations. Parameters including forage yield, LAI, above-ground N uptake, soil water content and mobile soil solute concentrations were used to evaluate the performance of the model.

5.4.2.1 Forage yield

Simulated forage yield followed similar trends to the measured data for all years, sites and N rates for both growth cycle (Figure 5.4) and cumulative (Figure 5.5). As expected, yield simulations increased with increasing N rates under both water stressed and non-stressed conditions (Figure 5.5). Simulated and observed forage yield for growth cycles were in good agreement for all N rates under water stressed and non-stressed conditions except in N_0 with some statistical parameters marginally outside the acceptable ranges brought about by the model not simulating high forage yields in the late season (last growth cycle) (Table 5.4).

Generally, the model simulated forage yields well under well-watered and water stressed conditions. The model's predictive capability of cumulative forage yield was good for both Hatfield (Table 5.4) and Cedara (Table 5.5) with all statistical parameters within acceptable limits (r^2 and D > 0.80 and MAE < 20%). The model also predicted forage yield of individual growth cycles well for most treatments at Hatfield (Table 5.4) and with reasonable accuracy at Cedara (Table 5.5).

The residual forage biomass after cutting ranged between 0.5 to 1.0 t ha^{-1} for all sites and treatment combinations. However, no attempt was made to match biomass remaining after cutting, instead an average residual biomass value of 0.75 t ha^{-1} was used to run the model for all treatments and seasons. This could be the source of some variation in yield between modelled and measured forage yield of growth cycles. In spite of these variations, the measured and predicted yields agreed well for most treatment combinations.

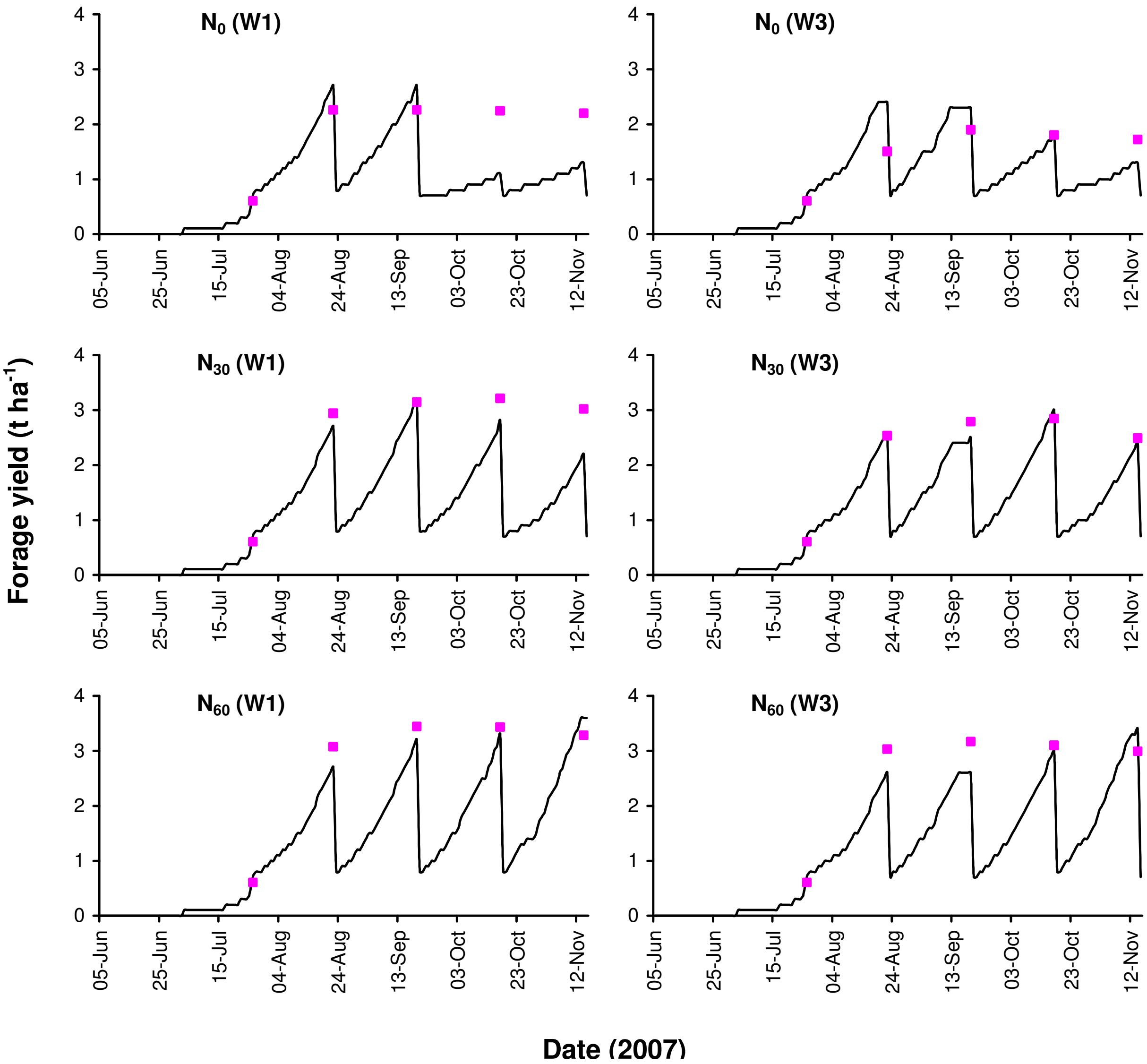

Figure 5.4 Simulated (solid lines) and measured (points) forage yield for growth cycles under a range of N rate (N_0: 0 kg N ha^{-1}; N_{30}: 30 kg N ha^{-1}; N_{60}: 60 kg N ha^{-1}) and water (W1: under well watered; W3: water stressed) treatments for Hatfield during the 2007 annual ryegrass growing season

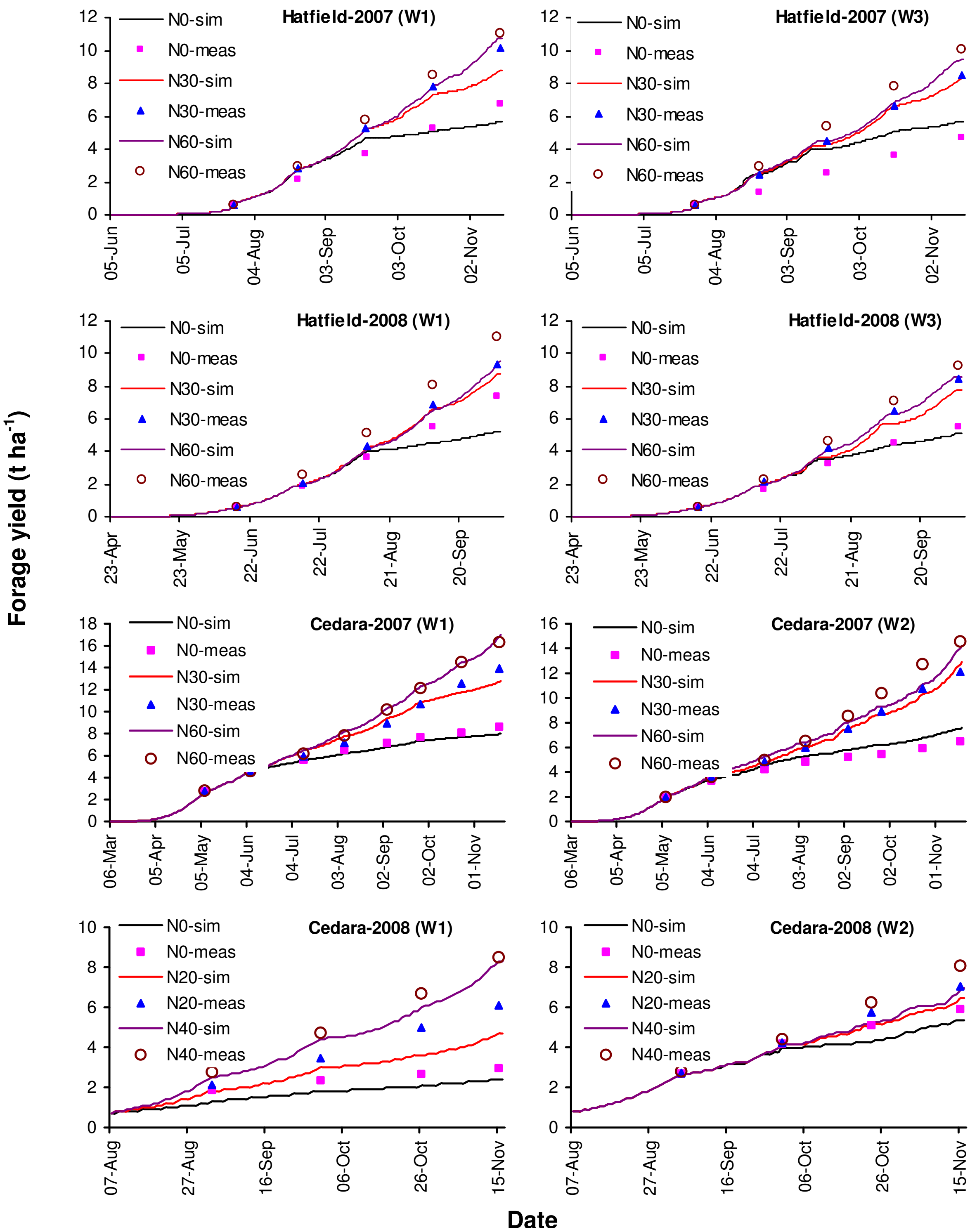

Figure 5.5 Simulated (solid lines) and measured (points) seasonal cumulative forage yield of ryegrass for well watered (W1) and water stressed (W2 and W3) under range of N application rate treatments for Cedara and Hatfield during 2007 and 2008 seasons

Table 5.4 Statistical evaluation between observed and predicted values of forage yield during model validation, Cedara 2007 and 2008 seasons

Field	Irrigation treatment	N treatment	Growth cycle yield			Cumulative yield		
			r^2	D	MAE (%)	r^2	D	MAE (%)
Cedara	Well watered (W1) 2007-2008	N_0	0.93	0.97	9.6	0.97	0.98	5.8
		N_{20}	0.40	0.70	15.0	0.98	0.99	7.6
		N_{30}	0.14	0.68	13.8	0.98	0.99	6.3
		N_{40}	0.48	0.82	9.9	0.97	0.99	4.2
		N_{60}	0.35	0.78	6.9	0.99	0.98	2.4
	Stressed (W2) 2007	N_0	0.83	0.92	12.7	0.99	0.96	5.4
		N_{30}	0.18	0.44	13.9	0.99	0.99	9.1
		N_{60}	0.17	0.36	20.0	0.98	0.98	12.9
	Water Stressed (W2) 2008	N_0	0.79	0.92	10.5	0.97	0.91	6.2
		N_{20}	0.70	0.88	8.6	0.98	0.94	5.2
		N_{40}	0.52	0.67	9.3	0.94	0.89	8.9
		N_{60}	0.60	0.68	9.9	0.96	0.93	9.7
Hatfield	Well watered (W1)	N_0	0.49	0.75	30.5	0.84	0.92	20.6
		N_{30}	0.97	0.97	8.9	0.99	0.99	11.3
		N_{60}	0.87	0.98	10.0	0.98	0.98	12.2
	Mild water stressed (W2)	N_0	0.46	0.81	26.7	0.86	0.96	17.1
		N_{30}	0.97	0.97	7.10	0.97	0.97	9.7
		N_{60}	0.94	0.98	8.40	0.98	0.99	8.8
	Severe water stressed (W3)	N_0	0.59	0.87	18.2	0.76	0.83	25.4
		N_{30}	0.95	0.98	6.8	0.96	0.98	11.8
		N_{60}	0.92	0.97	10.0	0.99	0.99	10.8

r^2: coefficient of determination; D: Willmott index of agreement; MAE: mean absolute error

5.4.2.2 Leaf area index

In general, LAI simulations were similar to the measured values under varying irrigation and N fertiliser conditions (Table 5.5 and Figure 5.6). The model was able to predict LAI well under most irrigation and N fertiliser conditions, except N_0 (Table 5.6). For the unfertilised N_0 treatments, model predictions were poor regardless of irrigation treatment. For N_0, agreement between measured and simulated was low with most statistical parameters outside the acceptable range with r^2 = 0.12, D = 0.55 and MAE 45.2% (Table 5.5).

Table 5.5 Statistical evaluation between observed and predicted values of leaf area index during model validation, Hatfield 2007 and 2008 seasons

Parameter	N treatment	r^2	D	MAE (%)
Non-stressed (W1)	N_0	0.12	0.55	45.2
	N_{30}	0.82	0.82	24.7
	N_{60}	0.86	0.89	19.6
Mild- stressed (W2)	N_0	0.20	0.56	41.4
	N_{30}	0.89	0.93	15.3
	N_{60}	0.87	0.92	16.2
Severe-stressed (W3)	N_0	0.16	0.62	39.2
	N_{30}	0.83	0.92	15.6
	N_{60}	0.86	0.89	17.7

r^2: coefficient of determination; D: Willmott index of agreement; MAE: mean absolute error

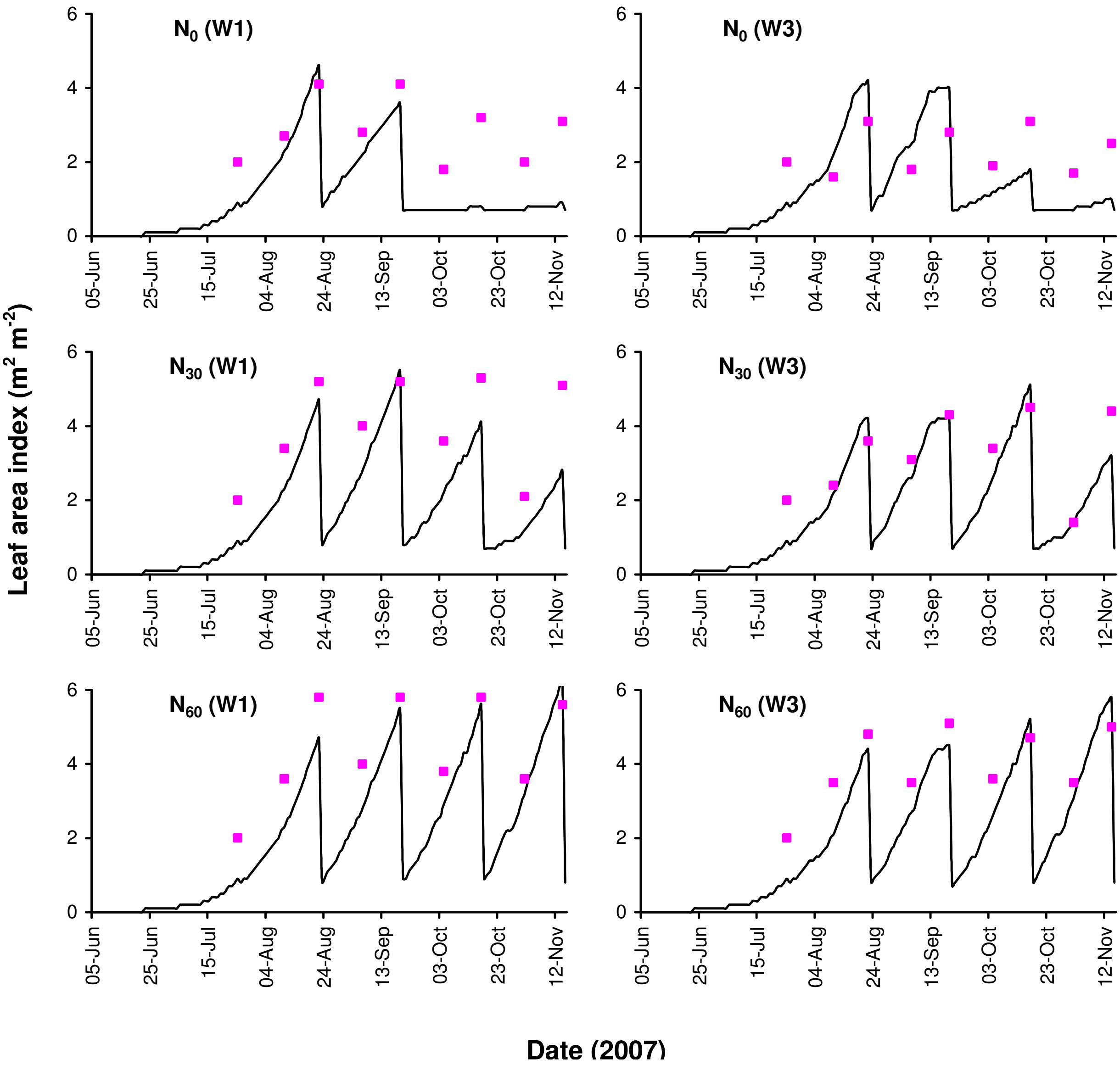

Figure 5.6 Simulated (solid lines) and measured (points) of leaf area index for a range of N rate treatments under well watered (W1) and water stressed (W3) treatments for Hatfield during the 2007 growing season

5.4.2.3 Forage N uptake

In most cases, the model overestimated N uptake of the individual growth cycles under-water stressed conditions (Figures 5.7), especially in 2008 (W2). As a result, the statistical parameters were outside the prescribed ranges (Table 5.6). However, simulated above-ground N uptake for growth cycles followed the pattern of measurements throughout the season (Figure 5.7), with modelled cumulative N uptake closely matching the observed data for most N rates and years (Figure 5.8).

Table 5.6 Statistical evaluation between observed and predicted values of forage N uptake during model validation, Cedara 2007 and 2008 seasons

Parameter	N treatment	Growth cycle			Cumulative		
		r^2	D	MAE (%)	r^2	D	MAE (%)
Well watered (W1) 2007-2008	N_0	0.94	0.97	20.6	0.94	0.98	6.6
	N_{20}	0.92	0.89	31.0	0.99	0.98	4.0
	N_{30}	0.82	0.11	17.7	0.97	0.90	10.3
	N_{40}	0.88	0.94	5.7	0.98	0.96	13.7
	N_{60}	0.23	0.90	12.8	0.99	0.93	9.09
Water stressed (W2) 2007	N_0	0.88	0.84	54.3	0.87	0.83	22.1
	N_{30}	0.36	0.58	31.5	0.93	0.94	7.0
	N_{60}	0.17	0.22	18.9	0.98	0.95	4.8
Water stressed (W2) 2008	N_0	0.88	0.78	52.4	0.95	0.75	24.5
	N_{20}	0.73	0.67	33.5	0.96	0.88	20.8
	N_{40}	0.28	0.29	25.5	0.97	0.95	15.1
	N_{60}	0.21	0.20	22.8	0.99	0.96	16.5

r^2: coefficient of determination; D: Willmott index of agreement; MAE: mean absolute error

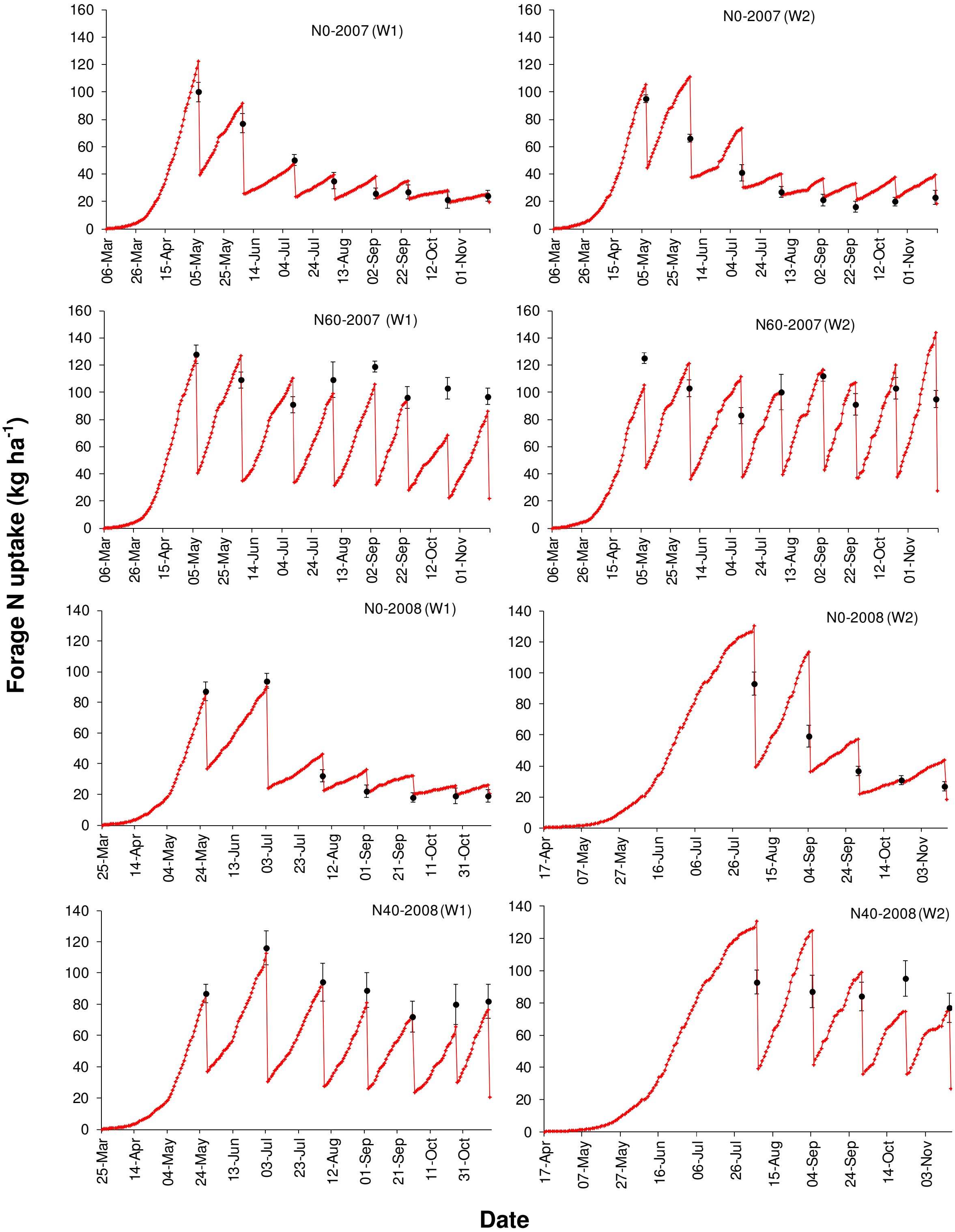

Figure 5.7 Simulated (solid lines) and measured (points) forage N uptake of growth cycles for range of N rate treatments under well watered (W1) and water stressed (W2) conditions for Cedara during 2007 and 2008 seasons

Measured and predicted cumulative above-ground N uptakes for the season were in a very good agreement (Table 5.6), with almost all parameters within the acceptable ranges ($r^2 > 0.80$, $D > 0.75$ and MAE < 25%). The model's better cumulative N uptake predicting capability as opposed to per growth cycle is most probably due to compensation of N uptakes between growth cycles. For planning N application strategies, overall seasonal N uptake simulations usually have more practical implication than individual growth cycles.

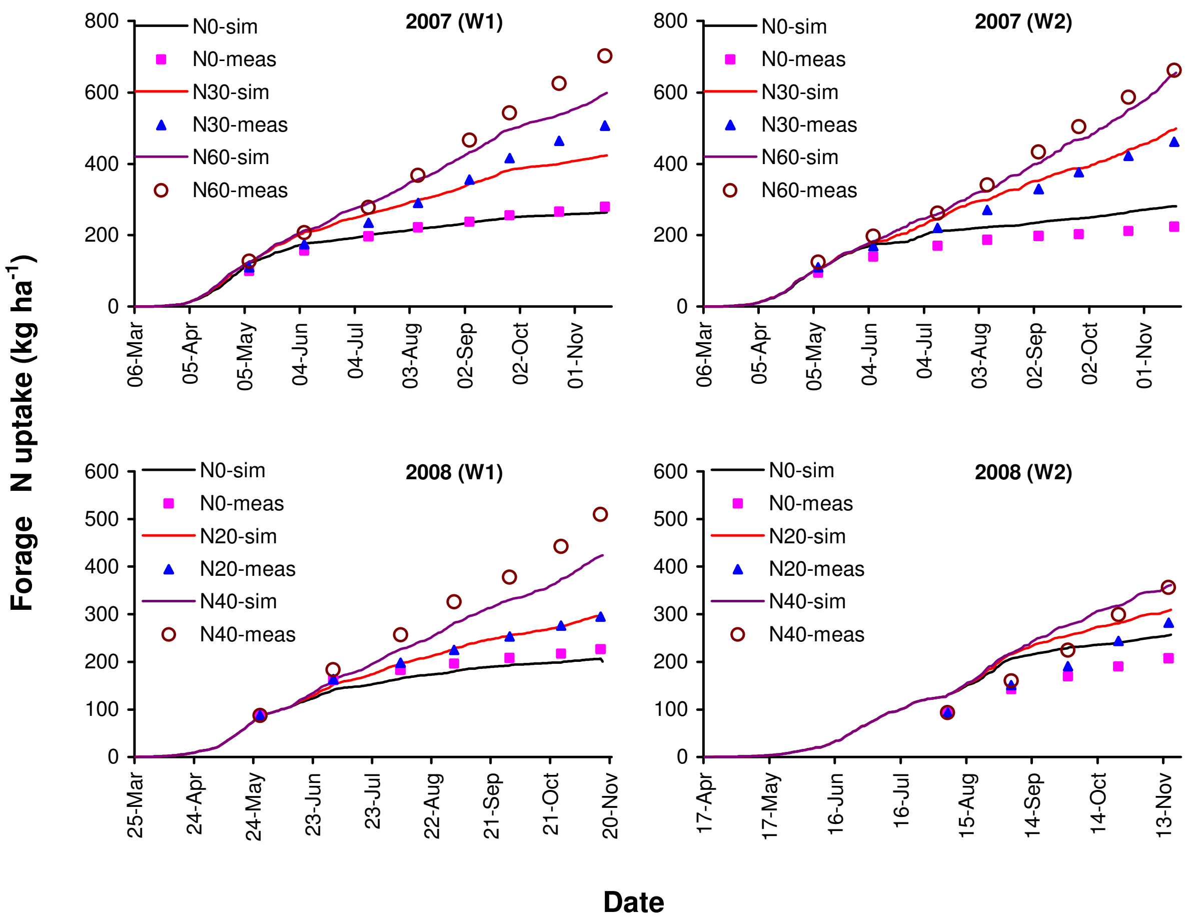

Figure 5.8 Simulated (solid lines) and measured (points) seasonal cumulative forage N uptake of annual ryegrass for range of N rate treatments under well watered (W1) and water stressed (W2) treatments for Cedara site during 2007 (N_0, N_{30} and N_{60}) and 2008 (N_0, N_{20} and N_{40}) seasons

The minimum and maximum biomass and N concentrations for starting dilution curves were set to default values of C_3. This was hardcoded in the model with slope set as an input parameter. The default slope for C_3 is -0.45 and for annual ryegrass this value was modified to -0.40 through calibration. Considering such generalised curves the model did well in predicting forage N uptakes.

5.4.2.4 Soil water content

Soil water deficit was under-estimated early in the season and over-estimated late in the season for the well watered treatments (Figure 5.9). The model simulated soil water content satisfactorily (D: 0.47-0.83 and MAE: 17-28%) for both Hatfield and Cedara (Table 5.7). Under water-stress conditions, soil water deficit predictions for Cedara were in good agreement with measurements at early and late in the season, but were overestimated in the mid-season (Figure 5.9). A notable difference between modelled and measured soil water contents were for the well watered zero N ($W1-N_0$) treatment at Hatfield where the modelled values were consistently higher than the measured ones (Figure 5.9).

It appears that the model did produce reliable estimates of the response of the soil to rain and crop water use. Generally the model predicted soil water content at Cedara better than at Hatfield under stress (water and N) conditions (Table 5.7). Although perfect simulations are impossible due to errors in measured data sets, sensor calibration and soil heterogeneity, the model can be still be improved by using a finite difference water balance approach as compared to the cascading approach used in the current simulation study. It is possible that while this alternative approach may improve simulations of soil water profiles only slightly, it may deal with movement of mobile nitrate concentration and N leaching more effectively. This, indirectly, can improve simulations of soil N availability, N uptake and crop growth.

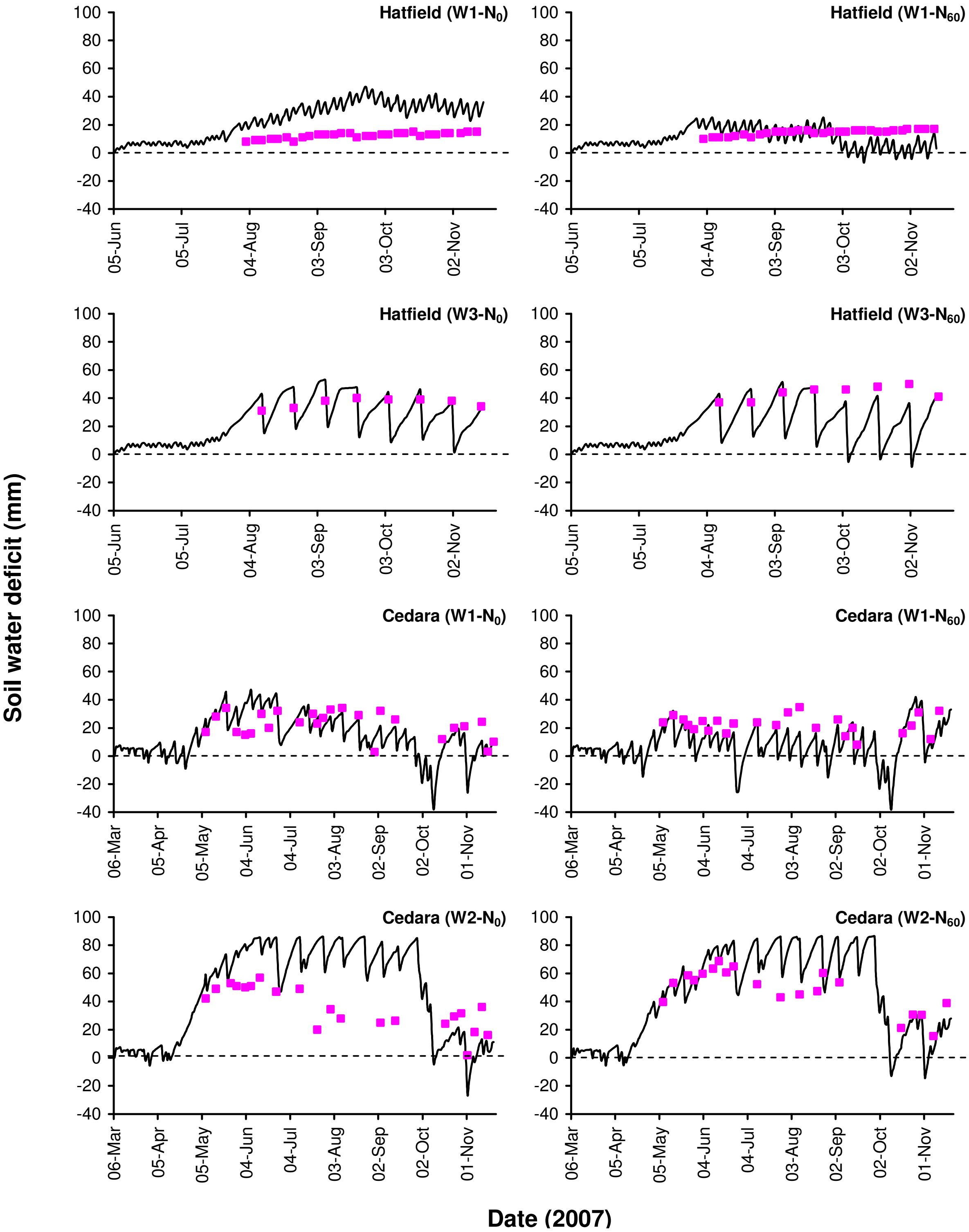

Figure 5.9 Simulated (solid lines) and measured (points) soil water deficit to field under a range of N rates and irrigation regimes data collected from Cedara during 2007 season

Table 5.7 Statistical evaluation between observed and predicted values of deficit water content to field capacity during model validation, Cedara 2007 and 2008 seasons

Water treatment	Hatfield				Cedara			
	N rates	r^2	D	MAE (%)	N rates	r^2	D	MAE (%)
Well watered	N_0	0.40	0.75	23.7	N_0	0.62	0.77	24.2
	N_{30}	0.37	0.84	8.9	N_{20}	0.23	0.47	28.2
	N_{60}	0.51	0.92	7.7	N_{40}	0.70	0.83	21.1
					N_{60}	0.46	0.68	18.7
Water stressed	N_0	0.29	0.28	26.4	N_0	0.52	0.68	21.9
	N_{30}	0.23	0.51	18.1	N_{20}	0.38	0.71	19.9
	N_{60}	0.28	0.55	15.4	N_{40}	0.53	0.74	22.3
					N_{60}	0.73	0.81	16.8

r^2: coefficient of determination; D: Willmott index of agreement; MAE: mean absolute error

5.4.2.5 Soil nitrate concentrations

Generally, model prediction was close to the observed data of nitrate in the soil solution at all depths (Table 5.8) with r^2 (0.16 -0.84, mean 0.76), D (0.50 - 0.79, mean 0.71). In both years, measured nitrate concentrations were higher than model predicted values at the beginning of the season. In most cases, the greatest deviation occurred in the upper soil layers where significant under-estimation and over-estimation was evident (Figures 5.10 and 5.11). In 2008, there was a consistent under-prediction of soil solution nitrate concentrations in the top 0.15 m soil layer, particularly in the early period when simulated nitrate remained below 200 mg L^{-1} after planting, but observations reached 500 mg L^{-1}. High measured nitrate values at the beginning of the 2008 season could be a result of rapid mineralisation due to soil disturbance around the WFDs (Figure 5.11). But this could not be compared to 2007, because measurements of nitrates were started in the middle of the season (Figure 5.10). Nevertheless, the model was able to follow the patterns of observed values in most cases (Figures 5.10 and 5.11).

Table 5.8 Statistical evaluation between observed and predicted values of soil solution nitrate concentration during model validation, Cedara and Hatfield 2007 and 2008 seasons

N treatment	r^2	D	MAE (%)
N0 -2008	0.84	0.79	64.4
N20-2008	0.80	0.73	76.0
N30-2007	0.16	0.50	53.5
N40-2008	0.54	0.66	62.8
N60-2007	0.44	0.67	56.4
2007	0.52	0.64	57.8
2008	0.84	0.73	56.6
ALL	0.76	0.71	57.0

r^2: coefficient of determination; D: Willmott index of agreement; MAE: mean absolute error

It is important to note that mobile nitrate concentrations are strongly dependent on soil water content and water applications. Hence, the differences between measured and simulated mobile nitrates could be as a result of complexities of N transformation processes, spatial soil variability, preferential paths of water and nitrate through the soil profile, non-uniform N fertiliser applications and crop N uptake. On the other hand, the trends of measured and predicted nitrates at different soil depths were similar (Figures 5.10 and 5.11). In general, considering the complexity of N cycle and heterogeneity of soil it can be said that the model showed good performance.

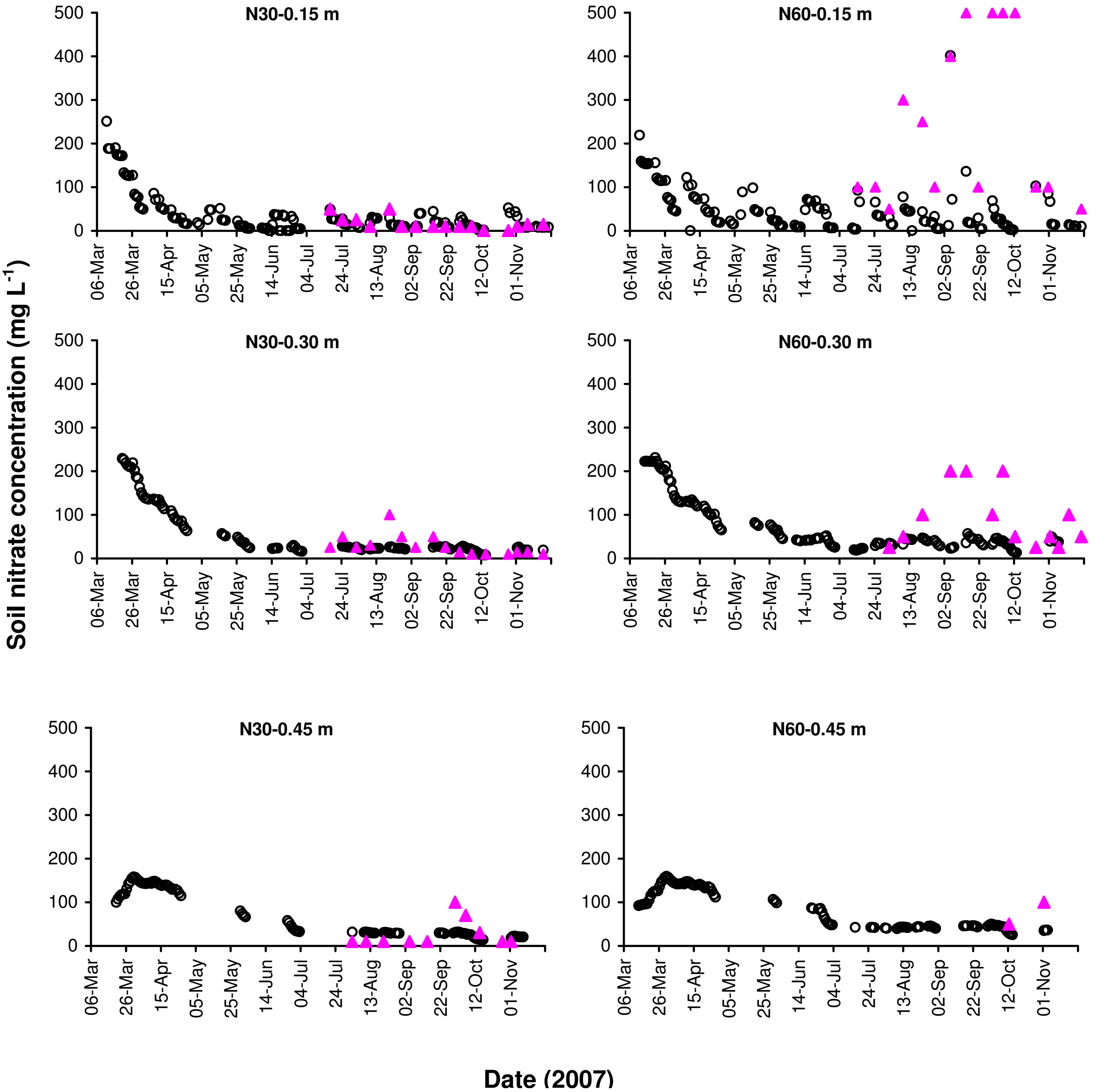

Figure 5.10 Simulated (O) and measured data (▲) soil nitrates concentrations at the depths of 0.15, 0.30, 0.45 m for well watered and range of N application treatments for Cedara site during 2007 season

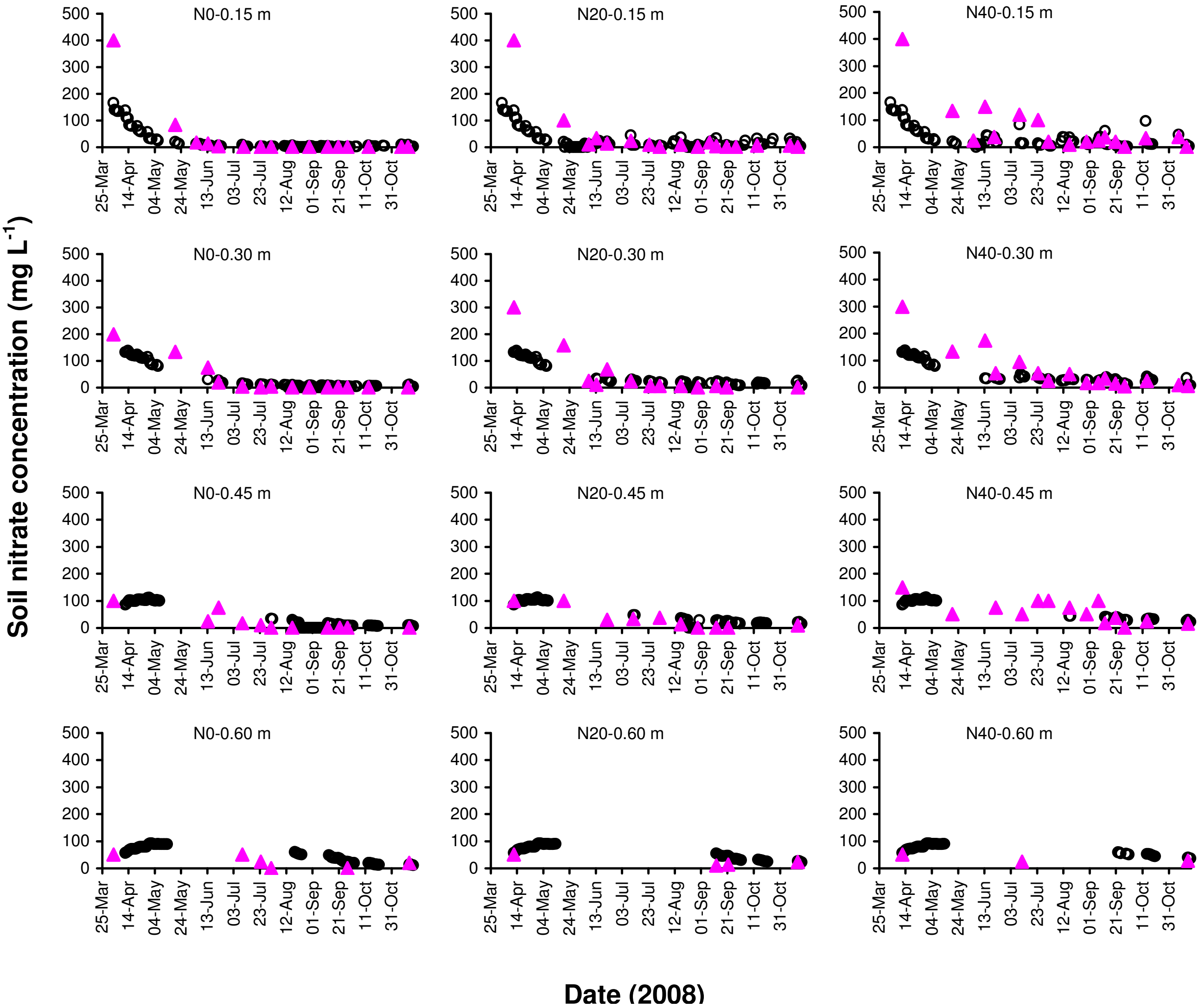

Figure 5.11 Simulated (O) and measured data (▲) soil nitrates concentrations at the depths of 0.15, 0.30, 0.45 and 0.60 m for well watered and range of N application treatments for Cedara site during 2008 season

5.5 CONCLUSIONS

In the current work, the SWB-Sci model was tested using different N fertiliser application rates and irrigation regimes at two sites. The model was sensitive to increased N application under water stressed and non stressed conditions as yield, LAI, above-ground forage N uptake and soil nitrates increased as levels of N increased. It predicted annual ryegrass growth, above-ground forage N uptake, soil water content and mobile soil nitrate reasonably well, as most of the statistical evaluation parameters were within acceptable ranges. Having gained confidence in modelling N and water interactions of pasture systems, the SWB-Sci model's simulation results can be used in conjunction with data collected from field experiments to better understand systems and extrapolate findings in time and space. Scenarios and conditions, including nutrient leaching and non-point source pollution, climate and soil variability, crop management, alternative irrigation and N management strategies can now be explored using the model. This can save money and time required for conducting long-term intensive field experiments for gathering information on potential pasture production.