CHAPTER 8

CALIBRATION AND VALIDATION OF THE SWB MODEL FOR POTATOES (*SOLANUM TUBEROSUM* L.) AND ONIONS (*ALLIUM CEPA* L.)

8.1 Introduction

Crop growth modelling is the dynamic simulation of crop growth by numerical integration of constituent processes with the aid of computers (Wajid & Hussain, 2005). It also involves the development of biological life cycles that can be described as a series of stages from germination to maturity (Matthews, 2004; Wajid & Hussain, 2005). Crop models have been used to quantify the yield gap between actual and climatic potential yields of different field crops (Montesinos *et al.*, 2001). It can also be used to evaluate possible causes for change in yield over time in a given region and yield forecasting prior to harvest. In addition, models are also used as a research tool to evaluate optimum management of cultural practices, fertiliser and water use (Mason *et al.,* 1980; Wajid & Hussain, 2005). The simulation approaches in crop modelling can be advantageous and, once the model is developed, it can be used for different conditions by changing the parameters, without rewriting the model (Matthews, 2004).

The Soil Water Balance (SWB) model is a mechanistic, real-time, generic crop, soil water balance, irrigation scheduling model, which is based on the improved generic crop version of the NEW Soil Water Balance (NEWSWB) model (Annandale *et al.*, 1999). SWB gives a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop management data (Annandale *et al.*, 1999). It calculates the water balance and crop growth with weather, soil and crop units. The nman-Monteith reference crop evapotranspiration (Allen *et al.*, 1998) together with a mechanistic crop growth model, which uses soil water and grows a realistic canopy and root system, provide the best possible estimate of the soil water balance. Most irrigators, however, could in the past not use this approach because it requires specialised knowledge, weather data and computers to run the model. On the other hand, high costs, associated with the management of the model, would be reduced by packaging the model in a user-friendly format, avoiding the need for detailed understanding of the soil-plant-atmosphere continuum (Annandale *et al*., 1999). Moreover, the accuracy of the mechanistic version and the universally valid estimation procedures increase the benefits of this model (Annandale *et al*., 1999).

The mechanistic approach used to estimate crop water use has several advantages over the more empirical methods (Smith, 1992b). The use of thermal time to describe crop development overcomes the need to use different crop factors for different planting dates and regions. In addition, splitting evaporation and transpiration solves the problem of considering irrigation frequency, particularly during the crop's initial stage, where crop canopy cover is low and evaporation from the soil is more important (Villalobos & Fereres, 1990). It also more accurately describes deficit irrigation strategies where water use is supply-limited (Annandale *et al*., 1999).

Irrigation scheduling with crop growth models has drawn the interest of farmers since personal computers have become more accessible. Most of the existing models are either crop specific or do not simulate daily crop water use. Some models are relatively simple to use for planning purposes, but do not allow real-time scheduling. Other models accurately describe the complexity of natural processes and this makes them suitable for research purposes. However, this may not be applicable for practical purposes due to large quantities of input data required and lack of a user-friendly interface.

Since SWB is a generic crop growth model, parameters specific for each crop need to be determined experimentally prior to using it for irrigation scheduling. Therefore, the objective of this study was to generate parameters for four potato cultivars and one onion cultivar in South Africa and one tropical potato cultivar of Ethiopia. These databases are to be included in the SWB model to create a user-friendly irrigation-scheduling tool for practical application. The SWB model was then calibrate and validate for the four potato cultivars grown at Bronkhorstspruit, RSA during September to December 2003, a tropical potato grown at Debre-Zeit, Ethiopia (from January to April 2005) and onions grown under water stress conditions applied at different growth stages at the Hatfield Experimental farm of the University of Pretoria (from May to December 2004).

8.2 Model description

The sub-components of SWB, the weather, soil and crop units are described in detail by Annandale *et al*. (1999) for further references. Therefore, only a brief outline of the model is given in this chapter.

According to Annandale *et al*. (1999), the SWB was two types of models:

- The crop growth, mechanistic model, which calculates crop growth and soil water balance components; and
- The FAO-type crop factor model, which calculates the soil water balance without simulating dry matter production mechanistically.

In this particular work, however, the crop growth model that calculates the crop growth and soil water balance is used in the simulations.

The weather unit of SWB calculates the daily Penman-Monteith grass reference evapotranspiration (ETo) according to the recommendations of the Food and Agriculture Organization of the United Nations (Smith *et al.*, 1996; Smith, 1992a). In the weather unit of SWB, potential evapotranspiration (PET) is divided into potential evaporation and potential transpiration by calculating canopy radiant interception from simulated leaf area (Ritchie, 1972). Under conditions where actual transpiration is less than potential transpiration, the crop has undergone stress that reduced leaf area development. This makes the crop growth model of SWB very suitable for predicting crop water requirements when deficit irrigation strategies are applied (Oliver & Annandale, 1998; Annandale *et al.*, 1999). SWB calculates the potential evapotranspiration (PET) according to eq 8.1:

$$PET = ETo * Kc_{max} \qquad (8.1)$$

Where

Kc_{max} represents the maximum value (Kc) following rain or irrigation (Allen *et al.*, 1998)

Transpiration rate depends on the atmospheric evaporative demand, the soil-water potential and FI of solar radiation by the crop canopy. FI is calculated from the LAI, using eq 8.2:

$$FI = 1\text{-}\exp(-k*LAI) \qquad (8.2)$$

Hence, $$k = Ln(1 - FI) / - LAI \qquad (8.3)$$

Where

K represents the canopy extinction coefficient, it can be calculated using field measurements of LAI and FI. K is calculated from FI measurements with the ceptometer, which measures photosynthetically active radiation.

The canopy extinction coefficient for PAR (K_{PAR}) can be used to calculate photosynthesis as a function of intercepted PAR. The canopy extinction coefficient for total radiation (Ks) is required for predicting radiation-limited dry matter production (Monteith, 1977), for partitioning ET into evaporation from the soil surface, and crop transpiration (Ritchie, 1972). The procedure recommended by Campbell and van Evert (1994) was used to convert K_{PAR} into K_S:

$$K_S = K_{bd} \sqrt{a_s} \quad (8.4)$$

$$K_{bd} = K_{PAR} / \sqrt{a_p} \quad (8.5)$$

$$a_s = \sqrt{a_p a_n} \quad (8.6)$$

Where

K_{bd} = Canopy radiation extinction coefficient for black leaves with diffuse radiation

a_s = Leaf absorptance of solar radiation

a_p = Leaf absorptance of PAR

a_n = Leaf absorptance of near infrared radiation (NIR) (0.7-3 µm)

the value of a_p was assumed to be 0.8, whilst a_n was assumed to be 0.2 (Goudriaan, 1977). a_s is the geometric mean of the absorptances in the PAR and NIR spectrum.

In the crop unit, SWB calculates crop dry matter accumulation in direct proportion to transpiration corrected for vapour pressure deficit (Tanner & Sinclair, 1983). It also calculates radiation-limited growth (Monteith, 1997) and takes the lower of the two.

This dry matter is partitioned to roots, stems, leaves and grains or fruits. Partitioning depends on phenology calculated with thermal time and modified by water stress.

The crop specific growth parameters required by SWB is generated to enable simulation of growth and water use of crops. According to Tanner & Sinclair (1983), the relationship between dry matter production and crop transpiration need to be corrected to account for atmospheric conditions, mainly for vapour pressure deficit (VPD). Hence, dry matter-water ratio (DWR) is calculated using eq 8.7 (Annandale *et al.*, 1999).

$$DWR = (DM*VPD) / ET \qquad (8.7)$$

Where

DM (kg m^{-2}) is measured at harvest

VPD represents the average of the season

ET represents the seasonal crop evapotranspiration in mm, which is equivalent to kg m^{-2}

DWR and VPD are measured in Pa

ET is obtained using the following equation for daily time interval:

$$ET = P + I - R - Dr \pm \Delta Q \qquad (8.8)$$

Where

R = runoff, Dr = drainage and ΔQ = the change in soil water storage, which is calculated from soil water measurement at the beginning and end of the irrigation season with the neutron water meter.

Dry matter production can also be calculated from the radiation conversion efficiency (Ec), under conditions of radiation-limited growth, according to Monteith (1977).

$$DM = Ec*FI*Rs \qquad (8.9)$$

Where, Rs = the solar radiation

In SWB, the daily dry matter increment and its partitioning into different plant parts are calculated as either transpiration-limited (eq 8.8) or radiation-limited (eq 8.9). Hence, SWB calculates the LDM and SDM as follows (Annandale *et al.,* 1999):

$$\mathrm{LDM} = \mathrm{CDM} / (1 + \mathrm{PART}^*\mathrm{CDM}) \qquad (8.10)$$

$$\mathrm{SDM} = \mathrm{CDM} - \mathrm{LDM} \qquad (8.11)$$

Similarly, SWB uses the LDM to calculate LAI as:

$$\mathrm{LAI} = \mathrm{SLA}^*\mathrm{LDM} \qquad (8.12)$$

SLA represents the specific leaf area, which is calculated as the seasonal average of the ratio of LAI and LDM. Leaf-stem dry matter partitioning parameter (PART) is determined as a function of SLA, LAI and CDM, by combining eqs (8.10) and (8.12). Hence, the correlation between CDM and (SLA*CDM)/LAI-1 and the regression line which is forced through the origin, represents PART in

m^2 kg^{-1}. PART is described as:

$$\mathrm{PART} = (\mathrm{SLA}^*\mathrm{CDM}/\mathrm{LAI}-1)/\mathrm{CDM} \qquad (8.13)$$

8.3 Materials and methods

Procedures followed during the field experiments, and materials and methods used were dealt with under each respective chapters. The growth performance and yield of potatoes (cv. Awash) grown under varying water regimes in the tropical environment of Ethiopia (January to April, 2005) were discussed in Chapter 4. The evaluation of growth performance and dry matter partitioning of the four processing potato cultivars grown at Bronkhorstspruit, South Africa (September to December, 2003) were also discussed in Chapter 5. In addition, the growth analysis and yield data of onions (cv. Texas Grano) grown under water-stress conditions applied at different growth stages was discussed in Chapter 7. In this chapter, the crop specific growth parameters developed from the field experiments are presented and discussed. In addition, the SWB model is calibrated and simulations evaluated.

Management, weather, soil and crop data are required as inputs in order to run both the crop growth and the FAO models of SWB.

Input data related to crop management include:

- starting date of the simulation;
- planting date;
- irrigation timing options;
- irrigation system; and
- area of the field (ha).

Soil data required per layer are:

- soil layer thickness (m);
- drainage factor;
- maximum drainage rate;
- volumetric water content at field capacity and permanent wilting point;
- initial volumetric water content ; and
- bulk density (Mg m^{-3}).

Weather data include:

- latitude (^{o}N or ^{o}S) and altitude (m.a.s.l.);
- maximum and minimum daily temperature (^{o}C);
- precipitation and irrigation (mm);
- solar radiation (MJ m^{-2} d^{-1});

- vapour pressure or minimum and maximum humidity (%) or wet and dry bulb temperatures (°C); and
- wind speed (m s^{-1}) and height of the measurement (m).

Crop parameters include:

- cardinal temperatures (base and optimum temperatures for development (°C);
- thermal time requirements (in degree days) for emergence, onset of the reproductive stage, transition period, crop maturity and leaf senescence;
- VPD-corrected dry matter water-ratio (DWR) (Pa);
- maximum RD (m);
- canopy solar radiation extinction coefficient (kc);
- radiation use efficiency (kg MJ^{-1});
- leaf-stem partition parameters (m^2 kg^{-1}); and
- maximum crop height (m).

Crop specific growth parameters for the five potato cultivars grown at two locations under different climatic conditions and an onion grown under water stress imposed at different growth stages are shown in Tables 8.2, 8.3 and 8.4. The basal temperatures, temperatures for optimum growth and cut-off temperatures were obtained from Annandale *et al.* (1999). Crop measurements recommended by Mason *et al.* (1980) were used to determine the following parameters: canopy solar radiation extinction coefficient (Kc), SLA, leaf-stem partitioning parameter (PART), canopy radiation extinction coefficient (K) and corrected dry matter water ratio (DWR).

8.4 Results and discussion

8.4.1 McCain trial

Two newly released potato cultivars, Frodo and Darius were grown along with two existing cultivars, Pentland Dell and Shepody at McCain experimental station in 2003. Table 8.2 provides the crop specific growth parameters determined from the measured data in the experimental field and some others obtained from literature.

The crop data measured from the experimental field was used to generate some of the crop specific parameters. The results revealed that the crop specific growth parameters generated were generally comparable with the other values previously published by Steyn (1997) and Annandale *et al. (*1999). The canopy solar radiation extinction coefficients generated from this experiment were generally on the lower range compared to the findings reported by Annandale *et al.* (1999). Table 8.2 reveals that the value for corrected DWR is higher for the new cultivars (Frodo and Darius) compared to the two established cultivars. Cultivar Darius exhibited a relatively high radiation conversion efficiency (Ec) of 0.0020 kg MJ^{-1} compared to the other cultivars, which had values lower than 0.00175 kg MJ^{-1} (Table 8.1). The comparably high values of DWR and Ec for Darius could be attributed to the fact that it is a slow maturing cultivar, which has long LAD. Table 8.2 also reveals that the SLA, which is the average ratio of LAI and LDM before leaf senescence, was the highest for Darius, followed by Frodo. All cultivars tested in this trial possessed high SLA values, compared to the cultivars included in the reports of Steyn (1997) and Annandale *et al. (*1999). Similarly, the thermal time requirements for different growth stages, mainly for emergence, maturity and the transition periods, were higher for Darius, compared to the other cultivars. In general, the thermal time recorded for cultivars were more or less comparable.

The crop data measured from the experimental field was used to calibrate the SWB model for the four cultivars. The performance outputs of the measured data (points) and the SWB model simulations (lines) are displayed in

- Figures 8.1a and 8.1b for Frodo;
- Figures 8.2a and 8.2b for Pentland Dell;
- Figures 8.3a and 8.3b for Darius; and
- Figures 8.4a and 8.4b for Shepody.

The SWB simulation performance was evaluated according to the statistical criteria proposed by De Jager (1994) in Table 8.1.

Table 8.1 Model evaluation parameters and their accuracy criteria levels (after De Jager, 1994)

Statistical parameters	Abbreviations	Reliability criteria
Number of measured values	N	-
Coefficient of determination	r^2	> 0.80
Willmot (1982) index of agreement	D	> 0.80
Root mean square error	RMSE	-
Mean absolute error expressed as a percentage of the mean of the measured values	MAE (%)	< 20

Table 8.2 Summary of crop growth parameters determined for the four potato cultivars from 2003 field data and from the literature, to calibrate the SWB model

Crop growth parameters	**Potato cultivars**				**Source**
	Frodo	**Pentland Dell**	**Darius**	**Shepody**	
Canopy radiation extinction coefficient	0.40	0.40	0.40	0.40	Data
Corrected dry matter-water ratio (Pa)	5.2	4.8	5.2	4.8	Data
Radiation conversion efficiency (kg MJ^{-1})	0.00174	0.00174	0.0020	0.00165	Data
Base temperature (^{o}C)	2	2	2	2	Annandale *et al.,* (1999)
Temperature for optimum crop growth (^{o}C)	10	10	10	10	Annandale *et al.,* (1999)
Cut-off temperature (^{o}C)	28	28	28	28	Annandale *et al.,* (1999)
Emergence day degrees (d ^{o}C)	400	400	525	360	Data
Day degrees at end of vegetative growth (d ^{o}C)	730	680	1200	820	Data
Day degrees for maturity (d ^{o}C)	2635	2240	2400	2280	Data
Transition period day degrees (d ^{o}C)	520	460	520	420	Data
Day degrees for leaf senescence (d ^{o}C)	1842	1646	1826	1410	Data
Maximum crop height (m)	0.75	0.75	0.75	0.75	Data
Maximum root depth (m)	0.8	0.8	0.8	0.8	Data
Fraction of total dry matter translocated to heads/tuber	0.45	0.45	0.45	0.45	Annandale *et al.,* (1999)
Canopy storage (mm)	1	1	1	1	Annandale *et al.,* (1999)
Leaf water potential at maximum transpiration (kPa)	-550	-550	-550	-550	Annandale *et a.,* (1999)
Maximum transpiration (mm d^{-1})	8	8	7	8	Steyn, (1997)
Specific leaf area (m^2 kg^{-1})	26	25	28	25	Data
Leaf-stem partition parameter (m^2 kg^{-1})	1.5	2	2	3	Data
Total dry matter at emergence (kg m^{-2})	0.005	0.005	0.005	0.005	Annandale *et al.,* (1999)
Fraction of total dry matter partitioned to roots	0.1	0.1	0.1	0.1	Annandale *et al,.* (1999)
Root growth rate (m^2 $kg^{-0.5}$)	3	2	2	2	Steyn, (1997)
Stress index	0.98	0.98	0.98	0.98	Annandale *et al.* (1999)

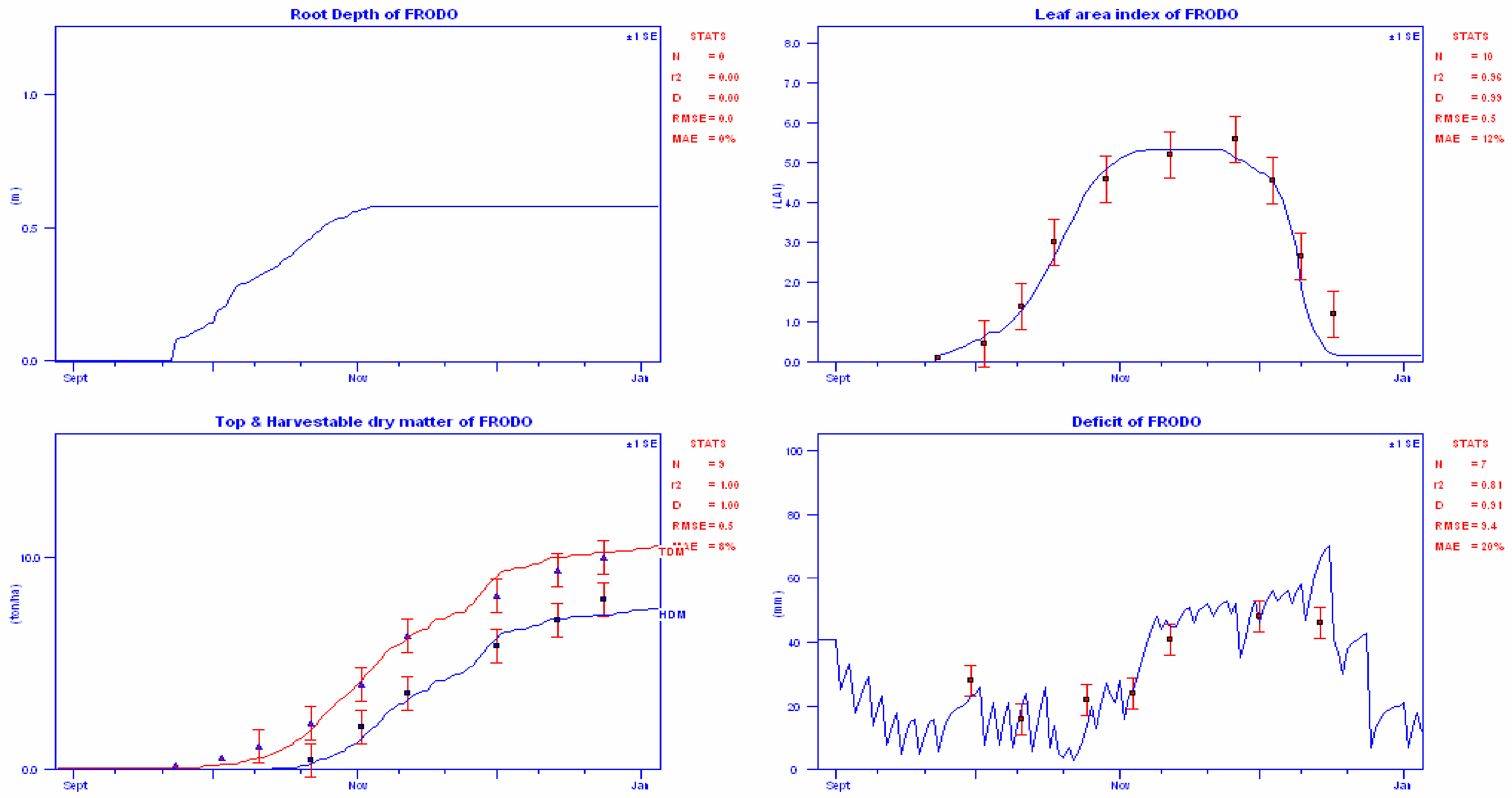

Figure 8.1a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for Frodo.

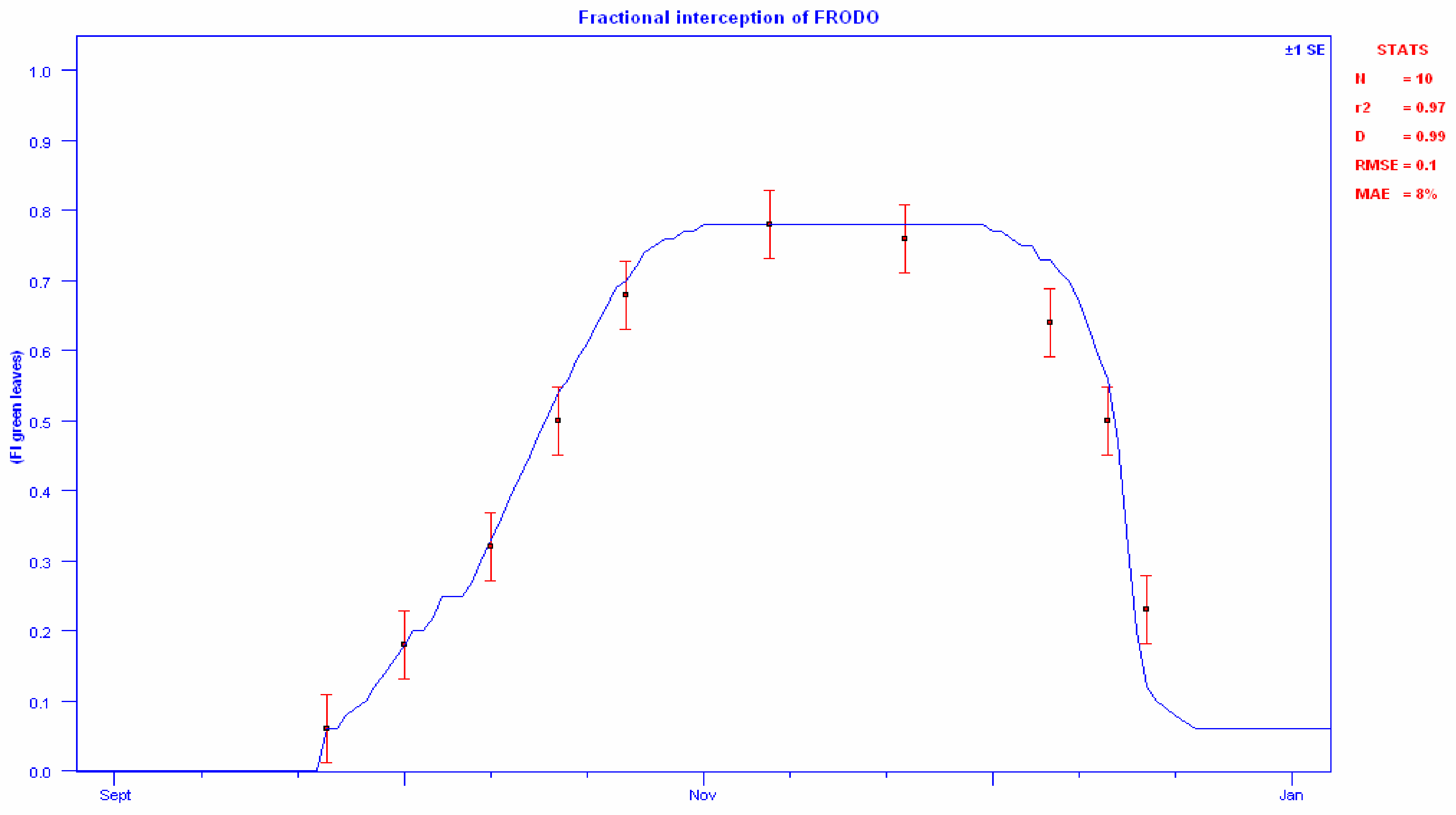

Figure 8.1b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for Frodo

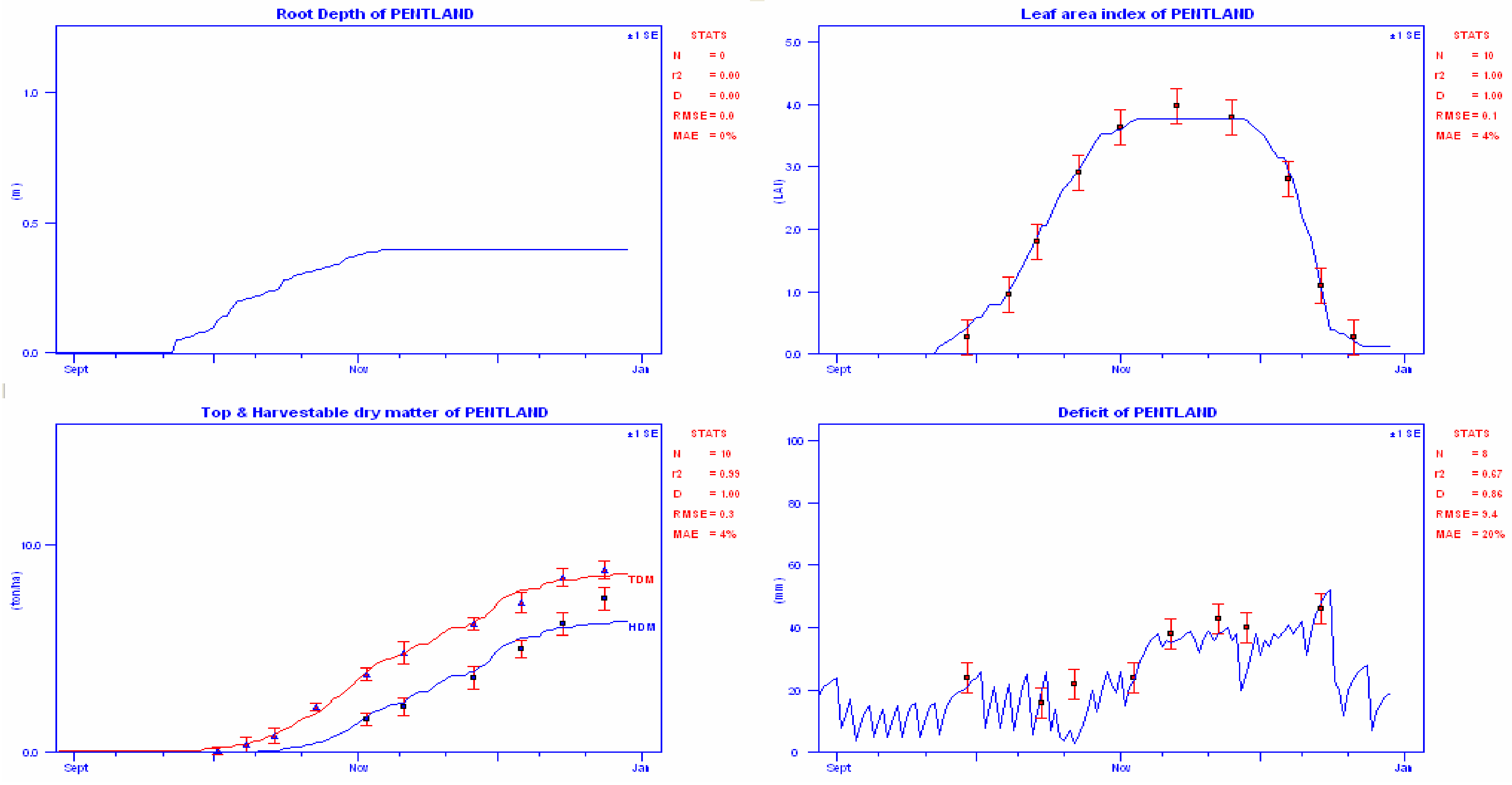

Figure 8.2a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for Pentland Dell

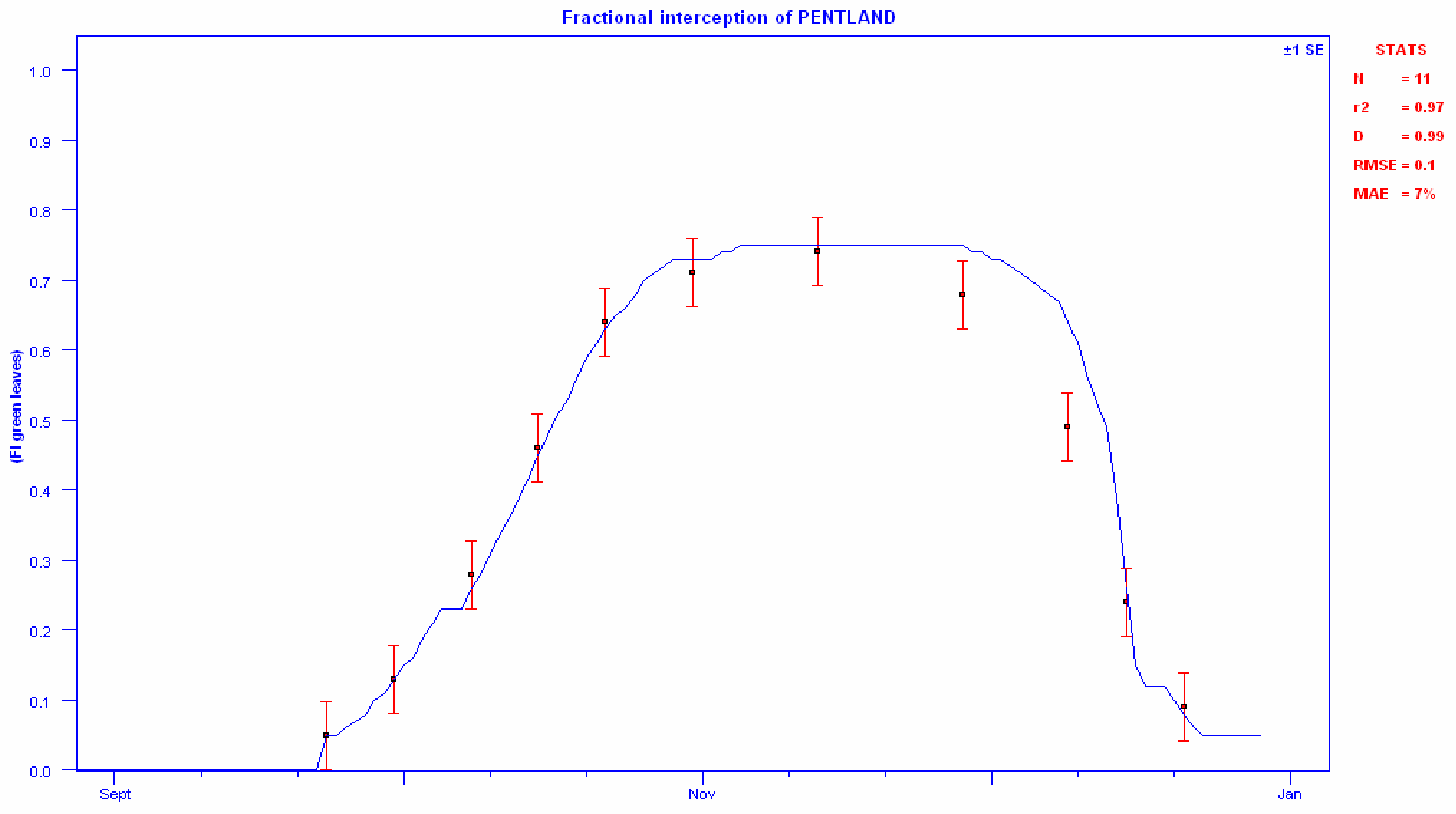

Figure 8.2b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for Pentland Dell

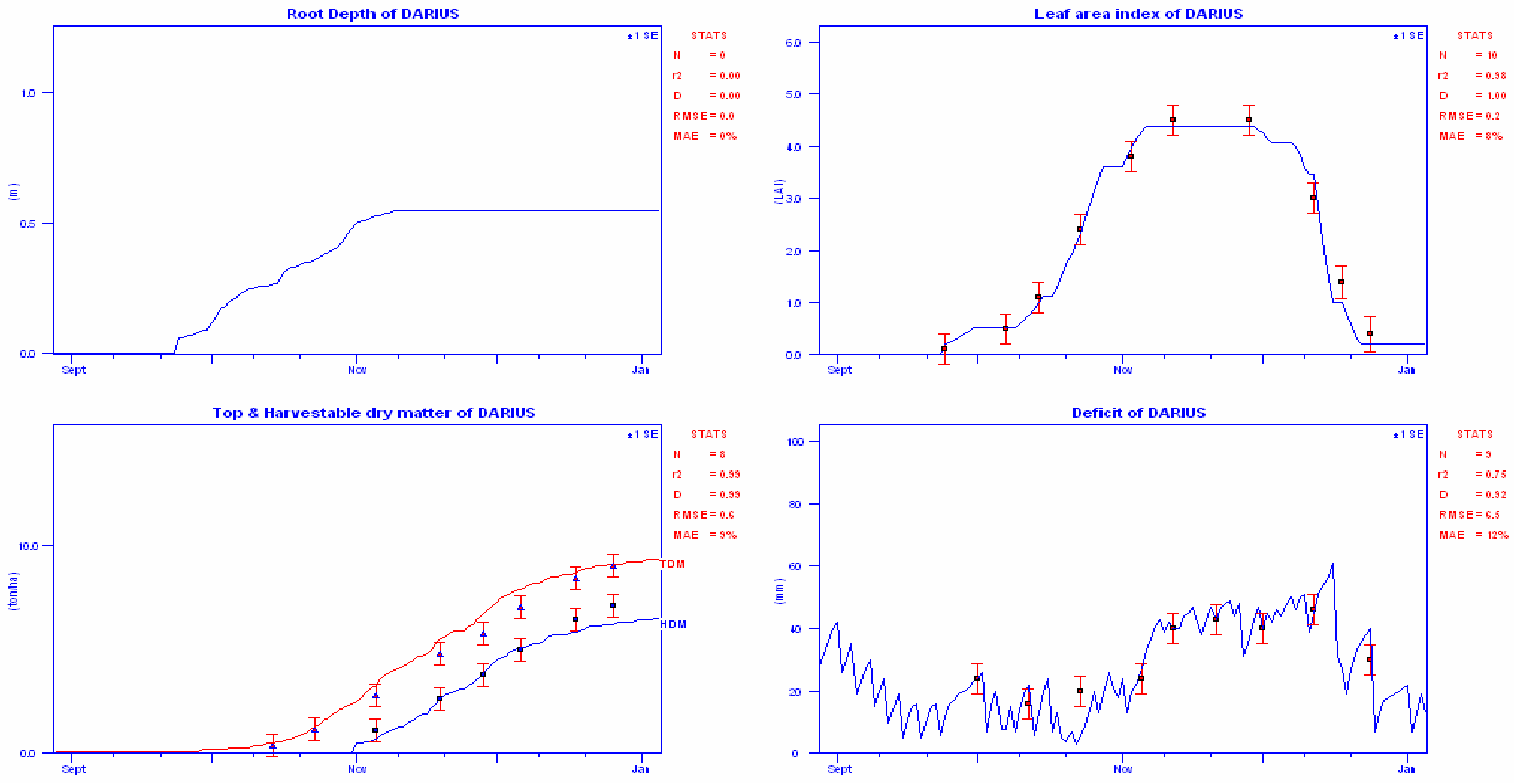

Figure 8.3a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for Darius

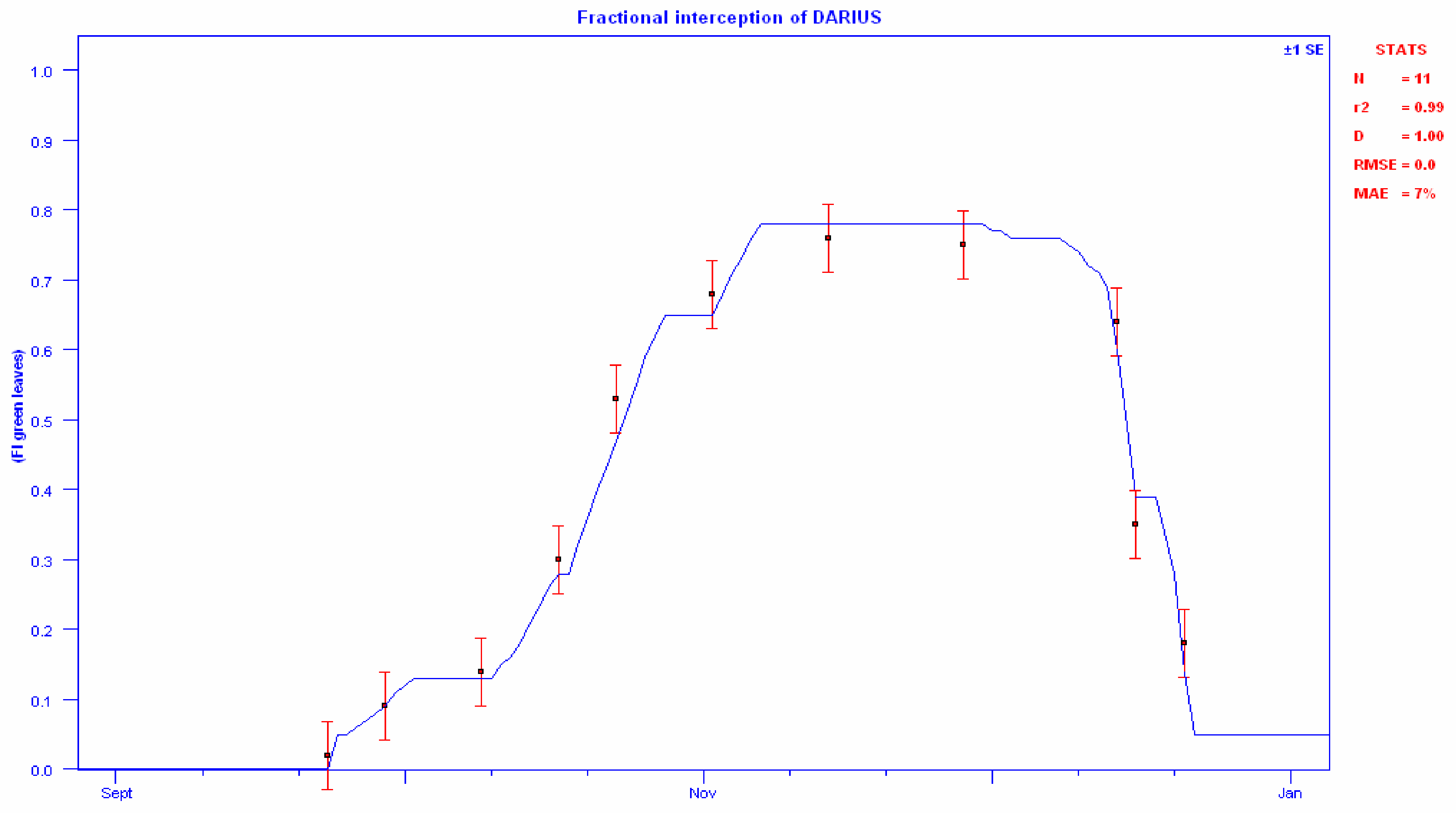

Figure 8.3b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for Darius

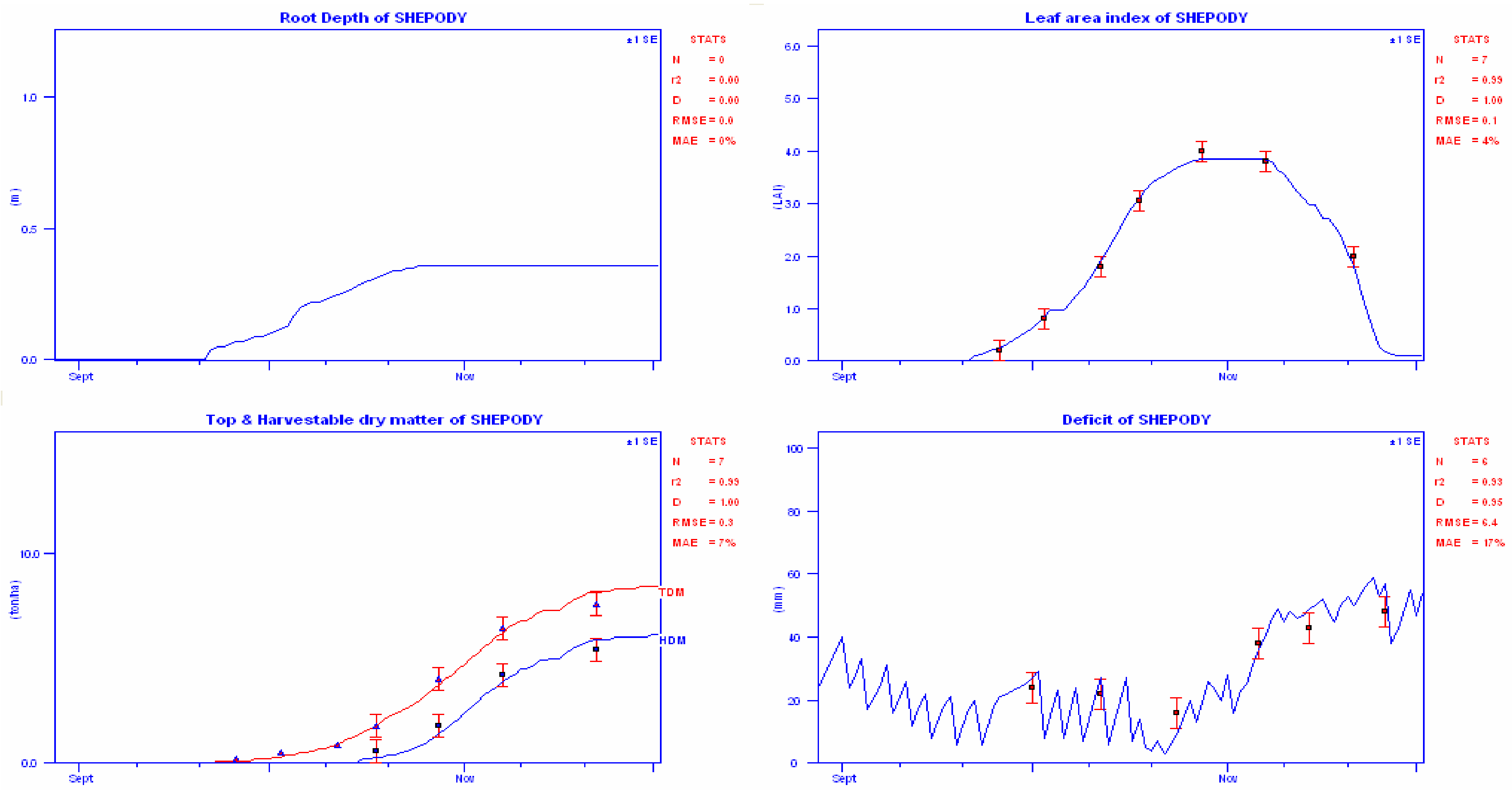

Figure 8.4a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for Shepody

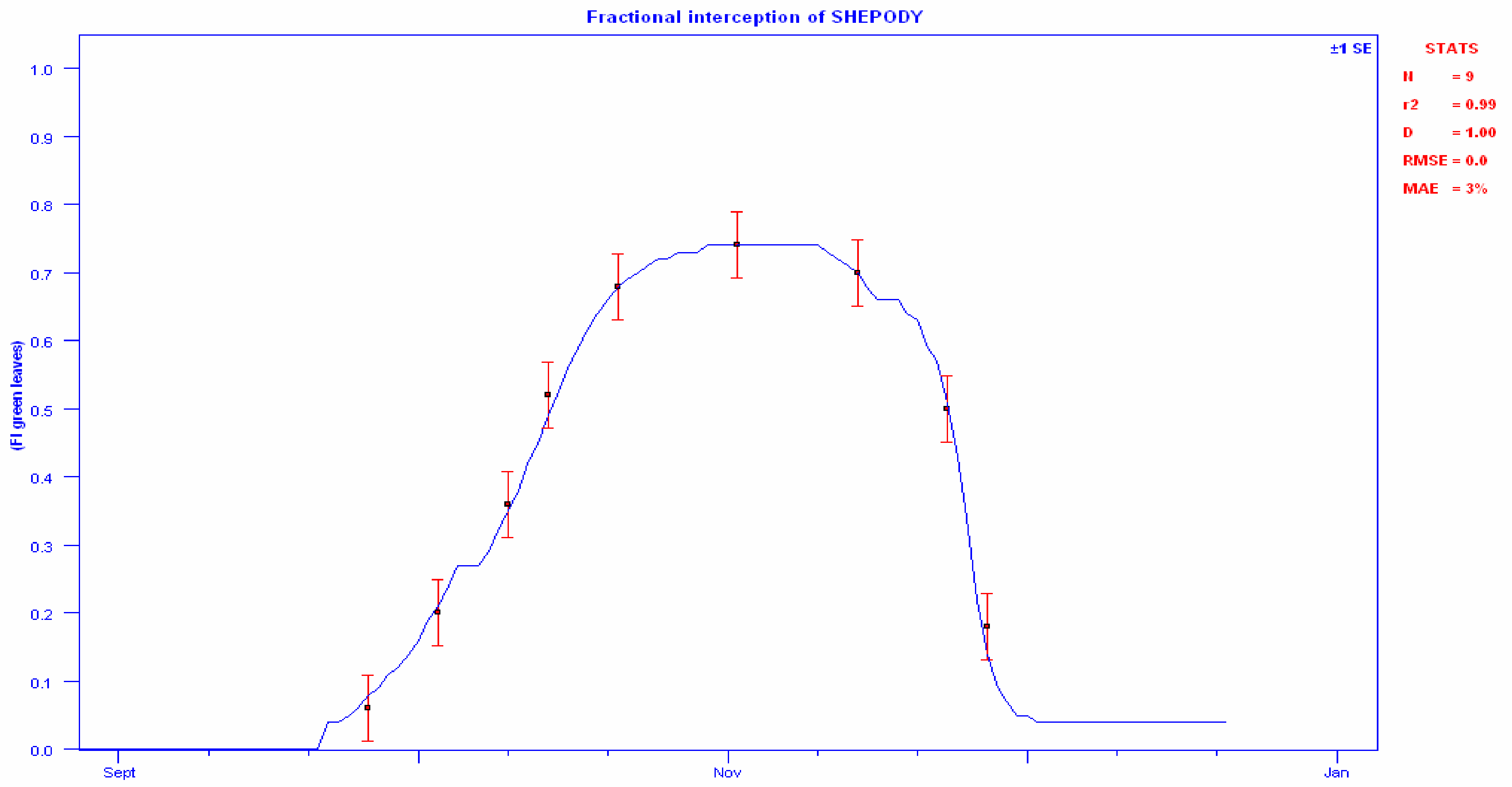

Figure 8.4b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for Shepody

Simulations of crop growth and the soil water balance were run for each potato cultivar. The root growth was not measured during the field experiment, and only the SWB model simulation is given in Figures 8.1a, 8.2a, 8.3a and 8.4a. Simulations for TDM, harvestable dry matter (HDM), the LAI and FI fitted very well for the four potato cultivars, Frodo, Pentland Dell, Darius and Shepody, as the statistical indicators lie within the accuracy limits recommended by De Jager (1994). The model, however, slightly under-estimated the LAI of cv Frodo during the vegetative growth stage, even though the statistical measures indicated acceptable simulation accuracy.

The SWB simulations revealed that all four the cultivars were probably water stressed from November to mid December (Figures 8.1a, 8.2a, 8.3a & 8.4a). The measured data for soil water deficits to field capacity also confirmed that the crops were most likely water stressed during the indicated growth periods. Water stress during crop growth also manifested on the LAI and FI simulations of Darius, where the graphs appeared to be irregular (stepped). Despite this, both the LAI and FI simulated values matched the measured values very well for all four cultivars. The water management, including irrigation was performed by McCain personnel. The soil water status was only measured to calibrate the SWB simulations and not for irrigation management. In general, the measured soil water deficits during crop growth were in good agreement with the SWB simulations for all cultivars. Both the measured data and the simulations indicated a high soil water deficit from tuber bulking to maturity, which probably resulted in growth and tuber yield reduction. Shepody, an early cultivar, senesced more than a month earlier than the other cultivars. This was confirmed from the field data collected and the model was able to simulate this too.

8.4.2 Potato irrigation regime experiment

An experiment was executed on potato (cv. Awash) at Debre-Zeit, Ethiopia in 2005, with four irrigation regime treatments. These included:

- irrigation calendars generated by the SWB model (DZ1);
- traditional water regime practiced by farmers (DZ2);
- irrigation regime practiced by the RCP (DZ3); and
- the conventional soil water monitoring by neutron water meter (DZ4). See section 4.2 for trial details. Table 8.3 shows the crop specific growth parameters determined from the measured field experimental data points and some others obtained from literature.

Table 8.3 Summary of crop growth parameters determined for potato cv. Awash at Debre-Zeit, Ethiopia in 2005 and from literature

Crop growth parameters	**Values**	**Units**	**Source**
Canopy solar radiation extinction coefficient (Kc)	0.36	-	Data
Corrected dry matter-water ratio (dwr)	5.0	Pa	Data
Radiation conversion efficiency (RUE)	0.00175	kg MJ^{-1}	Data
Base temperature (Tb)	2	^{o}C	Annandale *et al.*, (1999)
Temperature for optimum crop growth	10	^{o}C	Annandale *et al.*, (1999)
Cut-off temperature	28	^{o}C	Annandale *et al.*, (1999)
Thermal time: emergence	360	day degree	Data
Thermal time: reproductive phase	720	day degree	Data
Thermal time: maturity	2400	day degree	Data
Thermal time: transition	238	day degree	Data
Thermal time: leaf senescence	640	day degree	Data
Maximum crop height (Hc)	0.80	m	Data
Maximum root depth	0.70	m	Data
Fraction of total dry matter translocated to tuber	0.45	-	Annandale *et al.*, (1999)
Canopy storage	1.00	mm	Annandale *et al.*, (1999)
Leaf water potential at maximum transpiration	-550	kPa	Annandale *et al.*, (1999)
Maximum transpiration	8.00	mm d^{-1}	Steyn., (1997)
Specific leaf area (SLA)	26.00	m^{2} kg^{-1}	Data
Leaf-stem partition parameter	2.00	m^{2} kg^{-1}	Data
Total dry matter at emergence	0.005	m^{2} kg^{-1}	Annandale *et al.*, (1999)
Fraction of total dry matter partitioned to roots	0.10	-	Annandale *et al.*, (1999)
Root growth rate	3.00	m^{2} kg$^{-0.5}$	Steyn, (1997)
Stress index	0.98	-	Annandale *et al.*, (1999)

The crop growth data measured from the field experiment was compared with the SWB crop growth simulations. The performance output for the measured data set (points) and the SWB model simulation (lines) are displayed in:

- Figures 8.5a and 8.5b for the irrigation treatment predicted by SWB (DZ1);

- Figures 8.6a and 8.6b for water management traditionally practiced by farmers (DZ2);
- Figures 8.7a and 8.7b for water management practiced by the nearby RCP (DZ3); and
- Figures 8.8a and 8.8b for the water deficit refilled to field capacity as measured by the neutron water meter (DZ4).

The graphs represent simulated RD, TDM and HDM, LAI and the soil water deficit (SWD). No measured data points were available for root depth. The model simulation performances were evaluated by the statistical criteria according to De Jager (1994), which are given in Table 8.1.

The crop growth parameters determined from the irrigation regime experiment at Debre-Zeit appeared to be more or less comparable to the previously reported parameters of Steyn (1997) and Annandale *et al.* (1999). However, as for the previously discussed experimental results (Table 8.2), some parameters like canopy radiation extinction coefficient and dry matter-water ratio values are slightly lower than those determined by Steyn (1997) and Annandale *et al.* (1999). This could be attributed to genetic differences between cultivars and different climatic conditions under which the crops were grown. Kooman *et al.* (1996b) and Jovanovic *et al.* (2002) further explain that the small canopy size and low yield potential of potatoes in the tropics and subtropics result from high temperatures and short day lengths, to which most potato cultivars are less adapted. This usually results in a low final tuber yield.

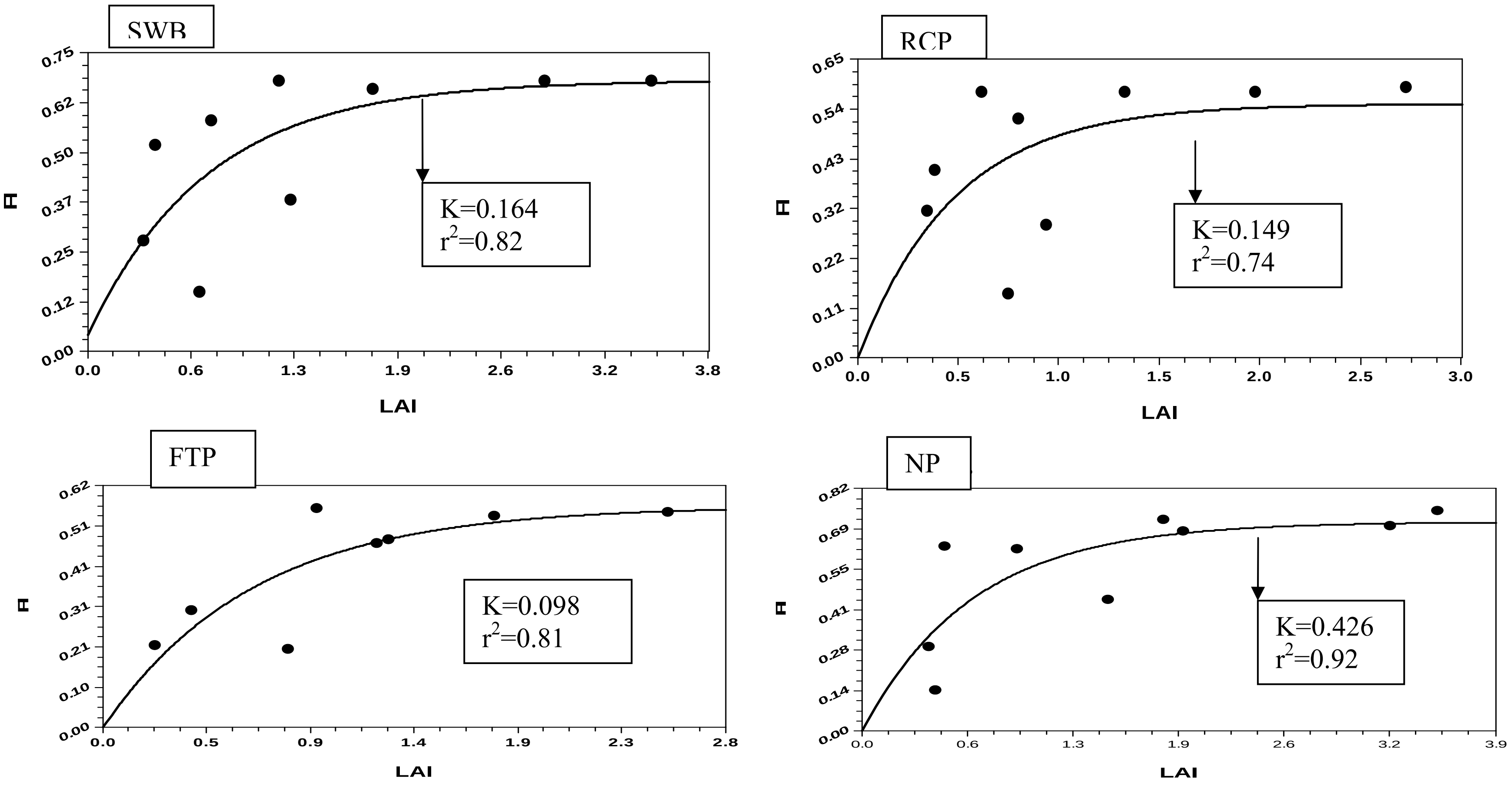

Figure 8.5 Correlation between leaf area index (LAI) and fractional interception (FI) of radiation for potato cv Awash. Canopy extinction coefficient (K) and coefficient of determination (r^2) of the exponential regression function.

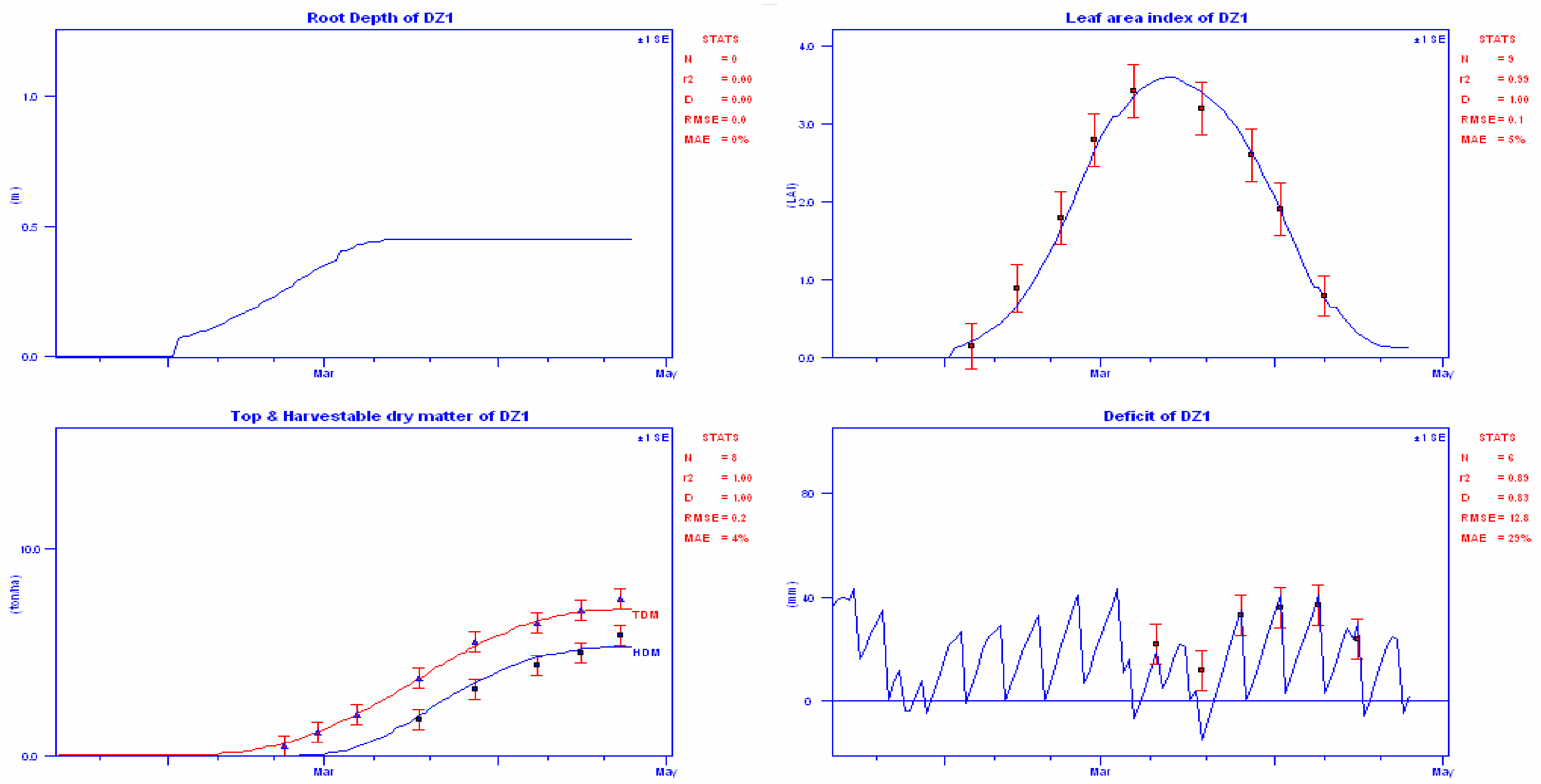

Figure 8.6a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for SWB treatment (DZ1)

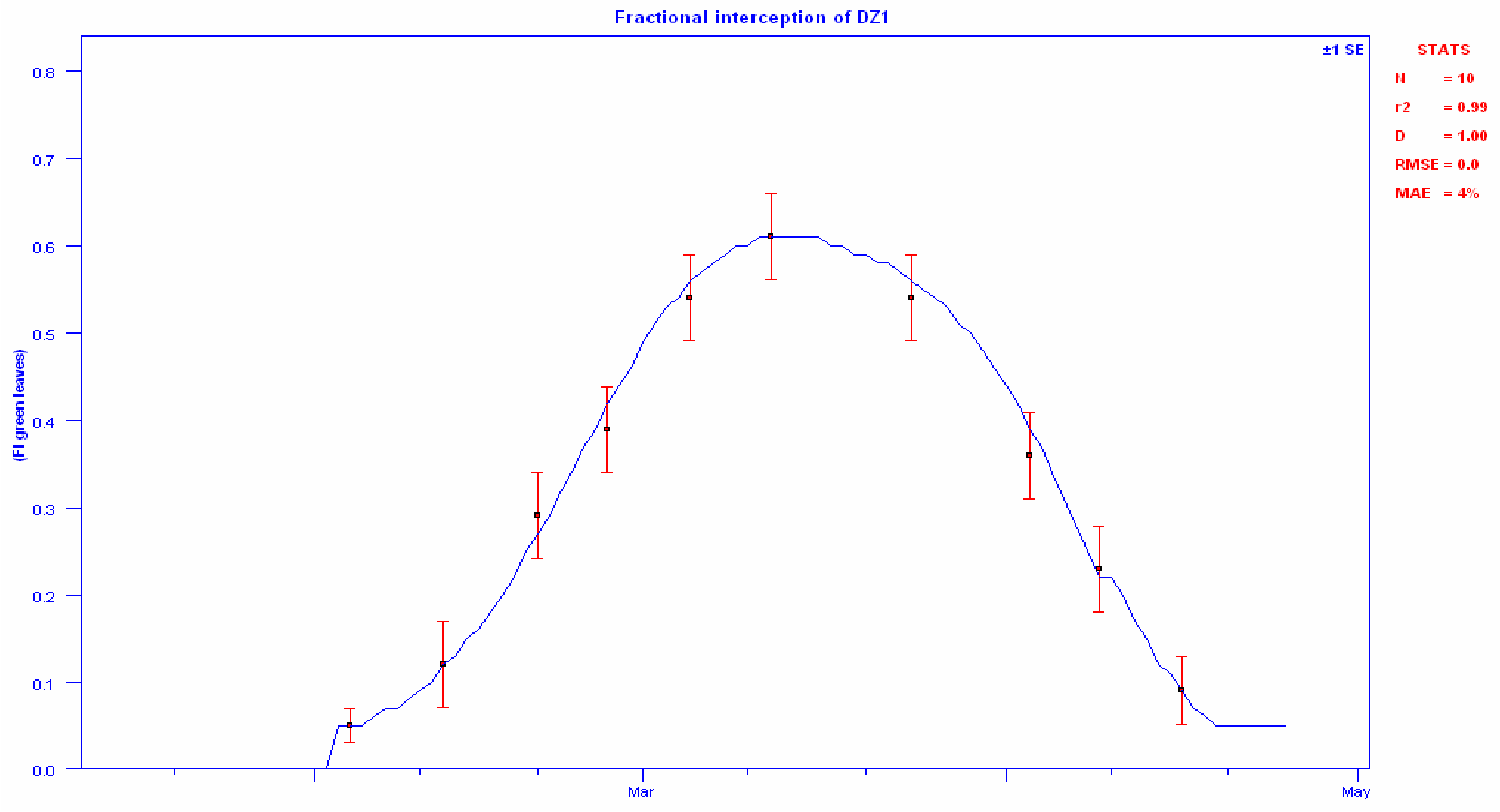

Figure 8.6b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for SWB treatment (DZ1)

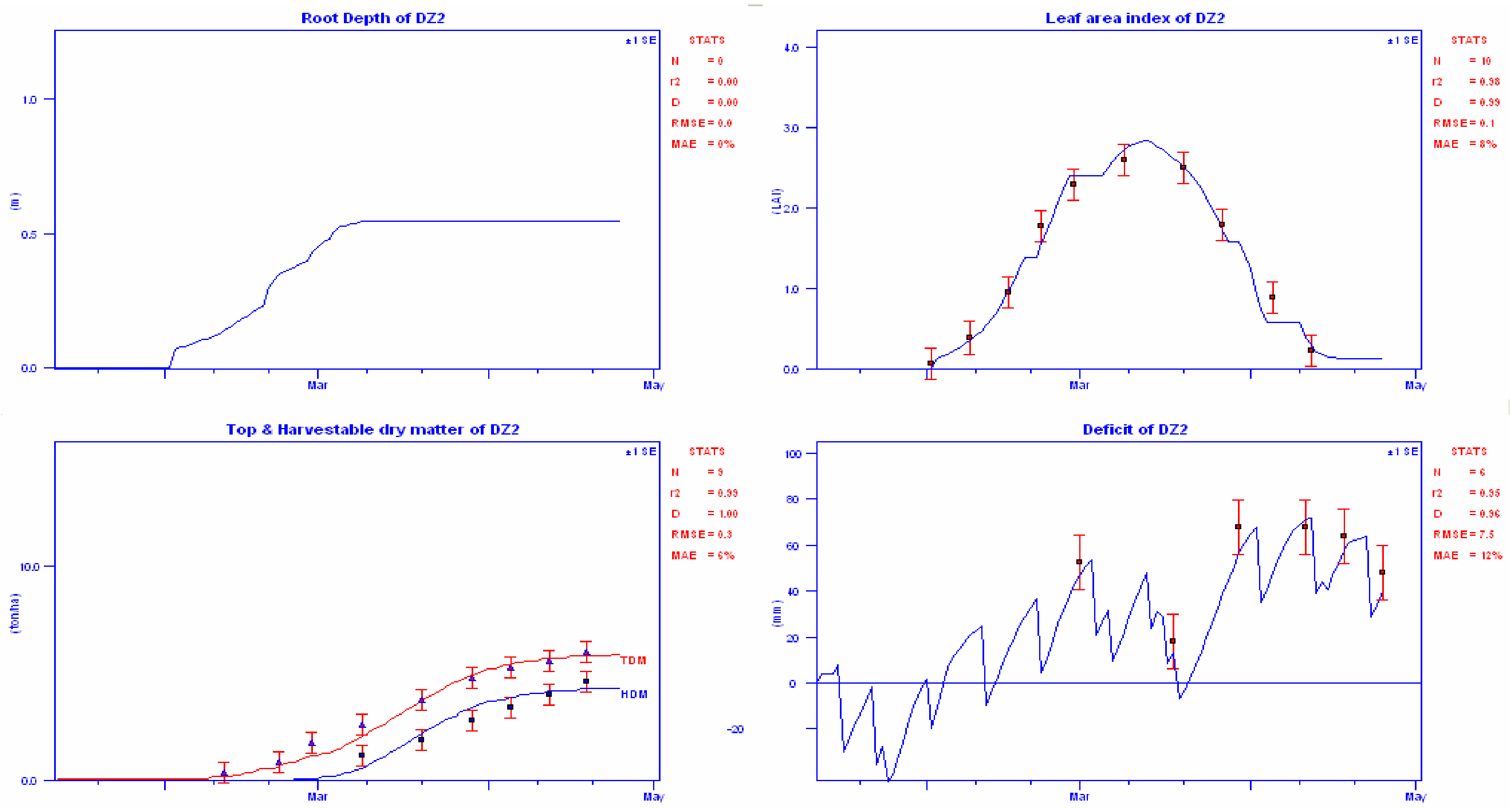

Figure 8.7a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for FTP treatment (DZ2)

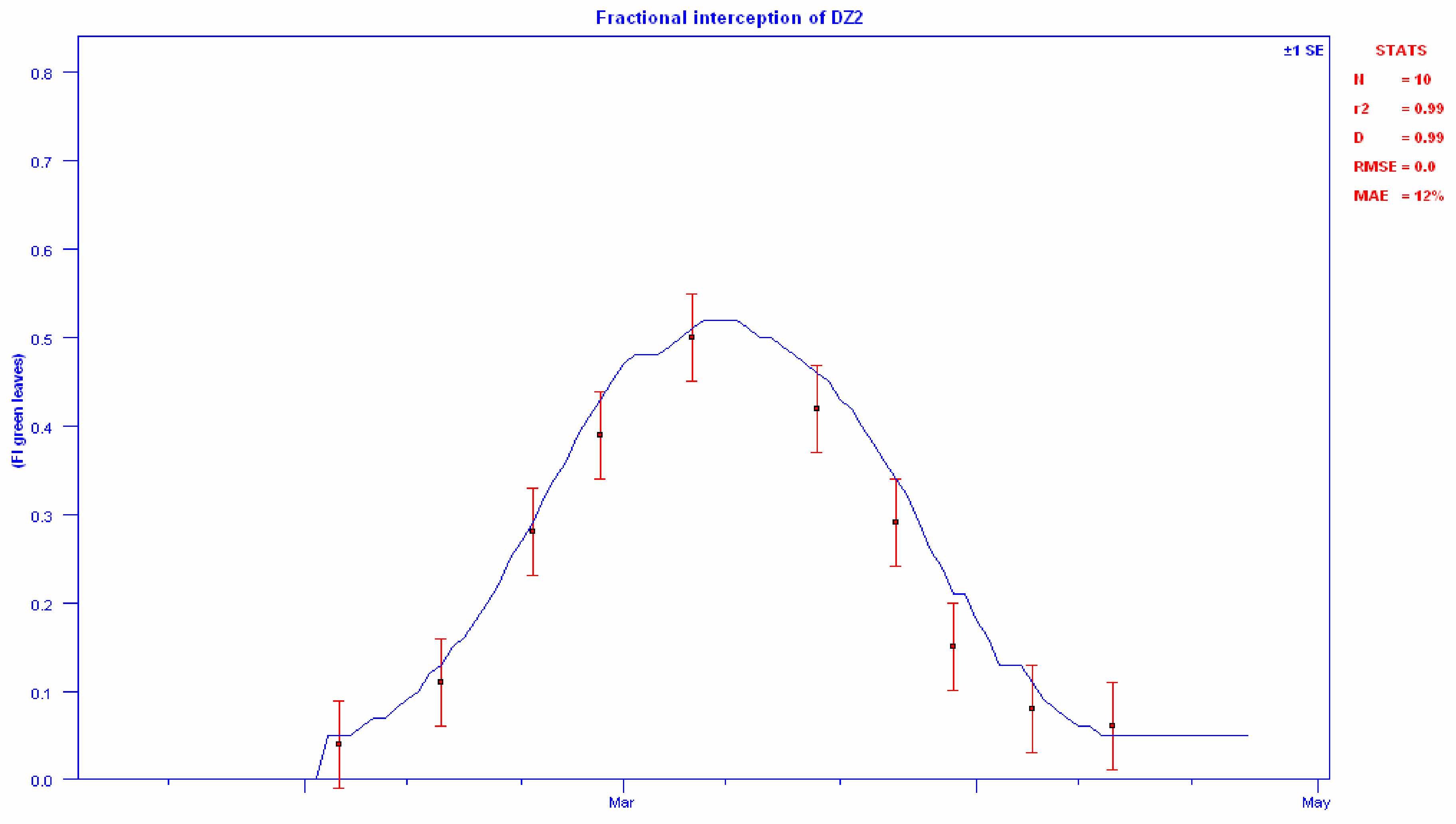

Figure 8.7b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for FTP treatment (DZ2)

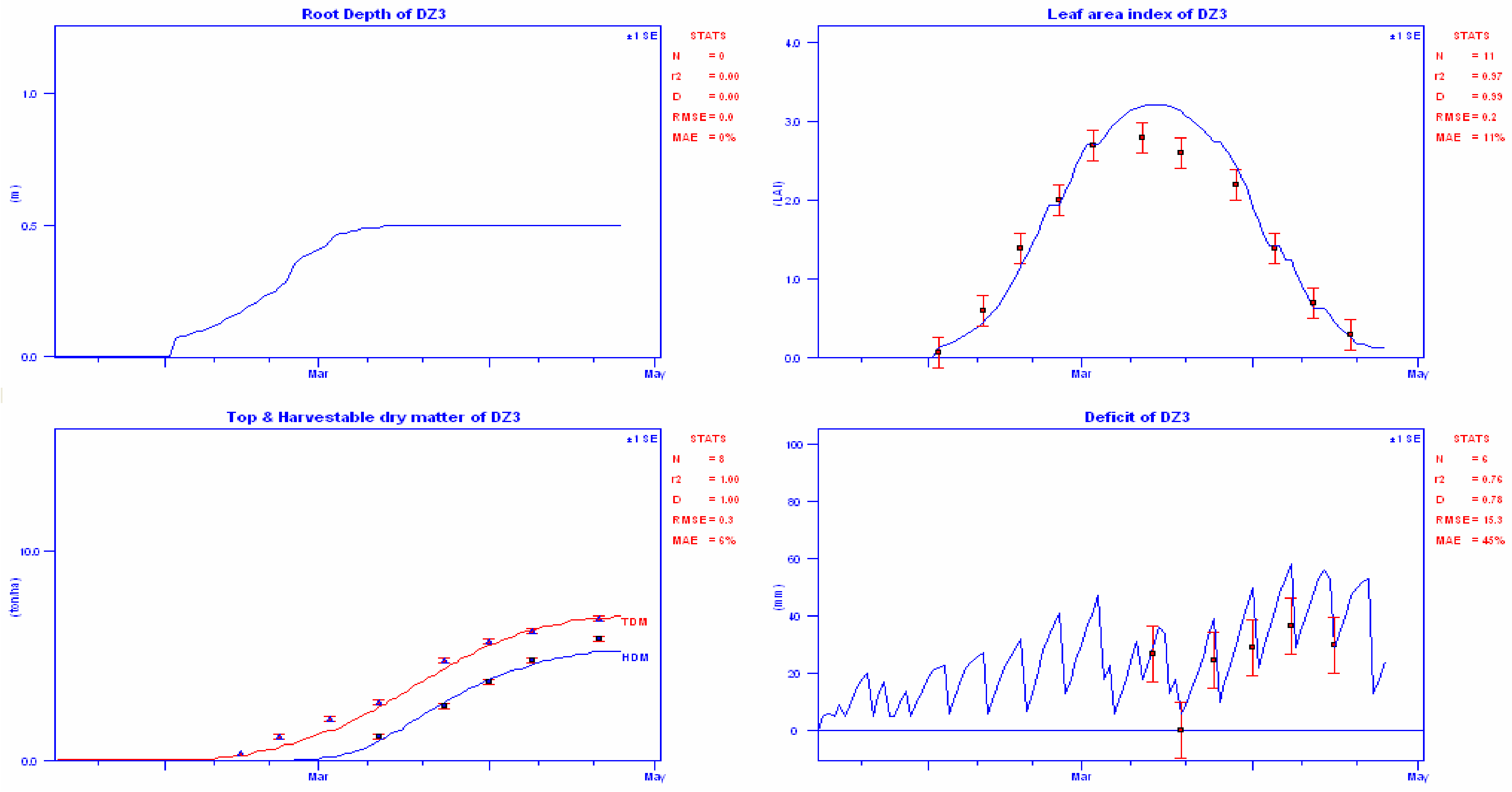

Figure 8.8a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for RCP treatment (DZ3)

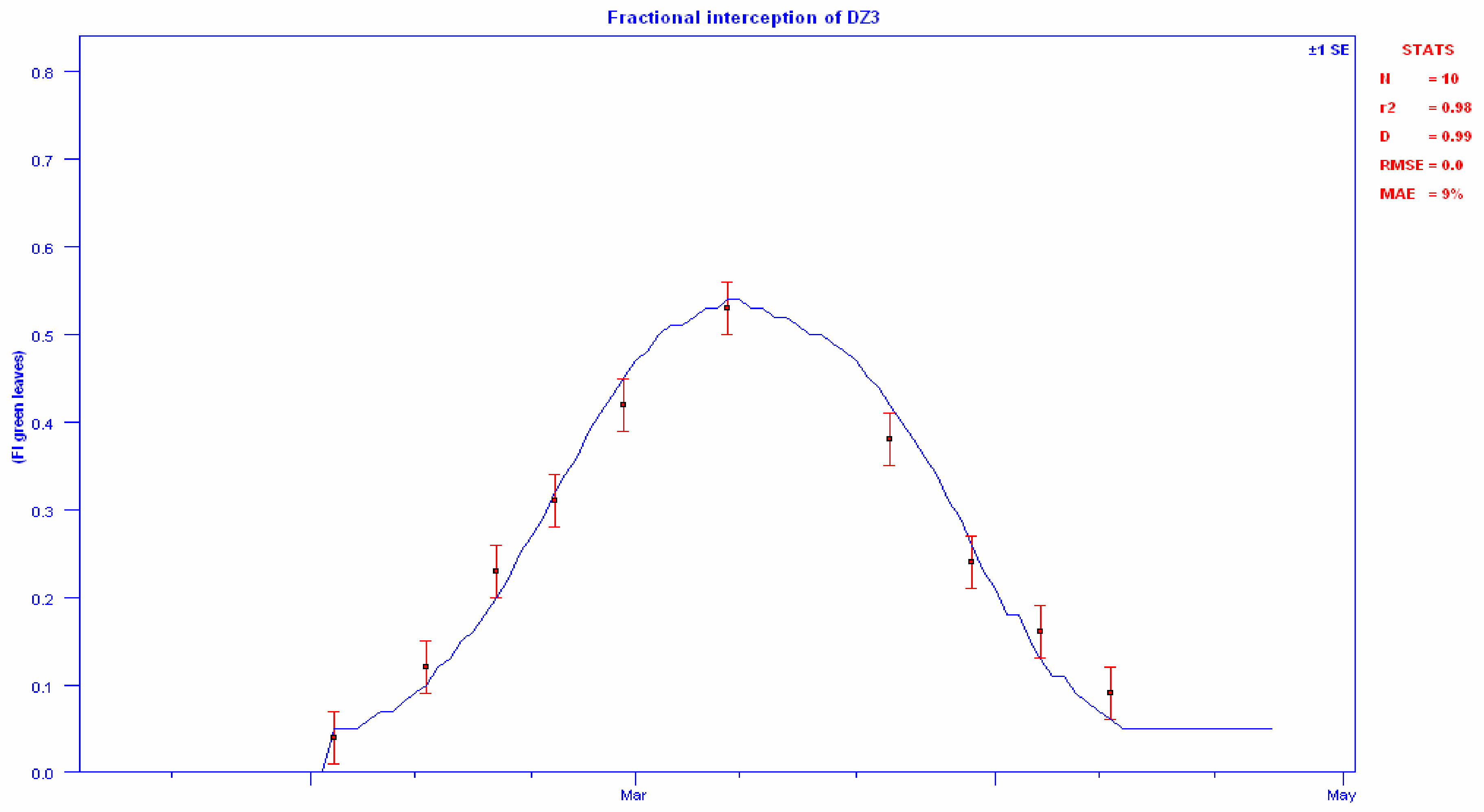

Figure 8.8b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for RCP treatment (DZ3)

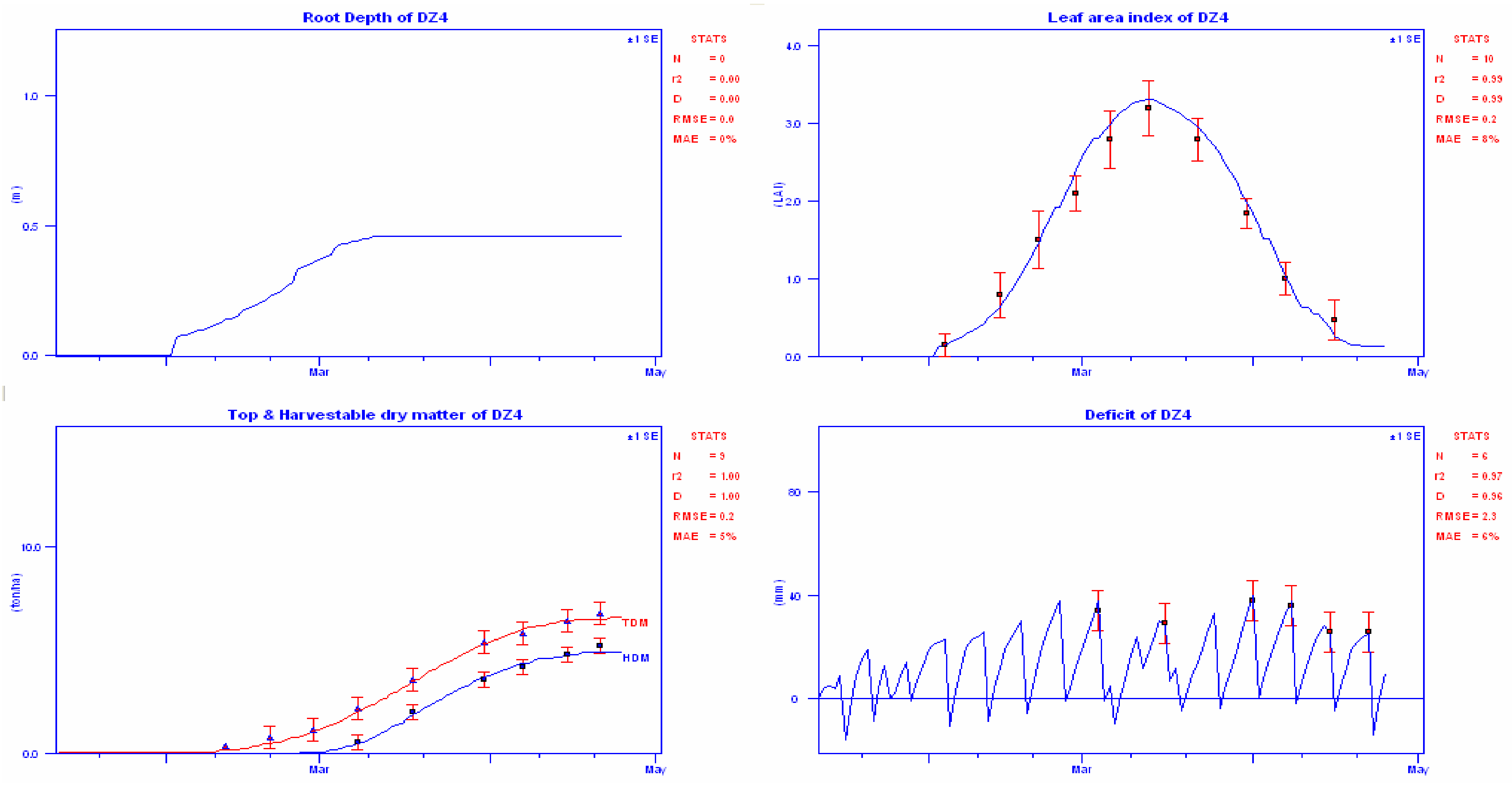

Figure 8.9a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for NP treatment (DZ4)

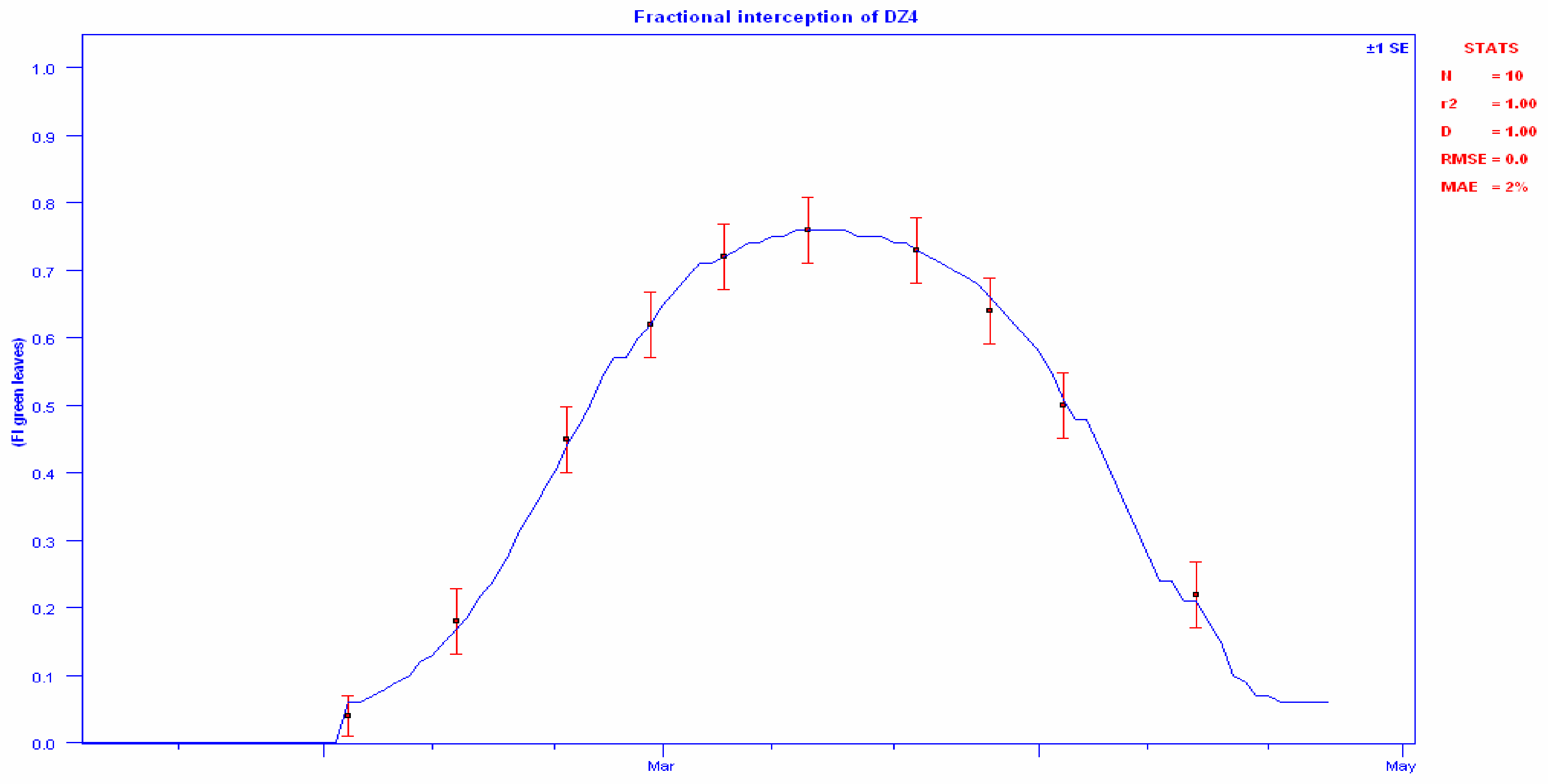

Figure 8.9b Simulated (lines) and measured values (points) of fractional interception (solar) for NP treatment (DZ4)

There was no independent data set developed prior to simulating these parameters. As a result the model was parameterised to the NP (DZ4) treatment, which was managed to refill the deficit soil water to field capacity according to the NP reading. The parameterised treatment (NP) was then tested against the others.

The SWB (DZ1) simulations for TDM, HDM, LAI and FI fitted the crop data measured from the experimental field well, and met the statistical criteria used (De Jager, 1994).

The farmer traditional scheduling (DZ2) revealed a severe water deficit throughout the growth period (Fig. 8.6a). The soil water balance graph (Fig. A6) of this treatment showed a high deficit that was more than the allowable depletion level, mainly during the second half of the growing season, except after the heavy rainfall of mid-March. The application of the irrigation amount traditionally used by farmers (50 mm every 10 days), could not re-fill the soil profile to field capacity, especially during the late growth stage. From the soil water deficit graph, it is clear that this treatment (with too long an irrigation interval) provided insufficient water. The low irrigation depth and too long frequency of this schedule resulted in poor crop growth and finally low tuber yield in the high evaporative demand conditions of the tropical climate.

On the other hand, the model simulations were slightly lower than the measured data points for TDM and HDM (Fig. 8.6a) around the crop maturity stage, even though the statistical parameters indicated a very high agreement. The soil water balance simulation fitted the measured data reasonably well, showing a severe water stress between March and April. Simulations for LAI and FI fitted very well, except that the graphs have a stepped shape which indicates water stress conditions during the growing period. Finally, the treatment (DZ2) resulted in higher soil water deficits and lower TDM and HDM. The crop growth analysis and yield (Chapter 4) indicate that this treatment resulted in significantly lower dry matter production and final tuber yield compared with DZ1 and DZ4, thus revealing that this particular schedule was under-irrigating the crop. It was also substantiated by both measured and simulated SWD that was increasingly building up after planting. Moreover, the stepped behaviour of LAI and FI simulation graphs are indicative of water stress during the growth period, mainly during the tuber bulking stage. It can thus be concluded that the farmer traditional irrigation scheduling was inferior compared to the other methods, which indicate the need for improvement or replacement by more efficient schedules.

DZ3 is the irrigation regime practiced by the nearby research centre and was also included in the comparison. The soil water balance graph for this treatment also reveals a high soil water deficit below the allowable depletion level (Fig. A7). From the graph, it is clear that the irrigation depth was not adequate to re-fill the soil profile to field capacity. Simulations for TDM, HDM, LAI and FI fitted the data sets collected from the field well, as the statistical parameters used for evaluation were all in a good accuracy range. On the other hand, the SWD predicted by the model did not show a good fit to the measured data sets and resulted in a low coefficient of determination ($r^2 = 0.76$), according to the recommendation of De Jager (1994). This, once again, could be attributed to less water actually applied to the field than intended, due to the low irrigation efficiency under furrow condition. The simulated graph for FI is slightly irregular, that once again indicates that this particular treatment was exposed to water stress.

The treatment used as a control for this experiment was DZ4, which was re-filled to field capacity every seven days as measured by the neutron water meter. For this treatment, the soil water balance summary graph indicated that the model simulation fitted to the experimental data points well and resulted in high statistical correlation (De Jager, 1994). Similarly, the model has shown high degree of accuracy simulations for TDM, HDM, LAI and FI. Generally, this treatment (DZ4) and the SWB irrigation calendar (DZ1) exhibited a good simulation fit when compared to the individual measured data sets, while the two traditional scheduling methods resulted in water stress conditions during crop growth. On the other hand, it has been widely observed that the actual water amount reaching the soil was less than the intended amount.

8.4.3 Onion water stress experiment

The influence of water stress on growth and yield of onions (cv. Texas Grano) induced at different growth stages were examined during the 2004 winter season at the Hatfield experimental farm. The crop growth parameters developed from the field experiment are displayed in Table 8.4, while the SWB model simulation in comparison to the measured data are given in Figures 8.9a to 8.12b. The accuracy of simulations are evaluated according to the De Jager (1994) criteria, which are detailed in Table 8.1. Crop-specific growth parameters were not developed prior to this experiment to test the model simulation against it. Hence, the model is parameterised using the NNN (control) treatment, which was non-stressed and the remaining treatment simulations were tested against that.

Table 8.4 Summary of crop growth parameters determined for onions (cv. Texas Grano) water stressed at different growth stages during the field experiment in 2004 at the Hatfield experimental farm, and obtained from literature, to calibrate the SWB model

Crop growth parameters	**Values**	**Units**	**Source**
Canopy radiation extinction coefficient (Kc)	0.40	-	Data
Corrected dry matter-water ratio (DWR)	7.8	Pa	Data
Radiation conversion efficiency (RUE)	0.0015	kg MJ^{-1}	Data
Base temperature (Tb)	7.2	^{o}C	Annandale *et al.*, (1999)
Temperature for optimum crop growth	20	^{o}C	Annandale *et al.*, (1999)
Cut-off temperature	29.4	^{o}C	Annandale *et al.*, (1999)
Thermal time: emergence	0	day degree	Seedling used for planting
Thermal time: reproductive phase	480	day degree	Data
Thermal time: maturity	1860	day degree	Data
Thermal time: transition	280	day degree	Data
Thermal time: leaf senescence	1860	day degree	Data
Maximum crop height	0.60	m	Data
Maximum root depth	0.80	m	Annandale *et al.*, (1999)
Fraction of total dry matter translocated to bulb	0.50	-	Annandale *et al.*, (1999)
Canopy storage	1.00	mm	Annandale *et al.*, (1999)
Leaf water potential at maximum transpiration	-1500	kPa	Annandale *et al.*, (1999)
Maximum transpiration	9.00	mm d^{-1}	Annandale *et al.*, (1999)
Specific leaf area	9	m^2 kg^{-1}	Data
Leaf-stem partition parameter	1.12	m^2 kg^{-1}	Data
Total dry matter at emergence	0.007	m^2 kg^{-1}	Annandale *et al.*, (1999)
Fraction of total dry matter partitioned to roots	0.20	-	Annandale *et al.*, (1999)
Root growth rate	7.00	m^2 $kg^{-0.5}$	Annandale *et al.*, (1999)
Stress index	0.95	-	Annandale *et al.*, (1999)

The crop growth parameters were determined for onions (cv. Texas Grano) from the crop growth data measured during the field experiment. Some parameters that were not determined from the experimental field data were obtained from similar results obtained earlier by Annandale *et al.* (1999) and are indicated in Table 8.4. Some parameters determined for this cultivar are slightly lower than parameters determined for other onion cultivars. For instance, the Kc (solar) determined for Texas Grano was 0.40, compared to 0.75 for cv. Mercedes (Annandale *et al.,* 1999). On the other hand, DWR was 7.5 Pa for this cultivar, compared to 7.0 Pa for cv. Mercedes (Annandale *et al.,* 1999). Similarly, the thermal time for transition period was 280 d°C for this cultivar as compared to 10 d°C for cv. Mercedes (Annandale *et al.*, 2005). The thermal time determined for maturity and leaf senescence were also higher for this cultivar as compared to the values reported by Annandale *et al.* (1999) for cv. Mercedes. Other parameters determined in this experiment are comparable to the values reported by Annandale *et al.* (2000).

The crop growth data measured from the experimental field and the SWB simulations were run for all the treatments. Treatments included non-stressed (NNN), or stressed from 35 to 70 DATP (SNN), from 70 to 110 (NSN) DATP and from 110 to 145 (NNS) DATP.

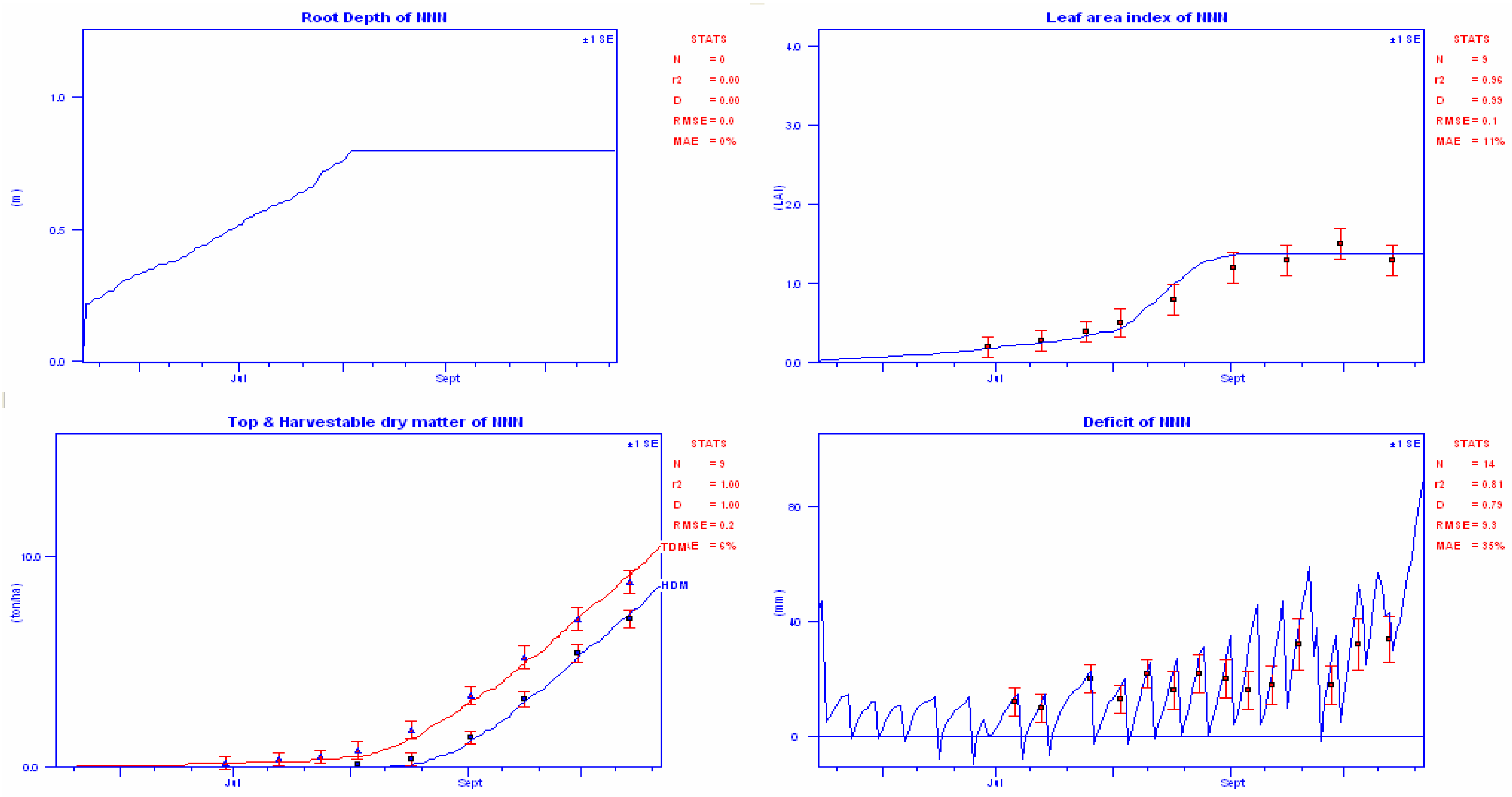

Figure 8.10a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for NNN treatment of onions.

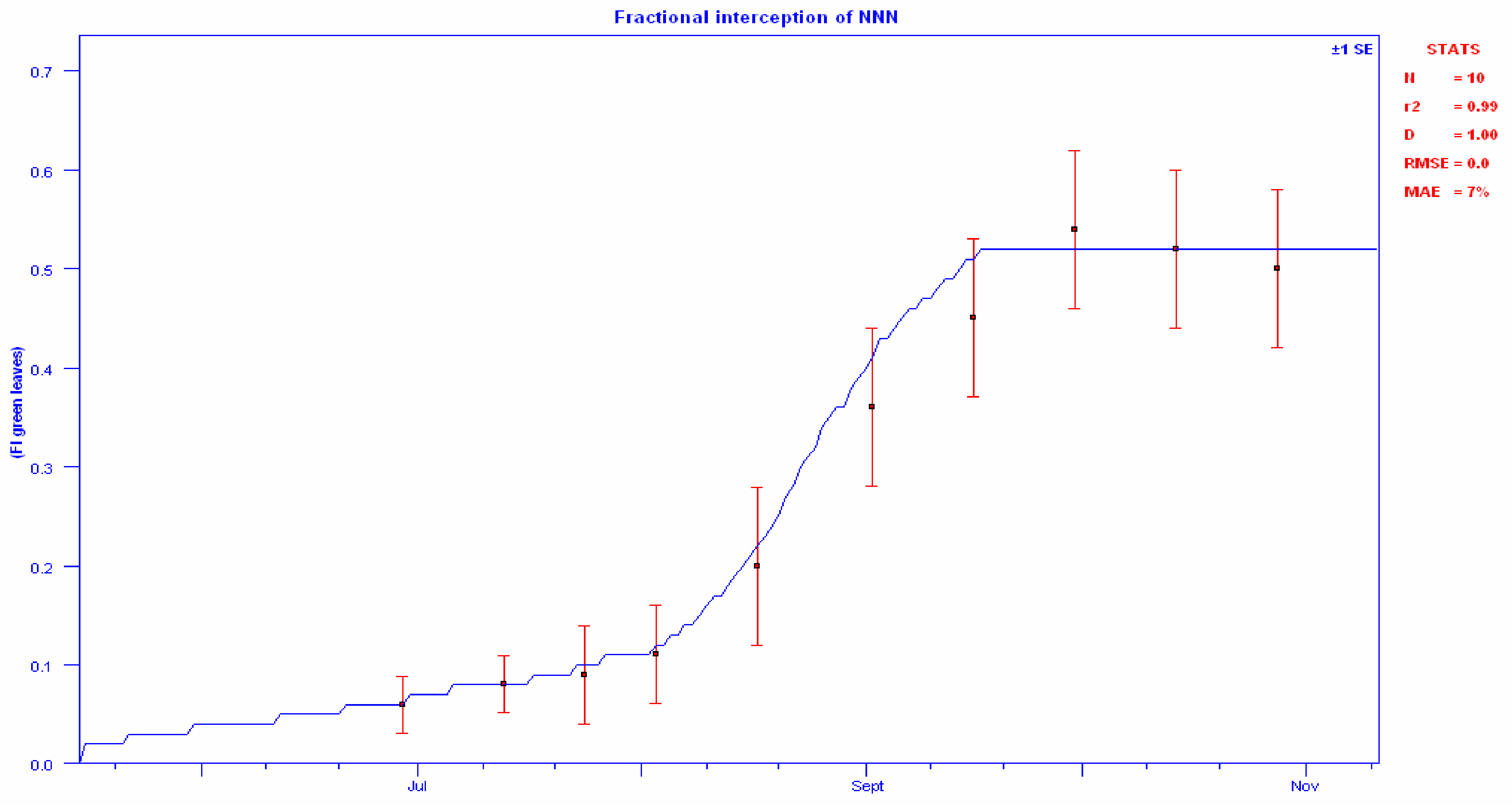

Figure 8.10b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for NNN treatment

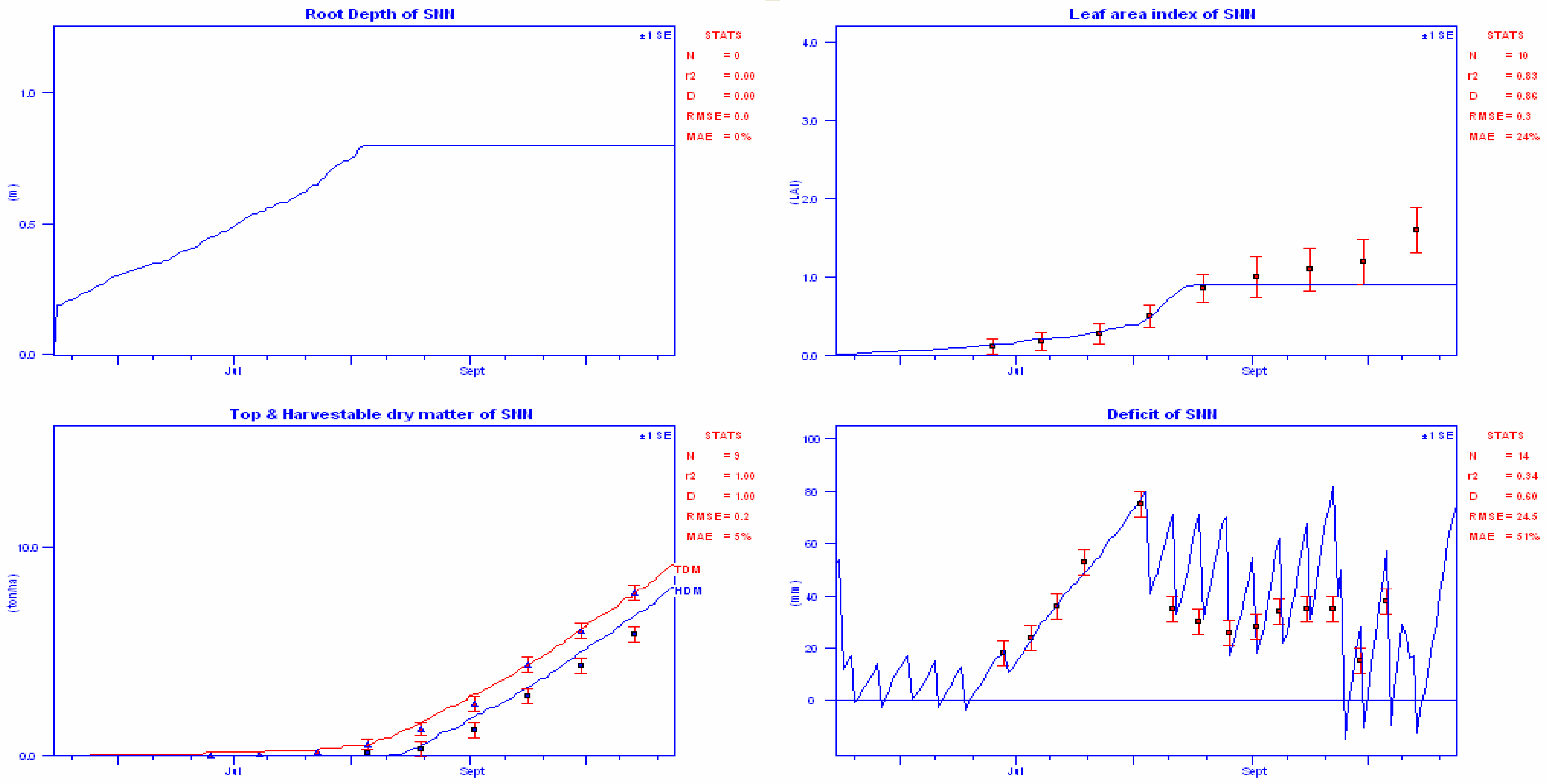

Figure 8.11a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for SNN treatment of onions.

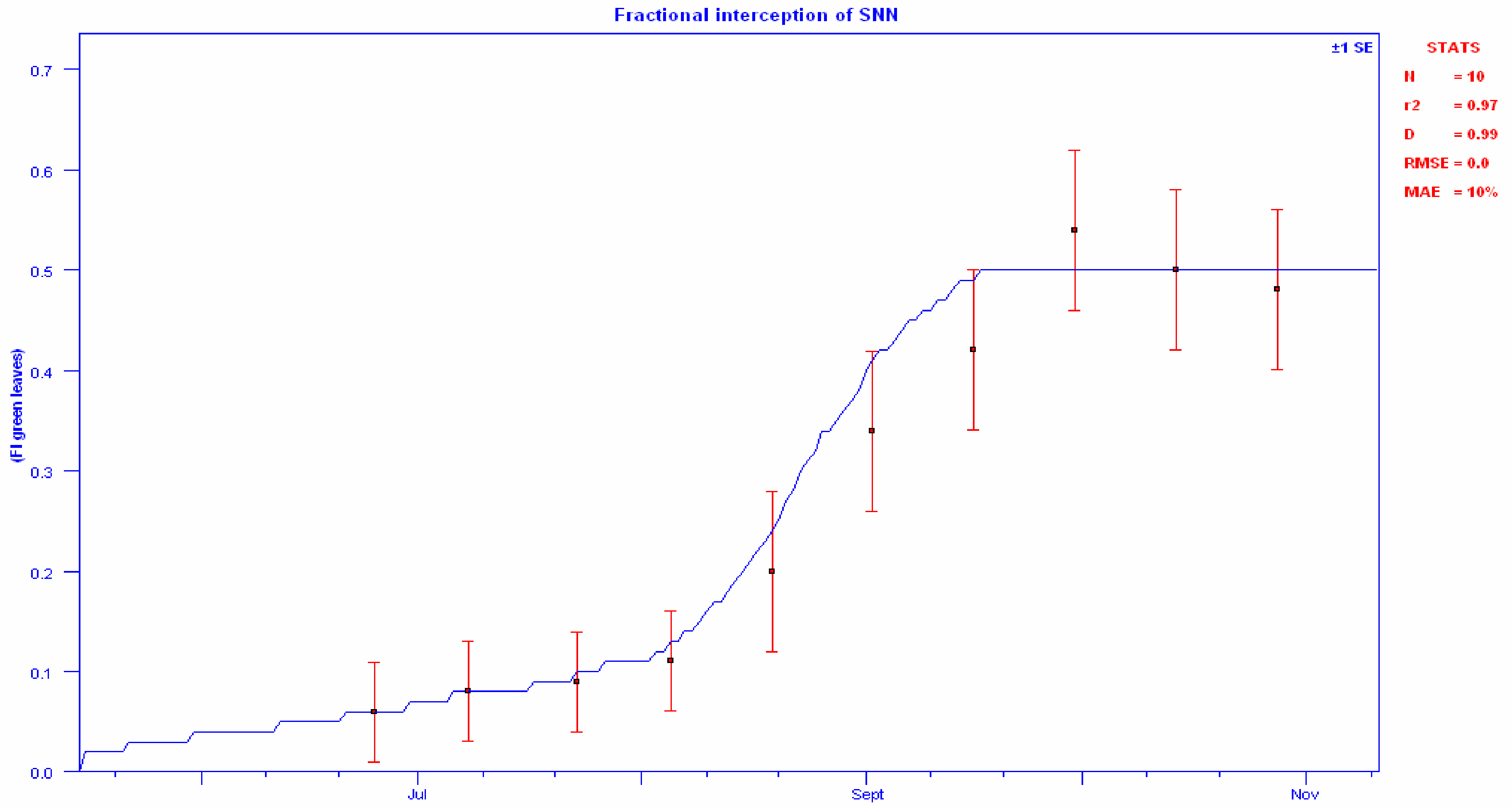

Figure 8.11b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for SNN treatment

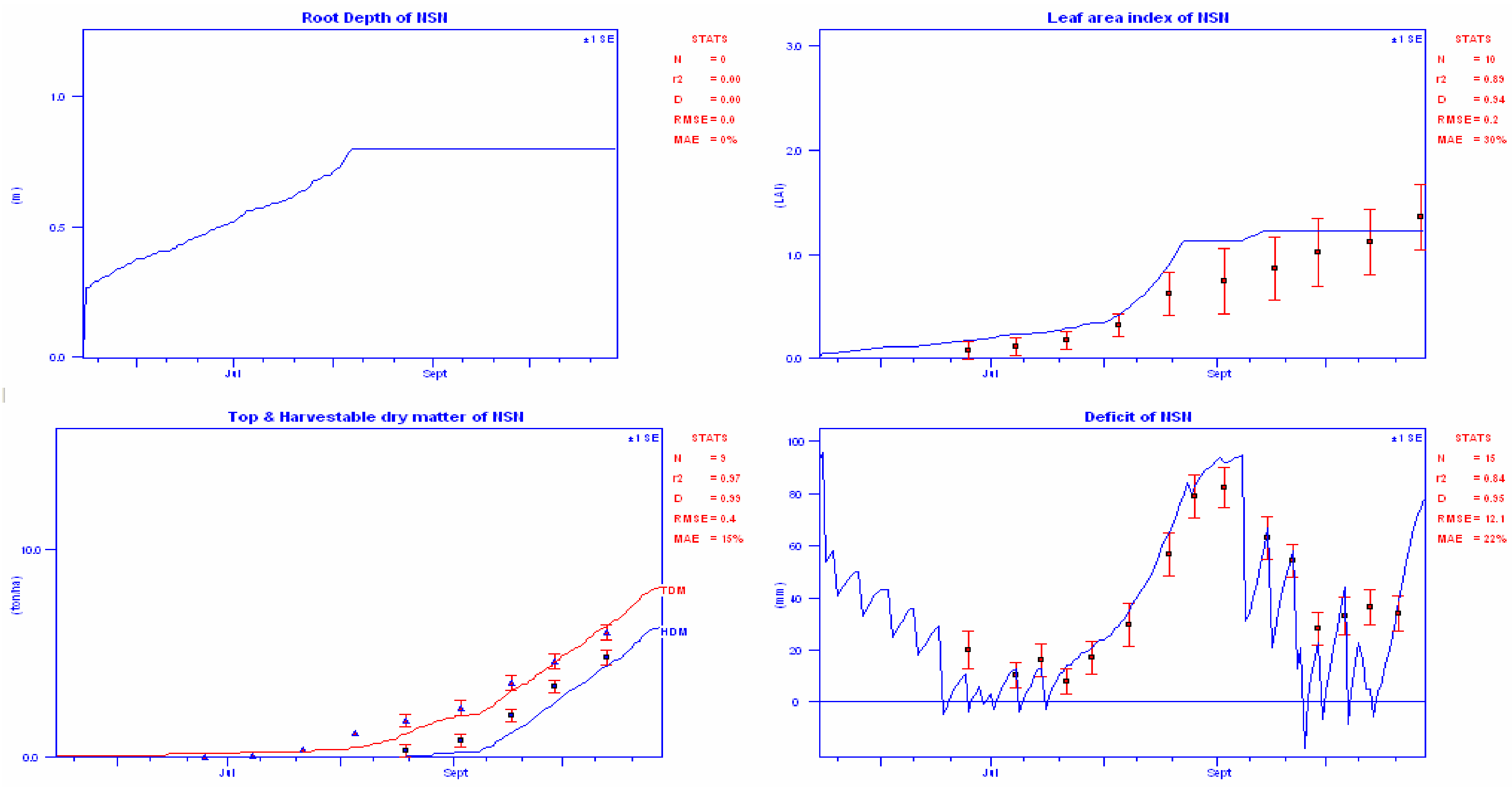

Figure 8.12a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for NSN treatment

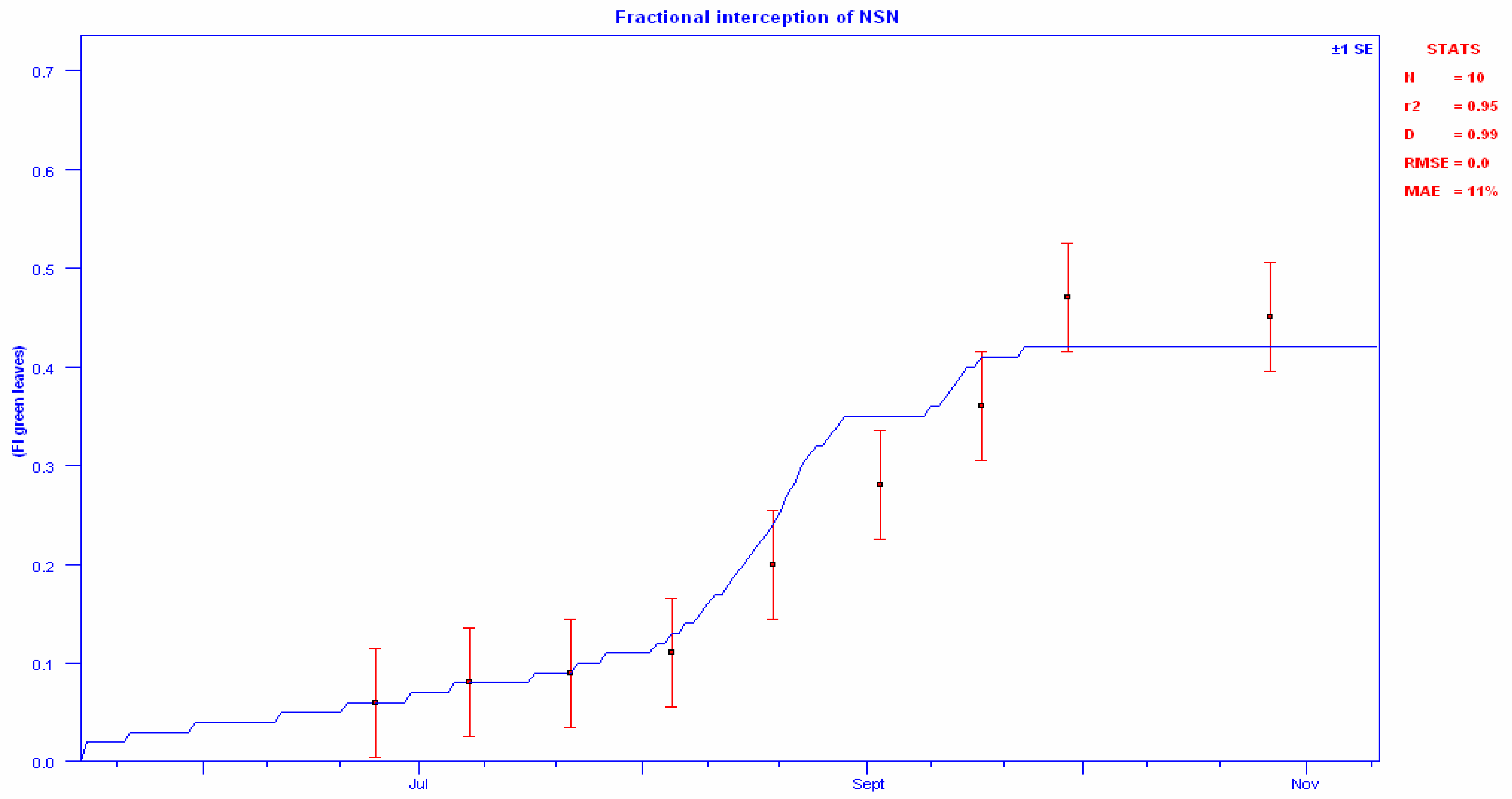

Figure 8.12b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for NSN treatment

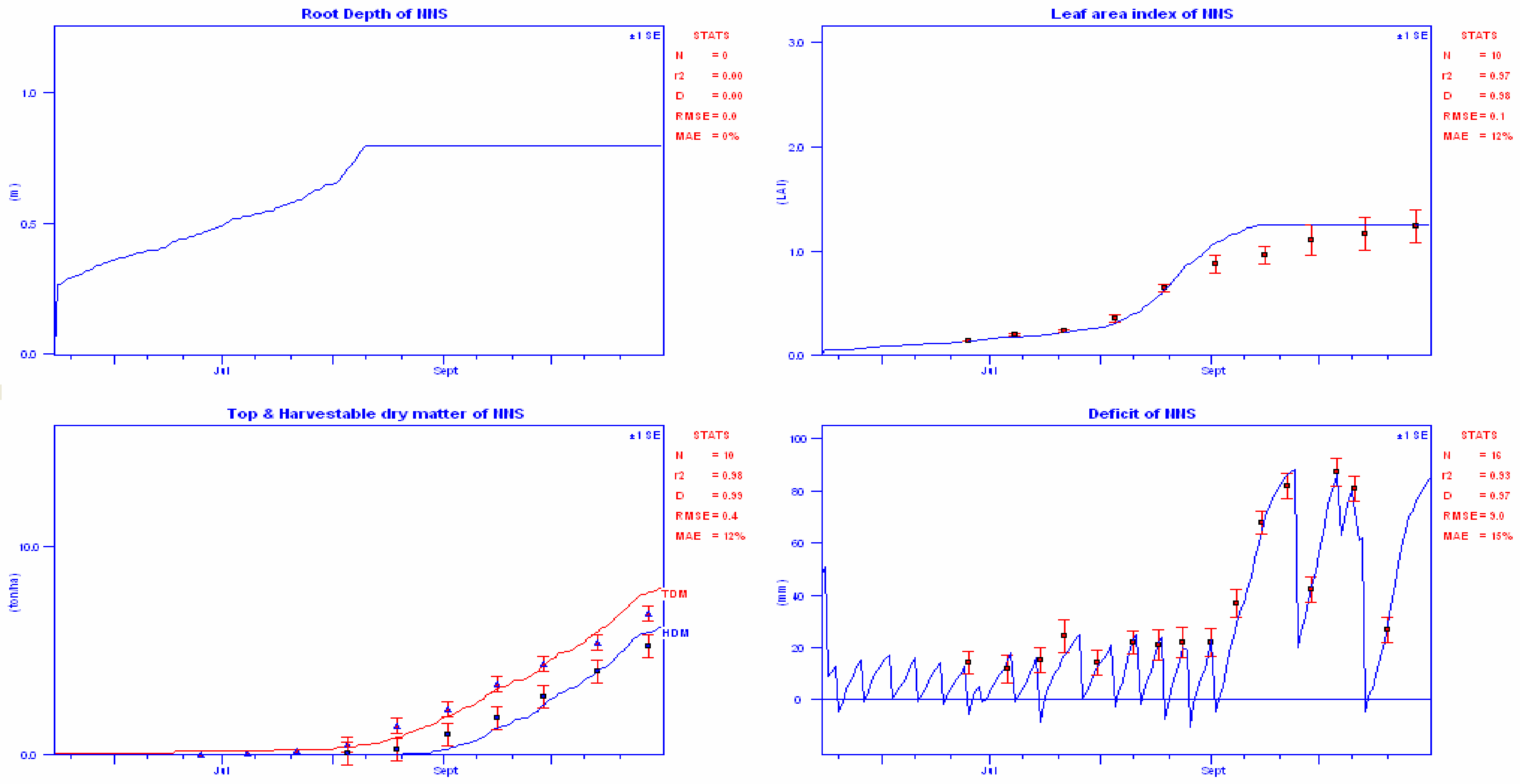

Figure 8.13a Simulated (lines) and measured values (points) of rooting depth (RD), leaf area index (LAI), total dry matter (TDM), harvestable dry matter (HDM) and soil water deficit to field capacity for NNS treatment

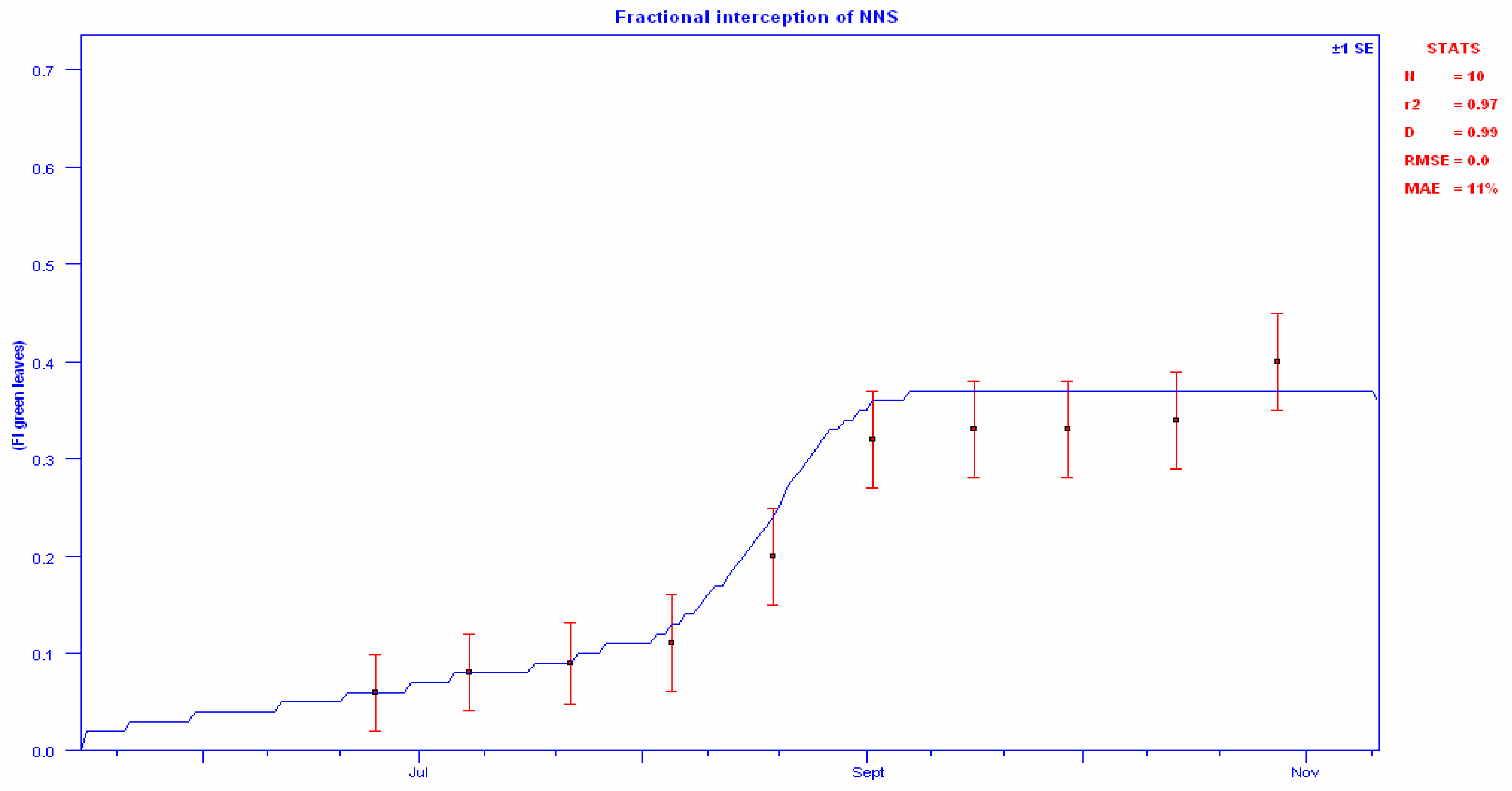

Figure 8.13b Simulated (lines) and measured values (points) of fractional interception (FI) (solar) for NNS treatment

NNN represents the non-stressed treatment, where the soil water deficit was measured every week and refilled to field capacity. The SWB model simulations revealed that it fitted the data collected from the experimental field very well for most parameters, except for LAI, which was slightly lower even though the evaluation criteria (De Jager, 1994) showed high accuracy levels. The summary of SWD simulation, however, shows slight over-simulations for some measured data points and slight under-estimations for others. In addition, the model slightly over-estimated FI during the mid-growth period in September (Fig. 8.9b).

SNN is the treatment for which water stress was induced between 35 and 70 DATP, whereafter the water deficit was refilled to field capacity on a weekly basis. During the stress period, there were a few days of high rain and these helped the crop to tolerate the stress. From the soil water balance simulation, the deficit remained higher than the allowable water depletion level during the stress period. The model simulations for TDM, HDM and FI fitted the experimental data points well, while the model under-estimated LAI during the late part of the growth period, from mid August to maturity (Fig. 8.10a). The treatment was stressed when it was in the early growth stage, which might have helped the crop to develop a deeper root system to cover larger soil volume for soil water and plant nutrient uptake. Other possible reasons why the model under-estimated the LAI could be the cool climate of the season when the stress was imposed. This treatment was stressed for 35 days from mid-June onwards, which was the coolest time of the year, with low daily ET. In addition, there were a few rain showers during the stress period that further helped the crop to withstand the stress effect. The growth and yield of this treatment also confirmed that stress during this period did not impose significant growth and bulb yield reduction as compared to the non-stressed treatment.

The NSN and NNS treatments both revealed the highest SWD during their stress periods (Fig. 8.11a & 8.12a). The measured and simulated SWDs revealed a high degree of agreement, although the statistical output parameters indicated some predictions were outside, or marginally inside the reliability criteria. The simulated SWDs during the stress periods of the NSN and NNS treatments were slightly higher than those measured at the time of the experiment. During the early growth stages, simulations for TDM and HDM were slightly lower than the data points for NSN, while these were slightly higher than measured data points for NNS, mainly during the crop maturity stage. The model over-estimated the LAI simulation for both NSN and NNS during crop maturity, even though the statistical parameters were within the required limits. The overall model simulations were in good agreement with the measured data for most parameters considered, according to the statistical accuracy used for evaluation (De Jager, 1998).

In general, high SWD is detected for NSN and NNS during water stress periods for both the measured and simulated data sets (Fig. A12). Onion water stress between 70 and 145 DATP, the most critical growth period, significantly reduced growth and final yield (data shown in Chapter 7). This is also confirmed by the dry matter and fresh bulb yield data (Chapter 7), which indicated that water stress during this growth stage resulted in a significant yield reduction.

8.5 Conclusions

A database for crop growth parameters was generated for potato and onion crops from three experiments, namely: evaluation of growth performance and dry matter partitioning of four potato cultivars under sprinkler irrigation; potato irrigation regime experiment under tropical climatic conditions using furrow irrigation; and determination of the critical growth stages of onions, grown under drip irrigation.

Detailed weather, soil and irrigation data from field trials, carried out at their respective sites, were used in the SWB model and simulations were run in order to calibrate the crop growth and soil water balance units of the model. Crop growth measurements from the field trial and SWB model simulations were evaluated according to the statistical accuracy parameters recommended by De Jager (1994).

Crop growth parameters were determined for the four potato cultivars, Frodo, Pentland Dell, Darius and Shepody and results were found to be comparable to the previous results reported by Steyn (1997) and Annandale *et al.* (1999). Summaries of soil water balance for the evaluation of these cultivars indicated that cultivars with longer growing seasons were water stressed during the peak tuber bulking stage. Simulations for TDM, HDM, LAI and FI, fitted with a high degree of accuracy the measured data sets. Simulations for the SWD also indicated a good fit and the statistical accuracies obtained were inside, or marginally outside, the recommended standards.

Crop growth parameters were generated for the potato cultivar Awash, grown under tropical climate using furrow irrigation. The parameters generated were generally comparable to the values reported by Steyn (1997) and Annandale *et al*. (1999), with slight variations around thermal time accumulation. Calibration of the crop growth and soil water balance units of the model were carried out using weather, soil and irrigation data from the field experiment. Simulations of the crop growth, TDM, HDM, LAI and FI fitted the measured data points very well, according to the reliability criteria used. Nevertheless, simulations for LAI and FI appeared to be irregular (stepped) for the treatment irrigated according to the traditional farmer schedule, showing typical behaviour of crop grown under water stress conditions. Even though the SWD simulations appeared to fit measured data well, some statistical parameters were slightly outside the set criteria. This performance could be attributed to the fact that actual water reaching the crop was probably less than the amount applied, due to low application efficiency of furrow irrigation. The irrigation efficiency of that experiment was estimated to be about 60%, due to water wastage during water distribution within the farm and on the plot.

A similar database for crop growth parameters were generated for onions (cv. Texas Grano) which was water stressed at different growth stages. Data measured from the Hatfield experimental farm was used in the SWB model and simulations were run in order to calibrate the crop growth and soil water balance units of the model. The crop specific growth parameters determined for this cultivar were generally comparable to the parameters reported by other researchers (Annandale *et al.,* 1999). The result depicted that SWB simulations for crop growth were inside, while some for SWD marginally outside the reliability criteria imposed (De Jager (1994).

In general, the SWB simulation performances against crop growth data sets were observed to be good. All simulations of TDM, HDM, LAI and FI were in agreement with measured values, with mostly a high degree of statistical accuracy (De Jager, 1994). Under furrow irrigation, even though the SWD simulations were found to fit well, some of the statistical measures were often low compared to the recommended values. This could be due to the low application efficiency of water under furrow irrigation that indicated a typical characteristic of water stress. Hence, in this activity crop parameters were for successfully generated five specific potato cultivars and one onion cultivar, for inclusion in the SWB database, in order to facilitate irrigation scheduling. Thus, it can be concluded that a powerful tool, the SWB model, has been parameterised, which will facilitate the generation of irrigation management guidelines for various irrigation districts in Ethiopia.