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OILCROP-SUN Model for Nitrogen Management of Diverse Sunflower (*Helianthus annus* L.) Hybrids Production under Agro-Climatic Conditions of Sargodha, Pakistan

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Abstract

Decision support system for agro-technology transfer (DSSAT), OIL CROP-SUN Model was used to stimulate the phenology, growth, yield of different two sunflower hybrids. *i.e.* Hysun-33 and S-78 by applying different nitrogen levels. The effect of nitrogen (N) on growth and yield components of different sunflower (*Helianthus annuus* L.) hybrids were evaluated under agro-climatic conditions of Sargodha, Pakistan during spring 2013. The experiment was laid out in a randomized complete block design with split plot arrangement having three replications, keeping cultivars in the main plots and nitrogen levels (0, 45, 90,135 and 180 kg/ha) in sub plots. OIL CROP-SUN Model showed that the model was able to simulate the growth and yield of sunflower with an average of 10.44 error% between observed and simulate achene yield (AY). The result of simulation indicates that nitrogen rate of 180 kg/ha produced highest achene yield in S-78 hybrid as compared to other treatments and Hysun-33 cultivar.

Keywords

Decision Support System for Agro-Technology Transfer, Sunflower, Nitrogen, Achene Yield, Crop Modeling

1. Introduction

Among the crops, oil crops are playing an important role as one of the largest sources of energy. These are being cultivated mainly due to the use of food and non-food oils. Pakistan is facing a serious shortage of edible oil because the domestic production is not sufficient to meet our total demand. Thus country is constrained to import edible oil in large quantities involving huge expenditure in foreign exchange. A developing country like Pakistan cannot afford such a huge amount indeed. So it is imperative to enhance the domestic production to meet the increasing demand of edible oils. The area under of sunflower crop in 2012-13 was 700 thousand acres with seed and oil production of 378 and 144 thousand tons, respectively [1]. The sunflower is a warm season and drought tolerant crop; adapt to high temperature and moisture limited conditions. In Pakistan, sunflower grown in both rain fed and irrigated area because it is a drought resistant and deep rooted crop and pulls out water from below the root zone of soil. It showed positive response on limitation of precipitation, soil water and irrigation to growth and yield [2]. It is considered a short duration crop and grown two times in a year spring and autumn easy to adopt and produced a good yield in both season. The numbers of days are required from sowing to physical maturity 90 - 120 days. In Pakistan cultivation of exotic sunflower hybrids are not good for better yield because these are not well adapted to our agro climatic conditions. Therefore, introductions of such hybrids which are early maturating, having high oil contents and producing high seed yield under summer temperature and drought conditions [3]. The sunflower is considered potential sources of high quality edible oil in all over the world after soybean. In our country, total cultivation area is limited because production is low due to lack of proper management practices and production technologies [4]. Because farmers are not known about good cultivars, proper nitrogen requirement, plant spacing and irrigation in order to produced high seed and oil yield per hector Pakistan is depended on cultivation of exotic sunflower hybrids, the newly local developed hybrids did not receive much attention due to lack of seed sector [5]. There are various factors are responsible for obtaining the higher yield for sunflower. many studies have been done to check the effect of nitrogen on sunflower crop in different parts of the world are concluded that nitrogen is positive effect on growth, development and higher achene yield [6]-[14]. Modeling is very important tool to manage the crops in poor soil and different environmental conditions. The simulation models are helpful to give solution and increase research efficacy and improved research direction through direct feedback [15]. Crop modeling is modern tool to predict the crop performance under changing environmental conditions [16]. (DSSAT) model is very good tool to observed crop growth and yield parameters with minimum error of 11% in the predicted grain parameters. OILCROP-SUN model is a good tool in fertilizer and other input management for obtaining good yield under irrigated and semiarid environment conditions in Punjab [17]. The temperature and radiation are most important factors that are greatly affecting on our crop. Therefore crop simulation models are very helpful to give better decision in each variety and each region [18].

2. Materials and Methods

2.1. Experimental Site and Soil

The experiment was carried out at the Agronomic Research Area of, University of Sargodha (32˚05"N, 72˚67"E), Pakistan during the spring seasons of 2013. The soil is sandy clay loamy somewhat poorly drained with pH ranging from 7.9 - 7.33. The nitrogen level was 0.066 to 0.052 are shown in Table 1.

2.2. Design and Treatments

Prior to planting. Seed bed preparation was prepared with chisel plough and 3 cultivation with the help of common cultivar. After the preparation of field make a ridges with help of plough. The experiment was set in a Split plot arrangement under RCBD having 3 replications. The crop sowing was done by dibbler method using seed rate of 5 kg/ha. The net plot size was 4.2 m × 6 m having row to row spacing 70 cm and plant to plant distance 20 cm. The treatments were included with two different type of Sunflower hybrids (Hysun-33, S-278) were kept in a main plots and five levels of chemical nitrogen fertilizer (urea) consisting of (0, 45, 90, 135 and 180 kg/ha) in sub plots. The sources of fertilizer are Nitrogen, Phosphorus and potassium were used in the form of urea, DAP and Potassium (k2so4).The Phosphorus and potash at the rate of 80 - 40 kg/ha with 1/3 of nitrogen were applied at the time of sowing in all the plots by broadcast method. Remaining 2/3 dozes of urea fertilizer was used in two splits, at first irrigation and flowering stage. All other agronomic practices such as hoeing, weeding, irrigation and plant protection measure were kept normal for whole the experiment.

2.3. Plant Sampling and Measurements

Phonological events as well as growth and canopy development were noted at vegetative and reproductive phases of sunflower crop. The randomly 5 plants were selected by visual observations from each treated plots and tagged them for determine the number of days are need from anthesis to gained physical maturity. The first growth sampling was done after the fifteen days of sowing. Then each sample was taken every 10 days interval. The every fifteen days of interval

Table 1. Physico-chemical soil analysis of crop area.

Characteristic	Soil sample depth			
	10 cm	15 cm	20 cm	Mean
Soil pH	7.9	7.9	8.0	7.33
Organic Matter (%)	1.32	1.32	1.04	1.22
Total Nitrogen (%)	0.066	0.066	0.052	0.061
Available P ($mg\cdot kg^{-1}$)	4.6	7.5	10.2	7.43
Available K ($mg\cdot kg^{-1}$)	188	164	144	165.33
Texture	Sandy loam	Sandy loam	Sandy loam	

Table 2. Mean monthly weather data for sunflower growing season March-June in 2013.

Month	Mean Temperature (˚C)	Total Rainfall (mm)	Mean Relative Humidity (%)
March	21	7.95	61.53
April	25.7	31	51
May	32.20	4.50	37.79
Jun	34.70	6.61	43.28

take 10 g sample of leaves from each treatments by using area meter (JVC Model TK-S310EG) for the measurement of leaf area and dry weights were recorded at each harvesting stage are explained by [13]. When crop reached maturity, back of head has turned from green to yellow and color of brackets changed to brown.The harvesting was done by mechanically, ten plants were taken from each treated plots for determine number of achene^{-2}, achene yield and total dry matter. All weather data was collected nearest meteorological around the experimental site. Weather station provided daily maximum and minimum air temperature (˚C) *i.e.* mean temperature, total rainfall (mm) and mean relative humidity are shown in **Table 2**.

2.4. Calibration and Evaluation of OILCROP-SUN Model

Calibration is a process of adjusting some model parameters to the local conditions. It is also necessary for genetic coefficients for new cultivars used in modeling study. The data obtained from experiments conducted during the years, 2013 was used as input file for calibration and evaluation of the crop-model under optimum growth conditions. The comparison of model simulated outcome with observed data assesses accuracy of the model [19]. Meteorological data of the location, soil as well as plant characteristics and crop management practices data was obtained from each site and used as input data for the model [20], Genetic coefficients of hybrids sown was calculated by decision support system for agro-technology transfer (DSSAT V 4.5), by using observed data of year 2013 [21]. The experimental files that were used as inputs files includes, weather data file for the experimental period (Weather Man), soil data of respective experiment (SBuild), crop management data file (XBuild) and crop cultivar coefficients file [22]. As a part of calibration and evaluation process the simulated data for different phonological developmental stages (anthesis and maturity date).

2.5. Statistical Indices

Simulation performance was evaluated by calculating different statistic indices like root mean square error (RMSE), mean percentage difference (MPD), error% and index of agreement [23] with the help of following equations:

$$RMSE = \left[\sum_{i=1}^{n} \left(p_i - o_i \right)^2 \Big/ n \right]^{0.5}$$

$$MPD = \left[\sum_{i=1}^{n} \left(\frac{\left| o_i - p_i \right|}{o_i} \right) \times 100 \right] \Bigg/ n$$

$$Error(\%) = \left(\frac{(p-o)}{o}\right) \times 100$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(p_i - o_i)^2}{\sum_{i=1}^{n}(|p_i'| - |o_i'|)^2}\right]$$

The p_i and o_i are demonstrated as predicted and observed values respectively, O is the observed mean value. The Index of Agreement (d) as presented by [24] that if the d-statistic value is closer to one, then there is good agreement between the two variables that are being compared and *vice versa*.

3. Result and Discussion

3.1. Model Calibration

The OILCROP-SUN model was calibrated with experimental data collected during 2010 sunflower crop season. The cultivar coefficients of Hysun-33 and S-278 were estimated through trial and error and comparison of simulated and observed data. The final values for the two cultivar coefficients that determine vegetative and reproductive growth and development are presented in **Table 3**.

3.2. Anthesis Date

A close agreement was noted between observed and simulated values for sunflower phenology. The model predicted the dates for days to anthesis with a difference of one and 2 days between observed and simulated dates for Hysun-33 and S-278 hybrids, respectively are shown in **Table 4**. The OILCROP-SUN model

Table 3. Cultivar coefficients used with OILCROP SUN Model for sunflower hybrids.

Genotype	P_1 ((˚C days)	P_2 (days)	P_5 (˚C days)	G_2 (Nr)	G_3 (mg·day^{-1})	O_1 (%)
Hysun-33	320	3.55	732	1500	2.40	65
S-78	260	0.80	712	1500	2.40	65

Table 4. Comparison of observed and simulated values of days to anthesis at different hybrids and different nitrogen rates.

Hybrids	Nitrogen Level (kg·ha^{-1})	Observed	Predicted	^{a}P-O	PD (%)
	0 kg·ha^{-1}	67	73	4	3.4
	45 kg·ha^{-1}	68	73	2	1.7
Hysun-33	90 kg·ha^{-1}	69	73	1	.8
	135 kg·ha^{-1}	70	73	−1	−.8
	180 kg·ha^{-1}	72	73	−2	−1.6
	0 kg·ha^{-1}	58	73	5	5
	45 kg·ha^{-1}	58	57	5	5
S-78	90 kg·ha^{-1}	59	57	4	3.9
	135 kg·ha^{-1}	60	57	2	1.9
	180 kg·ha^{-1}	61	57	0	0
Mean			0.77	0.83	
RMSE		1.65			

^{a}P-O = Predicted-Observed; RMSE = Root Mean Square Error.

was able to anthesis date well and calibration results described that value for root mean square error (RMSE) was observed (1.65), was same in both sunflower hybrid S-78 and Hysun-33.

3.3. Physiological Maturity

The observed and simulated values of physiological maturity are shown in Table 5. There was a good agreement between observed and simulated physiological maturity. The OILCROP-SUN model was able to simulate physiological maturity well and calibration results described that value was same in both sunflower hybrid S-78 and Hysun-33.root mean square error (RMSE) was observed (1.69).

3.4. Number of Achene m^{-2}

The OILCROP-SUN model was able to simulate final number of grain per meter square total well and calibrate results described there was a small difference in total number of grain per meter square between observed (5887 m^{-2}) and simulate (6977 m^{-2}) values of Hysun-33 hybrid and also small difference was noted in hybrid S-78 in total number of grain per meter square between observed (6535 m^{-2}) and simulate (6841 m^{-2}) root mean square error (RMSE) was observed (1.60) results are shown in Table 6.

3.5. Achene Yield ($kg\cdot ha^{-1}$)

The observed and simulated value of achene yield is shown in Table 7. There was a good agreement between observed and simulated values for achene yield ($kg\cdot ha^{-1}$). The OILCROP-SUN model was able to simulate achene yield and the calibration results described that maximum value for root mean square error (RMSE) was observed (191.81 $kg\cdot ha^{-1}$). The smallest difference between simu-

Table 5. Comparison of observed and simulated values of days to physiological maturity at different sunflower hybrids and different nitrogen rates.

Hybrids	Nitrogen Level($kg\cdot ha^{-1}$)	Observed	Predicted	[a]P-O	PD (%)
Hysun-33	0 $kg\cdot ha^{-1}$	117	121	4	3.4
	45 $kg\cdot ha^{-1}$	119	121	2	1.7
	90 $kg\cdot ha^{-1}$	120	121	1	.8
	135 $kg\cdot ha^{-1}$	122	121	−1	−.8
	180 $kg\cdot ha^{-1}$	123	121	−2	−1.6
S-78	0 $kg\cdot ha^{-1}$	100	105	5	5
	45 $kg\cdot ha^{-1}$	100	105	5	5
	90 $kg\cdot ha^{-1}$	101	105	4	3.9
	135 $kg\cdot ha^{-1}$	103	105	2	1.9
	180 $kg\cdot ha^{-1}$	105	105	0	0
Mean		2	1.9		
RMSE		1.69			

[a]P-O = Predicted-Observed; RMSE = Root Mean Square Error.

Table 6. Comparison of observed and simulated values number of achene m^{-2} at different hybrids and different nitrogen rates.

Hybrids	Nitrogen Level ($kg \cdot ha^{-1}$)	Observed	Predicted	aP-O	PD (%)
Hysun-33	0 $kg \cdot ha^{-1}$	5877	4489	−1388	23.6
	45 $kg \cdot ha^{-1}$	5887	6977	1090	18.5
	90 $kg \cdot ha^{-1}$	6073	8556	2483	40.9
	135 $kg \cdot ha^{-1}$	7622	9298	2576	38.3
	180 $kg \cdot ha^{-1}$	7543	9890	2347	31.1
S-78	0 $kg \cdot ha^{-1}$	4867	4555	−312	−6.4
	45 $kg \cdot ha^{-1}$	6535	6841	306	4.8
	90 $kg \cdot ha^{-1}$	7291	7944	658	9.0
	135 $kg \cdot ha^{-1}$	8983	8464	−512	−5.8
	180 $kg \cdot ha^{-1}$	9244	8768	−476	−5.4
Mean				676.5	14.9
RMSE		1.60			

aP-O = Predicted-Observed RMSE = Root Mean Square Error.

Table 7. Comparison of observed and simulated values of achene yield at different hybrids and different nitrogen rates.

Hybrids	Nitrogen Level ($kg \cdot ha^{-1}$)	Observed	Predicted	aP-O	PD (%)
Hysun-33	0 $kg \cdot ha^{-1}$	2923	486	−2437	−83.4
	45 $kg \cdot ha^{-1}$	3078	1658	−1420	−46.1
	90 $kg \cdot ha^{-1}$	3500	3315	−185	−5.2
	135 $kg \cdot ha^{-1}$	3884	3944	60	1.5
	180 $kg \cdot ha^{-1}$	3935	3915	−20	−0.5
S-78	0 $kg \cdot ha^{-1}$	3212	496	−2716	−84.6
	45 $kg \cdot ha^{-1}$	3406	2028	−1378	−40.4
	90 $kg \cdot ha^{-1}$	3805	3314	−491	−12.9
	135 $kg \cdot ha^{-1}$	4055	3671	−384	−9.5
	180 $kg \cdot ha^{-1}$	4095	2932	−1163	−28.4
Mean				−1013	−30.9
RMSE		191.81			

aP-O = Predicted-Observed RMSE = Root Mean Square Error.

lated (3935 $kg \cdot ha^{-1}$) and observed (3915 $kg \cdot ha^{-1}$), value for achene yield was in hybrid Hyun-33 with nitrogen application 180 $kg \cdot ha^{-1}$. In generally, all values are almost close to each other. However, maximum difference was in Hysun-33 without receiving of Nitrogen. The OILCROP-SUN model was also calibrate for hybrid S-78 and results showed the smallest difference between simulated (3671 $kg \cdot ha^{-1}$) and observed (4055 $kg \cdot ha^{-1}$), value for achene yield with nitrogen application 135 $kg \cdot ha^{-1}$. In general, all values are almost close to each other. However, maximum difference was in S-78 hybrid in control treatment, where model over estimated similar approaches were explained by [17] [19].

3.6. Total Dry Matter (kg·ha−1)

The OILCROP-SUN model simulated final total dry matter well and calibrated results described there was a small difference in total dry matter (TDM) between observed (11,586 kg·ha^{-1}) and simulate (10,970 kg·ha^{-1}) values for Sunflower 33and also minimum difference was noted between observed (9496 kg·ha^{-1}) and simulated (8623 kg·ha^{-1}) values of hybrid S-78. The OILCROP-SUN model also simulated total dry matter well and the calibration results described that maximum value for root mean error (RMSE) was observed 735 are shown in **Table 8**. All results of TDM was generated from DSSAT as shown in **Figures 1-10**.

3.7. Leaf Area Index

The OILCROP-SUN model was able to simulate leaf area index well and calibration results described there was a small difference between observed and simulate value (0.19) of leaf area index in Hysun-33 with treatment level of (135 kg N ha^{-1}). However, highest (1.6) difference was in control treatment where model over estimated. In general, model over estimated the value of LAI. The OILCROP-SUN model was able to simulated leaf area index well and calibration results described there was a small difference between observed and simulated value (1.26) of leaf area index in S-78 with application level of (135 kg N ha^{-1}). However, highest (2.18) difference was in control treatment where model over estimated. In general, model over estimated the value of LAI as shown in **Figure 11** and **Figure 12**.

Table 8. Comparison of observed and simulated values of total dry matter at different sunflower hybrids and different nitrogen rates.

Hybrids	Nitrogen Level (kg·ha^{-1})	Observed	Predicted	aP-O	PD (%)
Hysun-33	0 kg·ha^{-1}	7771	1212	−6559	−84.4
	45 kg·ha^{-1}	8529	5097	−3432	−40.2
	90 kg·ha^{-1}	9725	8155	−1570	−16.1
	135 kg·ha^{-1}	11,123	9734	−1389	−124.8
	180 kg·ha^{-1}	11,586	10970	−616	−53.1
S-78	0 kg·ha^{-1}	7518	1128	−6390	−85
	45 kg·ha^{-1}	7676	5004	−2672	−34.9
	90 kg·ha^{-1}	8555	7492	−1063	−12.4
	135 kg·ha^{-1}	9496	8623	−873	−9.0
	180 kg·ha^{-1}	9722	8450	−1272	−13.0
Mean		−2583.6	−47.29		
RMSE		735			

aP-O = Predicted-Observed, RMSE = Root Mean Square Error.

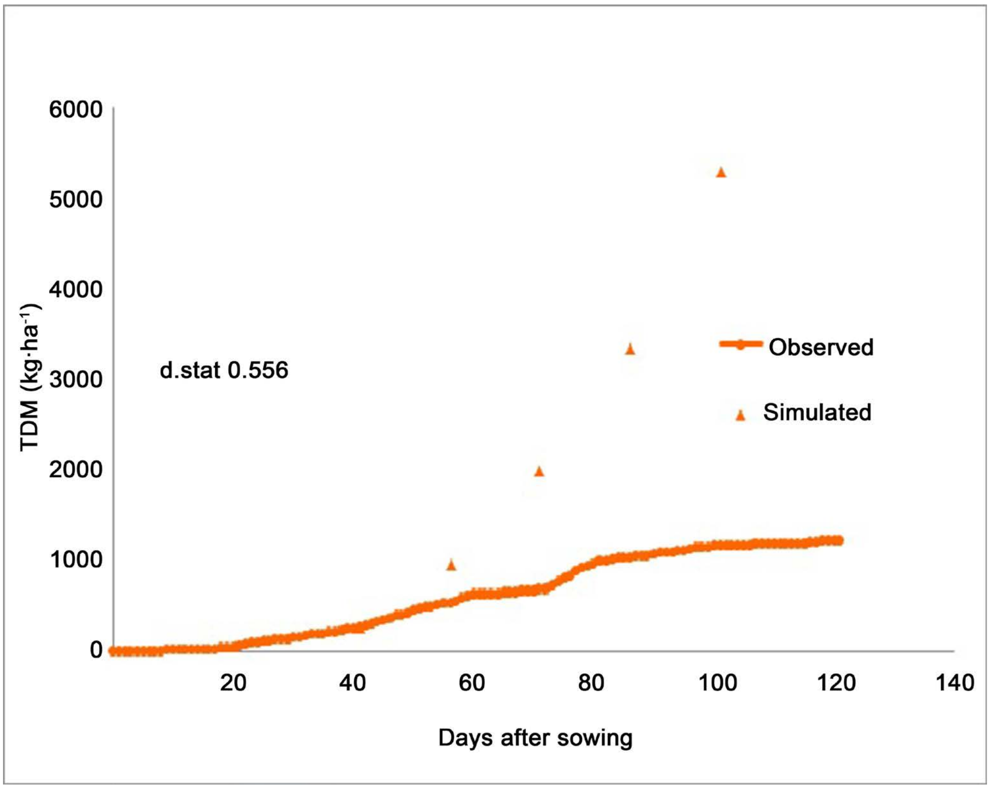

Figure 1. Comparison of observed and simulated values of TDM for treatment H_1N_1 (H_1 = Hysun-33 and N_1 = 0 kg N ha^{-1}).

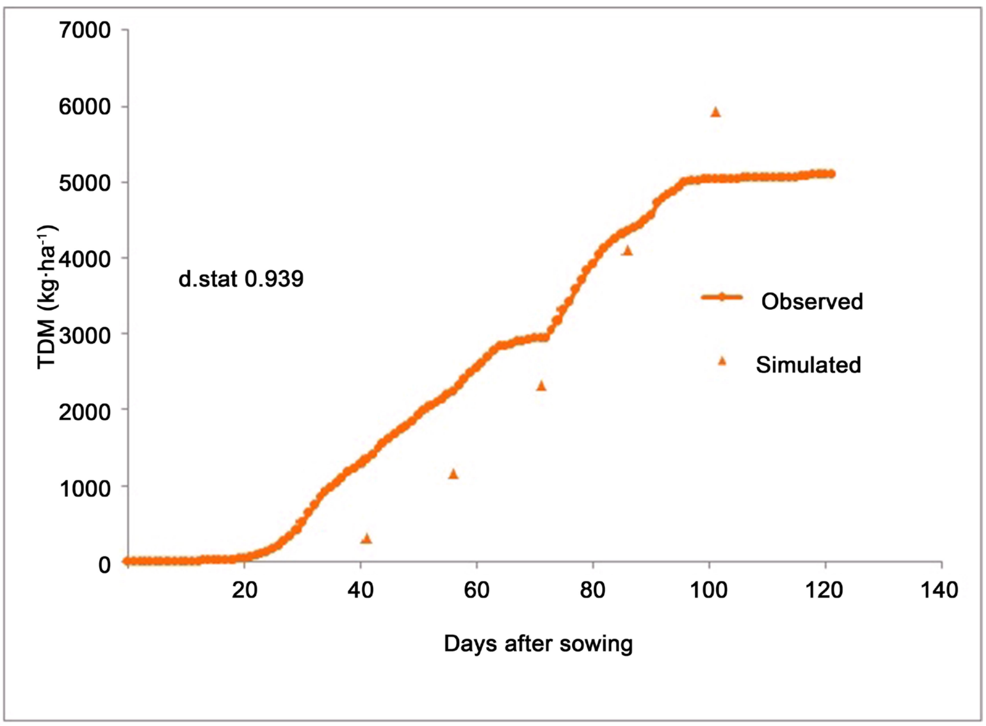

Figure 2. Comparison of observed and simulated values of TDM for treatment H_1N_2 (H_1 = Hysun-33 and N_2 = 45 kg N ha^{-1}).

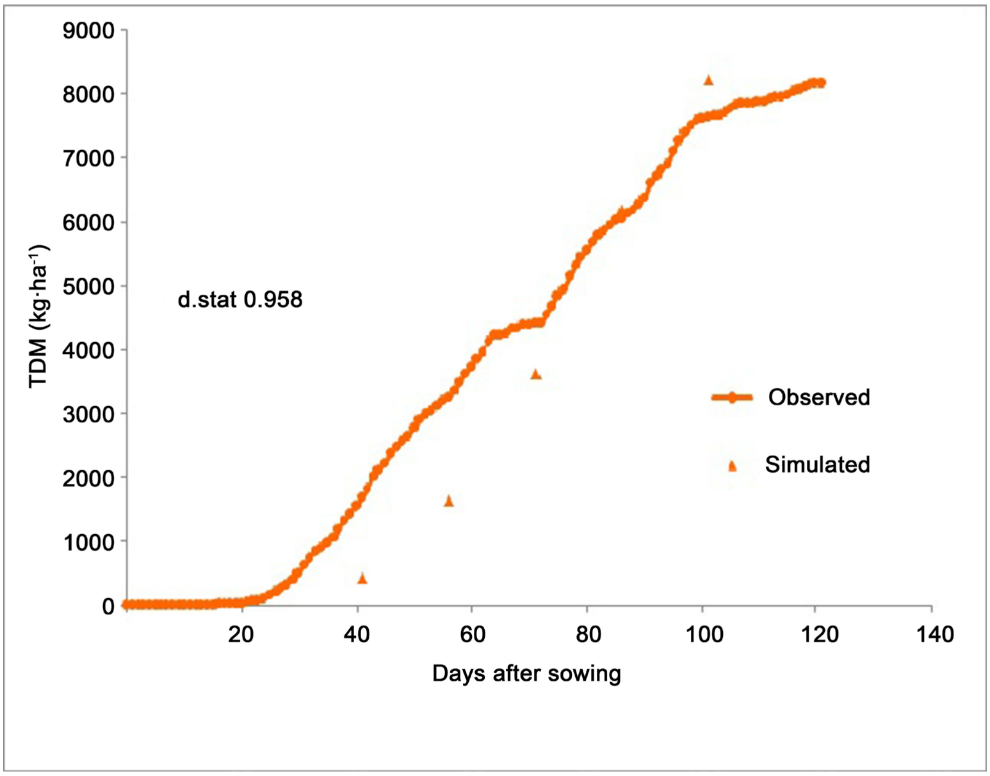

Figure 3. Comparison of observed and simulated values of TDM for treatment H_1N_3 (H_1 = Hysun-33 and N_3 = 90 kg N ha^{-1}).

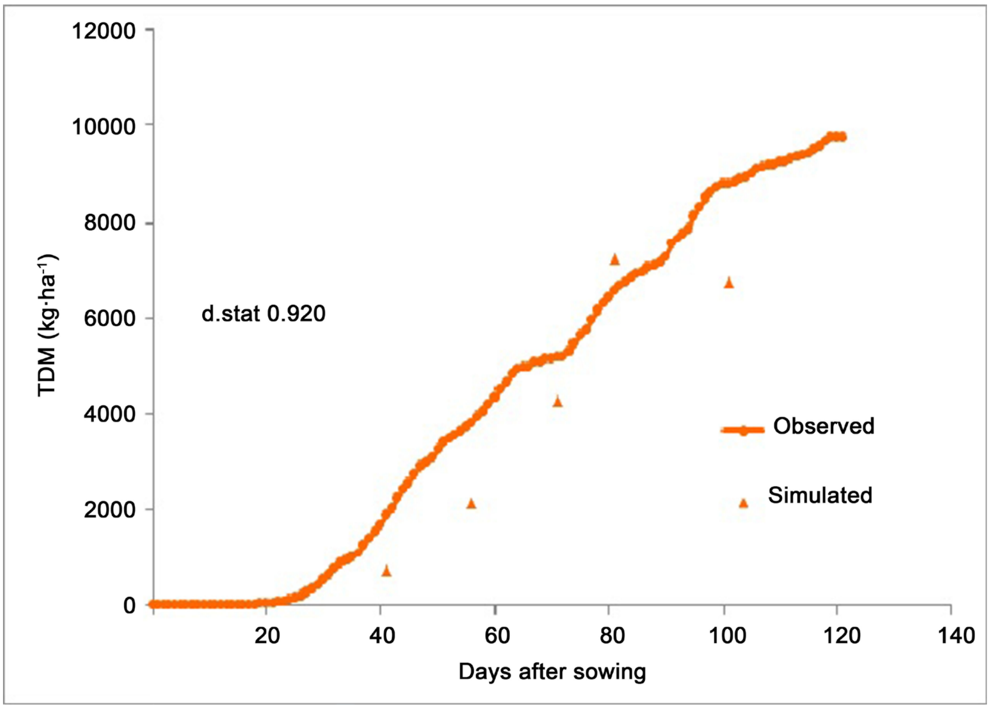

Figure 4. Comparison of observed and simulated values of TDM for treatment H_1N_4 (H_1 = Hysun-33 and N_4 = 135 kg N ha^{-1}).

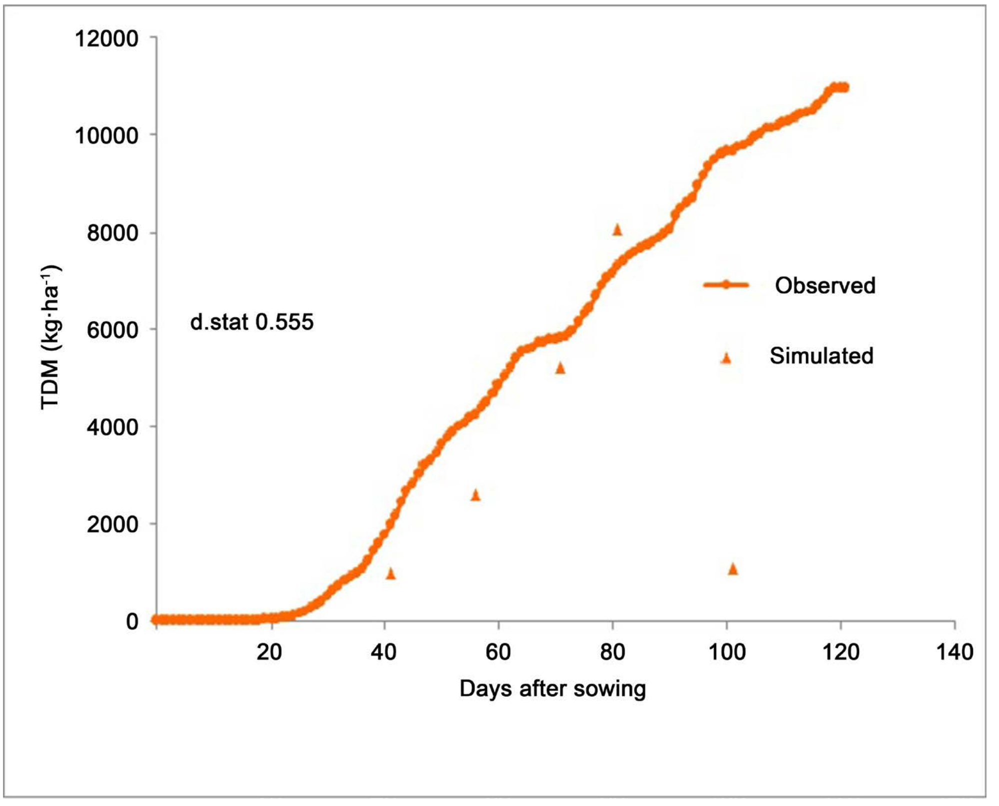

Figure 5. Comparison of observed and simulated values of TDM for treatment H_1N_5 (H_1 = Hysun-33 and N_5 = 180 kg N ha^{-1}).

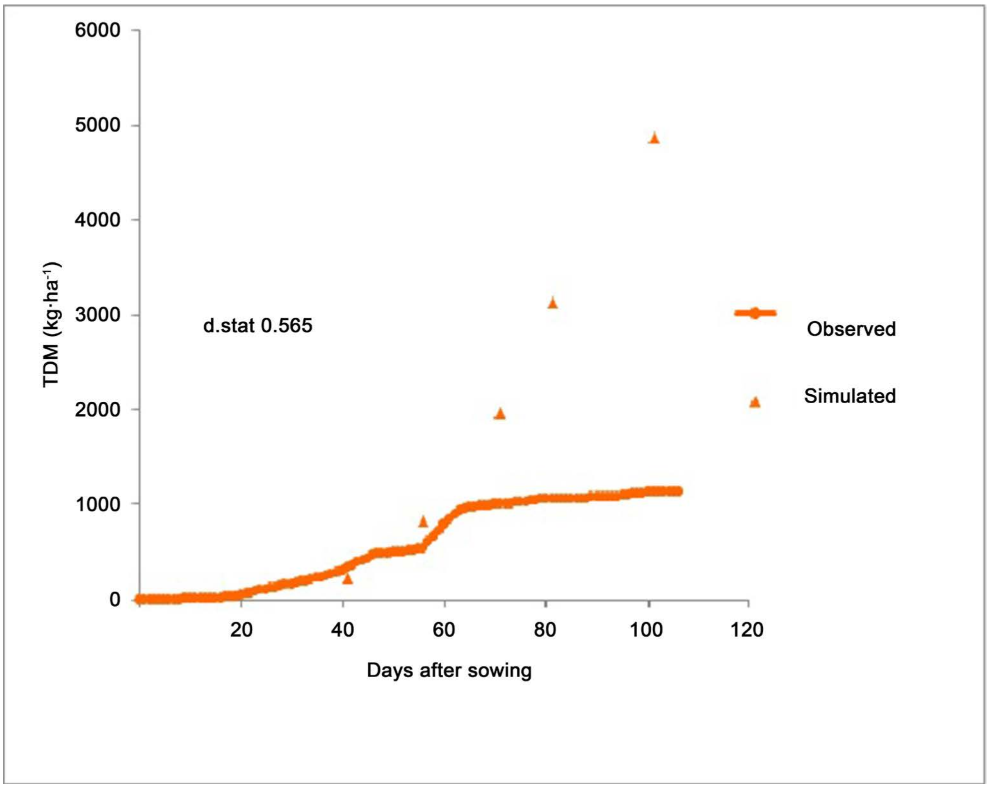

Figure 6. Comparison of observed and simulated values of TDM for treatment H_2N_1 (H_1 = Hysun-33 and N_1 = 0 kg N ha^{-1}).

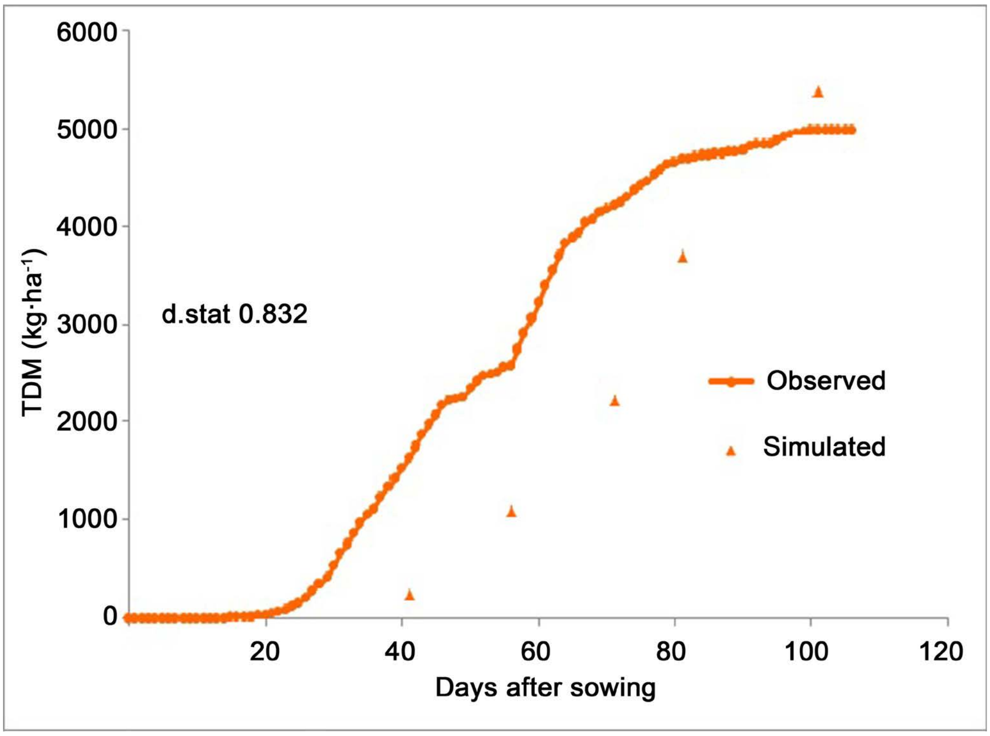

Figure 7. Comparison of observed and simulated values of TDM for treatment H_2N_2 (H_1 = Hysun-33 and N_2 = 45 kg N ha^{-1}).

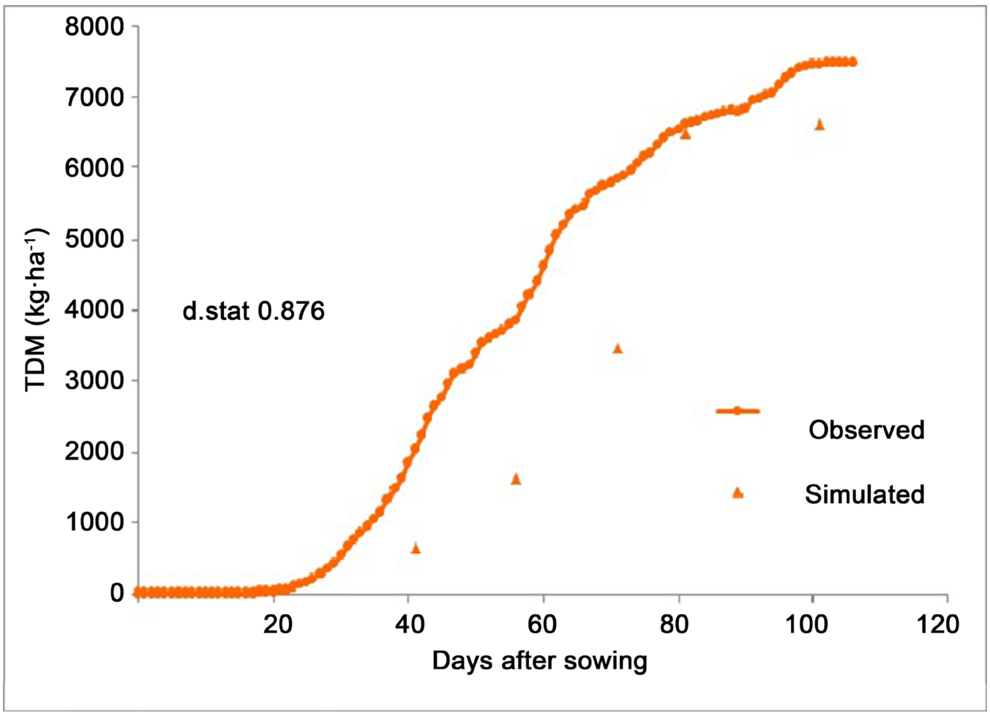

Figure 8. Comparison of observed and simulated values of TDM for treatment H_2N_3 (H_1 = Hysun-33 and N_3 = 90 kg N ha^{-1}).

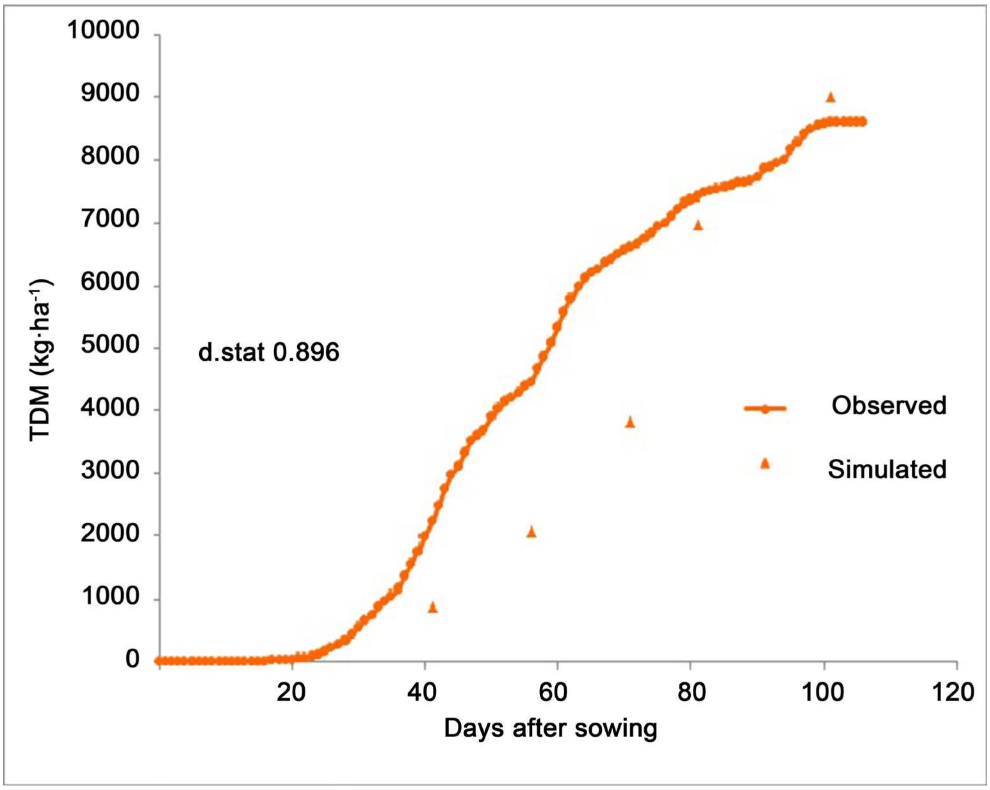

Figure 9. Comparison of observed and simulated values of TDM for treatment H_2N_4 (H_1 = Hysun-33 and N_4 = 135 kg N ha^{-1}).

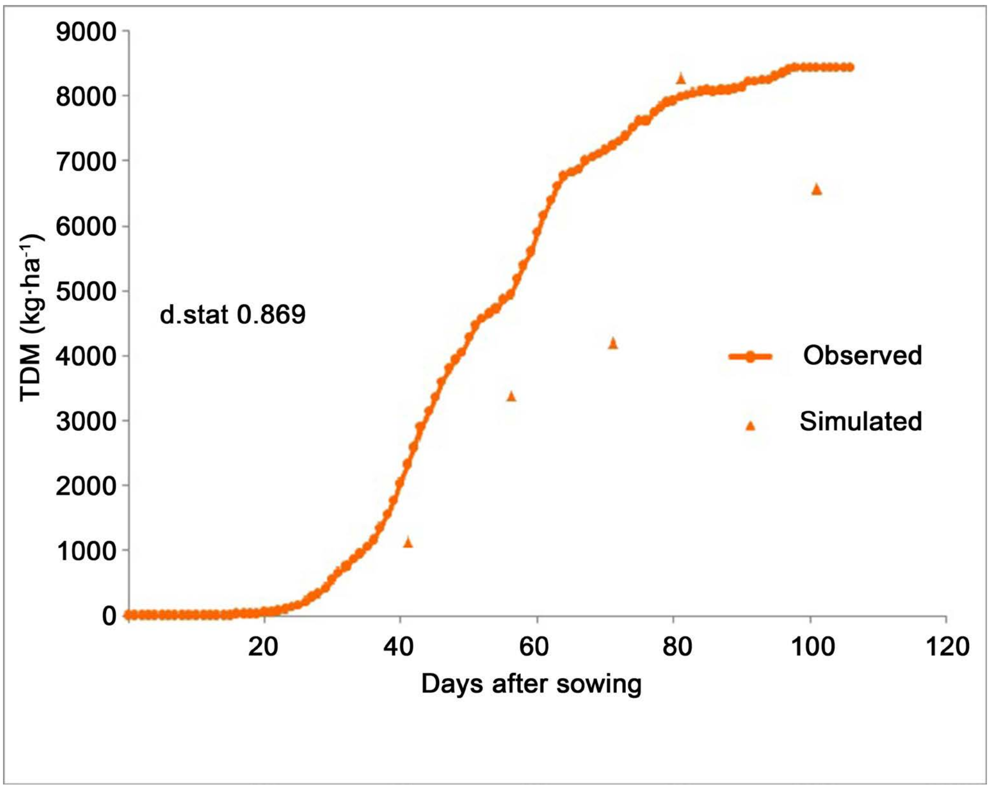

Figure 10. Comparison of observed and simulated values of TDM for treatment H_2N_5 (H_1= Hysun-33 and N_5= 180 kg N ha^{-1}).

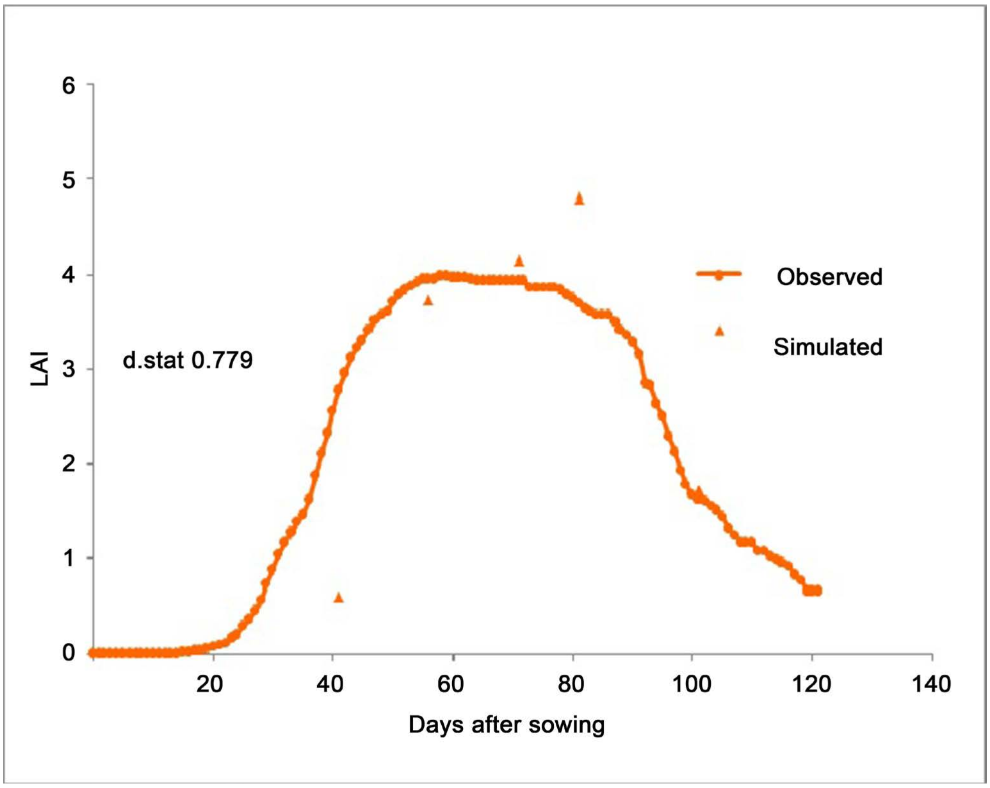

Figure 11. Comparison of observed and simulated values of LAI for treatment H_1N_4 (H_1 = Hysun-33 and N_4 = 135 kg N ha^{-1}).

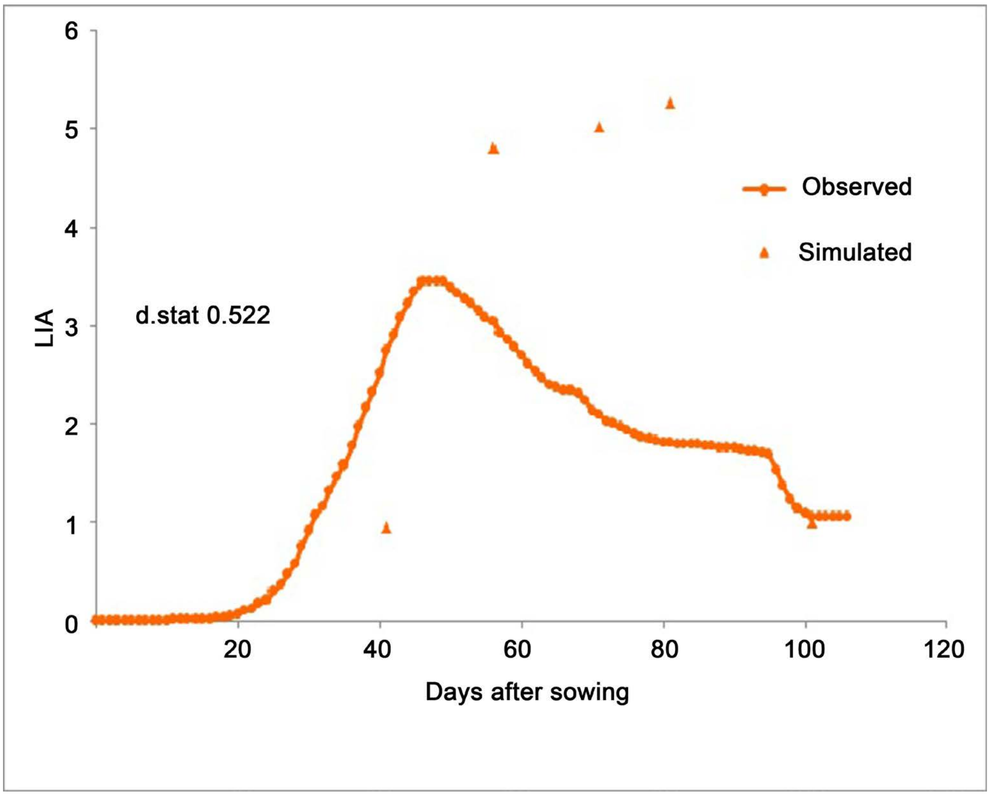

Figure 12. Comparison of observed and simulated values of TDM for treatment H_2N_4 (H_1 = Hysun-33 and N_4 = 135 kg N ha^{-1}).

4. Conclusion

Crop modeling is becoming a valuable tool to understand and mimic climatic constraints and yield gaps. The outcomes of the study clearly depicted that DSSAT model is predicted crop growth and yield parameters of sunflower crop. This study also showed the OIL-CROP-SUN model served as a tool for determining the best nitrogen levels for growing sunflower under irrigated conditions in semi-arid environment in Pakistan. This study illustrates the potential for using crop simulations models as information technology for determining suitable management strategies for sunflower production in Sargodha, Punjab, Pakistan. Therefore, we can conclude that the OILCROP-SUN model could potentially assist resource-poor farmers in Pakistan and provide them with alternate management options.

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