Acta Scientific AGRICULTURE (ISSN: 2581-365X)

Volume 9 Issue 1 January 2025

Research Article

Optimizing Nitrogen Management for Winter Wheat Cultivars (*Triticum aestivum* L.) in Semi-Arid Environments Using CERES-Wheat Model

Musawer Abbas[1]*, Aftab Wajid[1], Zhang Qiying[2], Aftab Jamal[3], Emanuele Radicetti[4]*, Adil Zia[5] and Roberto Mancinelli[6]

[1]Department of Agronomy, University of Agriculture Faisalabad, Pakistan

[2]College of Agronomy Northwest A and F University, China

[3]Department of Soil and Environmental Sciences, Faculty of Crop Production Sciences, The University of Agriculture, Peshawar, Pakistan

[4]Department of Chemical, Pharmaceutical and Agricultural Sciences (DOCPAS), University of Ferrara, Ferrara, Italy

[5]Department of Agronomy, Amir Muhammad Khan Campus Mardan, Faculty of Crop Production Sciences, The University of Agriculture, Peshawar, Pakistan

[6]Department of Agricultural and Forestry Sciences (DAFNE), University of Tuscia, Viterbo, Italy

***Corresponding Author:** Musawer Abbas, Department of Agronomy, University of Agriculture Faisalabad, Pakistan.

Received: December 09, 2024

Published: December 20, 2024

Abstract

Worldwide, winter wheat (*Triticum aestivum* L.) is one of the major staple foods and its production is strongly affected by nitrogen (N) fertilization levels and cultivar choice. The adoption of crop simulation models may be used to determine the optimal crop N requirements under a variety of soil conditions in a less time-consuming and cost-effective manner. In this study, a dynamic mechanistic model CERES (Crop Environment Resource Synthesis)-Wheat was validated for forecasting growth and yield of two winter wheat cultivars under different nitrogen fertilization levels subjected to semi-arid climate conditions for optimizing N management tool. Field experiment was carried out in 2020-2021 growing season at the Agronomic Research Farm, University of Agriculture (Faisalabad, Pakistan). Two winter wheat cultivars (Gandam1-17 and Anaj-17) were sown at the seed rate of 125 kg ha^{-1} and subjected to five N fertilization rates (0, 50, 100, 150 and 200 kg ha^{-1}). A Randomized Complete Block design with three replications was adopted. The CERES-Wheat model was calibrated by using crop, soil, genotype, and weather data against best performing nitrogen level. The results showed that Gandam1-17 combined with 150 kg N ha^{-1} performed the highest output in yield and yield-related attributes. The yield gap between simulated and observed values was well calibrated. The evaluation of R2 between observed and simulated values for selected variables, grain yield has a very strong adjustment and exhibits a high R2 (>0.90), a low RMSE of 0.81, and Wilmot's index of agreement (d-index) (0.99). Grain yield modeling results revealed that CERES-Wheat responded effectively to N application rates as recorded in the field. The model performed best in forecasting grain yield when Gandam1-17 was used instead of Anaj-17. While the model indicated that Anaj-17 cultivar is more appropriate in predicting biomass of wheat showing better agreement with the observed values (MAPE = 1.9, RMSE = 19.44, d-index = 0.994). Based on the results of this study, the DSSAT-CERES-Wheat could help farmers of the semi-arid environment to calculate the optimum nitrogen doses using different cultivars for maximum economic return from wheat.

Keywords: Decision Making; Wheat Model; Genetic; Grain Yield; N Management

Introduction

Winter wheat (*Triticum aestivum* L.) could be cultivated from a variety of climates, soil types and economic conditions, and supply primary food requirement for one-third of humanity. Although different wheat varieties have distinctive growing characteristics, winter wheat production per hectare can be linked to several issues, especially ineffective crop management and climate change [2]. The average wheat yield is also significantly impacted by variables such as a shortage of irrigation water and inputs, high input prices, damage from pests, unequal fertilizer use and difficulty marketing [1]. The initial step that must take to boost grain yields is to select the ideal cultivar and then plant it in the optimal environment [3].

Among nutrients required for the growth and development of plant cells, nitrogen (N) is of special importance [4]. Nitrogen comprises up to 7% of the total dry matter of higher plants and is a constituent of many fundamental cell components such as nucleic acids, amino acids, and hence enzymes and photosynthetic pigments [5]. As nitrogen is an essential macronutrient for wheat growth and yield, fertilizer management is generally the most effective way to increase grain yield in winter wheat production [5].

A clean and healthy environment can be maintained by using N in the most possible efficient manner [6]. The N fertilization to improve grain and flour quality might depend upon the edapho-climatic conditions of the given area [7,8]. There are multiple elements, i.e., agronomic, environmental, climatic and edaphic, that eventually result in lower production; judicious application of fertilizer being a crucial requirement effects wheat outcome and ultimately influences food security [9,10]. However, particular agro-ecosystem conditions, such as alkaline soils, calcareous in nature and low in organic matter contents, required additional N availability to achieve maximum grain yield [12]. Worldwide, winter wheat is planted on 53% of the entire harvestable land, which needs improved N management in order to maximize productivity [13]. Therefore, proper nitrogen fertilizer management should seek to meet plant N requirements, improve crop yield, and reduce environmental risk [14]. Excessive nitrogen fertilizer use has resulted in serious environmental issues, higher fertilizer loss, and decreased agricultural returns [15]. In many areas of the world, farmers commonly tend to apply nitrogen fertilizer at pre-planting due to the convenience of such an application and its priming effect on wheat seedling growth [16]. However, the nitrogen requirements of wheat have been shown to vary among growth stages [16]. The timely application of N at the correct rate is essential to a crop's success [17,18]. The yield has increased while using the optimum amount of N during the booting stage. The crop's need for N varied depending on its growth stage and the soil and climate in which it was growing [19].

In agriculture, decision making and planning entail executing multiple model-based decision support systems in response to changing climate scenarios and management activities [20]. Mechanistic models are quite useful in determining the optimal crop development and yield management options [21]. A crop model is a quantitative scheme used for prediction of crop growth, development and production at given set of genetic coefficients and environmental conditions [22]. Crop simulation models take into account the complex interactions between weather, soil properties, and management factors that affect crop performance [21]. Only when the models have been adequately calibrated for the specific set of conditions can they be used to examining the impact of varied environmental and management conditions on crop yield.

The DSSAT (Decision support system for Agrotechnology transfer) and several other models have been used marvelously to simulate production of crops, their adaptation and sustainable production and enhanced risk management [23]. CERES (Crop Environment REsource Synthesis)-Wheat is a process-based, management-oriented model that can simulate the crop growth, development and yield taking into account the effects of weather, genetics, soil (water, carbon and nitrogen), planting, irrigation and nitrogen fertilizer management [21].

The ability to simulate optimal N requirements for wheat yield by CERES-Wheat has been evaluated in a wide range of environments across the world. Though performance evaluation under different N management conditions has been reported [24] but it was not evaluated under various N and wheat cultivars in semi-arid conditions like those prevalent in agro-ecological region of Faisalabad (Pakistan).

The present research was conducted with the objectives: (i) evaluating wheat cultivars for N rates using CERES-wheat Model and (ii) yield gap analysis through modeling approach.

Materials and Methods

Study location, experimental design, and treatments

To evaluate the performance of CERES-Wheat crop simulation model under various N rates and wheat cultivars, research was laid out at a research farm of agronomy department at the University of Agriculture, Faisalabad (UAF, Pakistan) (31.42° N latitude -73.07° E longitude) during November 2020 to April 2021. The experiment was conducted in a factorial approach with three replications, where one factor was the two wheat cultivars (Gandam1-17 and Anaj-17) which were assigned to the main plot and the other was different nitrogen (N) levels (N0= control, N1= 50 kg ha^{-1}, N2= 100 kg ha^{-1}, N3= 150 kg ha^{-1} and N4= 200 kg ha^{-1}) which were allocated to the subplots, all these were arranged under Randomized Complete Block Design (RCBD). Each plot size was 5.0 m × 1.76 m having 8 rows per plot with 22 cm row to row spacing. Before twelve days of sowing, plots were filled with water which is locally known as a round of 100 mm then waited until the appropriate field capacity was achieved. After achieving appropriate moisture condition for sowing purpose (*wattar* condition), two ploughings and two cultivations were performed, followed by using planker to develop suitable plots. Single-row hand drill was used for sowing the seeds of two wheat cultivars (Gandam1-17 and Anaj-17) on November 15^{th}, 2020. According to recommendations, 125 kg ha^{-1} of seed was placed at recommended R×R distance (22 cm). At the time of seed bed preparation, one portion of Nitrogen (after its division in three parts) was applied along with phosphorus at the rate of 90 kg P_2O_5 ha^{-1}, the remainder N used with first and second irrigations of 75 mm. The first irrigation was applied on the 25th day of sowing, followed by two 3-acre inch irrigations at the booting and milking stages, respectively. All the plant protection measures were implemented.

Weather and soil physico-chemical data

Respective weather parameters were collected at a meteorological observatory near the experimental site at UAF. The weather data included temperature (°C), sunlight hours (h) and rainfall (mm), Weatherman in DSSAT used the sunshine hours to determine the radiation coming from sun in MJ m^{-2} day^{-1}. A thermometer digital in its functioning was used to record the daily day and night temperatures throughout the duration of treatment.

The climate of the area can be considered as semiarid, with very hot and humid summers and dry cool winters. The highest temperature (36.3°C), lowest temperature (5.8°C), average maximum temperature (26.8) and average minimum temperature was recorded in October, 2021 and January 2022 respectively, (Figure 1a). Likewise, the highest pan evaporation (5.96 mm) and highest evapotranspiration (4.13 mm) was recorded in April 2022, whereas the lowest pan evaporation (0.98 mm) and lowest evapotranspiration (0.70 mm) was recorded in Dec-2021 and Jan-2022 respectively (Figure 1b). Moreover, the maximum sunshine hours (9.54) were recorded in Oct-2021 and minimum sunshine hours (5.20) was recorded in Jan-2022, (Figure 1b). Weather data regarding rainfall pattern during the growing season indicated that highest rainfall (51.1 mm) and relative humidity (83.9%) was recorded during Jan-2022 whereas, no rainfall occurred during the month of Oct-2021 and Feb-2022, however, lowest relative humidity (54.6%) was recorded during April-2022, (Figure 1c). To characterize the soil, samples from the upper horizon (0-20 cm) were collected in each plot before starting the experiment using a soil auger. The samples were air-dried, crushed to pass through a 2 mm sieve, mixed to make a composite sample, labeled, and stored in plastic bags. Standard laboratory methods were used for physical and chemical characterization [25]. The soil texture of the experimental field was classified as sandy clay loam, according to the USDA-NRCS classification (sand 40.70 %; silt 37.30 %; clay 22 %), alkaline in reaction (pH 7.7), calcium carbonate content (5.5%), low in organic matter content (1.2 %) with an electrical conductivity of 1.5 dS m^{-1}. Furthermore, the soil registered a low concentration of extractable phosphorous 5.46 mg kg^{-1}, a total N of 0.06 g kg^{-1}, and exchangeable potassium (AB-DTPA) of 129 (mg kg^{-1}).

Crop characteristics

Managerial data comprises plant spacing, planting depth, seed application method, cultivar used, quantity, method, and time of irrigation, type of fertilizer used, and its amount and time of application. Physiological characteristics such as planting date, emergence, crown root initiation, tillering, jointing, milking, physiological maturity, and harvesting must also be observed under various treatments. Taking into account the critical input variables for successful model execution, plant height, plants m^{-2}, leaf area index, number of grains per spike, 1000 grain weight (g) were assessed.

Growth and development parameters

After 30 days of sowing, destructive sampling of plots was started by cutting at ground level and from 30 cm row area with 15 days'

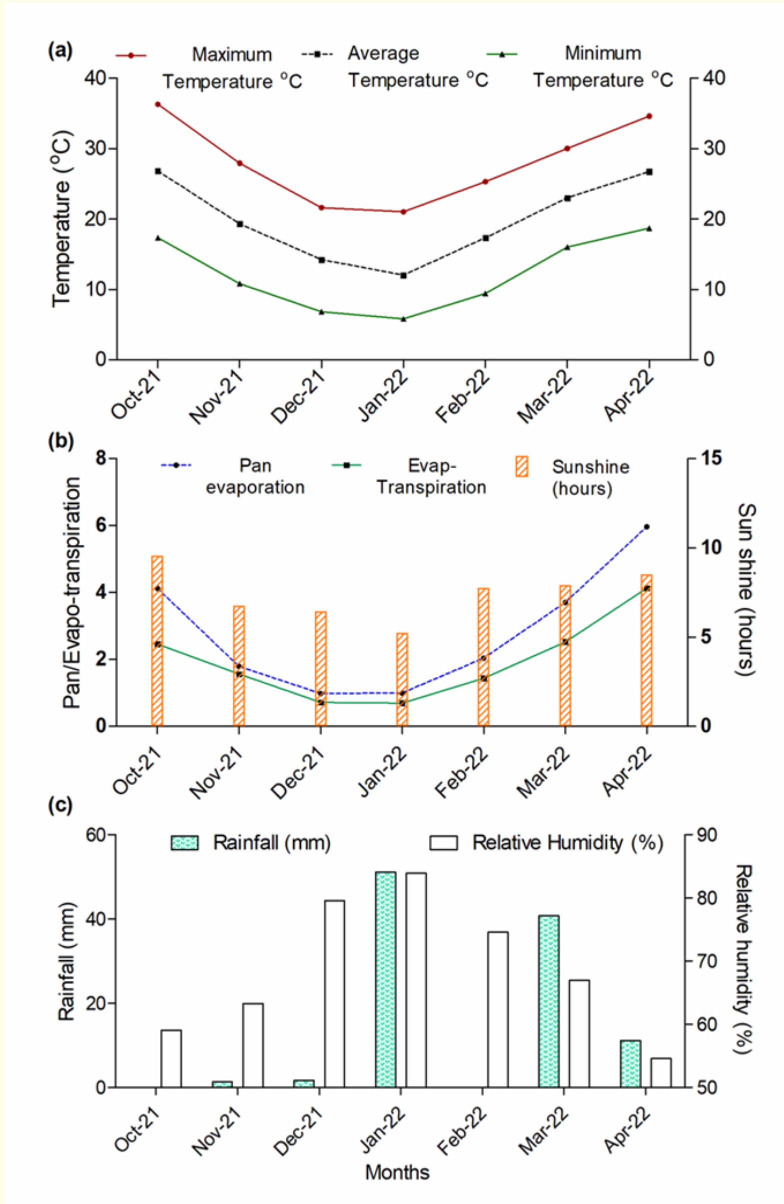

Figure 1: Study area weather variables of the wheat growing season Oct-2021 to Apr-2022 (a). Maximum, average, and minimum temperature (oC). (b). Monthly average of pan evaporation, evapotranspiration, sunshine (hours), (c) Rainfall (mm) and humidity (%).

interval. In all plots, fresh weight of plants harvested was measured, then were segregated different parts of harvested plants and further divided them in sub samples. After that dry weight of sub samples was determined after oven dry until constant weight. Leaf area meter was used to determine the leaf area of 5g sub sample. All data are reported for meter square area (by unity rule) to determine the total dry weight.

Leaf area index

LAI is the ratio of leaf area to land area and it is associated to the solar radiation that can be captured by plants

$$\textbf{Leaf area index} = \frac{\textbf{Leaf area}}{\textbf{Land area}} \text{ ------- (1)}$$

Crop growth rate

Increase in biomass of a crop at a given time from selected land area.

$$\textbf{Crop growth rate} = \frac{\textbf{weight}_2 - \textbf{weight}_1}{\textbf{time}_2 - \textbf{time}_1} \text{ -------- (2)}$$

Leaf area duration

The long-term series of data found from the leaf Area Index, where the area of land occupied in relation to upper plant canopy is recorded against time.

$$\textbf{Leaf Area Duration} = \frac{\textbf{LAI}_1 - \textbf{LAI}_2}{2} \times (\textbf{t}_2 - \textbf{t}_1) \text{ --------(3)}$$

Net assimilation rate

The increment in leaf's dry weight with the passage of time

$$\textbf{Net assimilation rate} = \frac{\textbf{(Final) Total dry matter}}{\textbf{(Final) Leaf area duration}} \text{ ---------- (4)}$$

Morphological and yield parameters

At maturity, an area of 2.5 m^2 was selected from all units of each replication for manual harvesting and threshing in order to determine the final grain yield. Plants should not be harvested from side borders. Grain and straw yield were used in combination to determine the final biomass. From all plots we selected 10 wheat plants, then took the mean of each sample to estimate these parameters. Data on plant height (cm) were recorded by measuring plant height from bottom to tip of ear, with the help of meter rod. Then from all plots we calculated mean height of ten plants. For Number of productive tillers (m^{-2}) a ring of 1 m^2 was placed in each experimental unit at the time of harvest. Then the productive and non-productive tillers were counted. The productive tillers were then determined by subtracting the productive tillers from total number of tillers. For calculating the grains per spike again the same selected plants were used. Then the average of ten plants were calculated. Thousand grains weight (g) data were recorded using an electronic balance by counting a thousand grains from each plot at random. The biological yield was measured by harvesting four central rows in each plot. The harvested crop was sun-dried and weight with spring balance. Using equation 6, the yield was equivalent to (t ha^{-1}) [26], and grain yield and harvest index for each treatment were calculated using equations 7 and 8, respectively [27].

$$\text{Biological yield (t ha}^{-1}\text{)} = \frac{\text{Total plant weight in 4 central rows}}{\text{R} - \text{R distance (m)} \times \text{ Row length(m)} \times \text{ No. of rows}} \times 10 - - - - - (6)$$

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{\text{Biological yield in 4 central rows}}{\text{R} - \text{R distance (m)} \times \text{ Row length(m)} \times \text{ No. of rows}} \times 10 - - - (7)$$

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100 - - - (8)$$

Model description

In this study, we deployed CERES-Wheat cropping system model embedded under DSSAT software version 4.7 for simulation of wheat performance under different cultivation practices induced by varying cultivars and nutrient (specifically in terms of nitrogen). DSSAT is a dynamic mechanistic model and integrates numerous factors that affect growth and development and predicts wheat growth and development on a daily basis.

Input parameters

DSSAT model v.4.7 primarily operated on the 3 databases: soil, climate and crop management practices. Physical and chemical parameters of soil samples at the experimental location were included to the soil file as inputs. Daily records of minimum and maximum temperature and precipitation and relative humidity were used to generate the weather file (file T) used in the simulation. Data on solar radiation was generated in the DSSAT weatherman shell from daily minimum and maximum temperature. The "genetic coefficients" inputs are coefficients related to photoperiod sensitivity, duration of grain filling, conversion of mass to grain number, grain filling rates, vernalization requirements, stem size, and cold hardiness [28]. Management input information includes crop variety, plant density, planting depth, date of planting, N fertilization, P fertilization, and irrigation carried out during field experimentation were used to create the experimental file (file X) of the DSSAT shell. The soil parameters required for the model were estimated at sowing of the crop and used to generate the soil file (file A).

Output parameters

The CERES wheat model was therefore calibrated by comparing observed and predicted total dry matter and grain yield under optimal condition (150 N kg ha^{-1}), and wheat cultivars and adjusting the genetic coefficients until a close agreement was found.

The origin of CERES-Wheat model belongs to Joe Ritchie and some other scientists of 1970s [29]. Radiation use efficiency used to model the growth. Both temperature and day length potentially affect the development. We can distinguish the penology of winter wheat, spring wheat and facultative wheat by their response to verbalizing temperatures. Ritchie et al. [30] recommended a unique way to simulate growth, development and yield. So far, the prime focus of developmental work on CERES-Wheat model is the simulation of all CERES-Wheat parameters [31].

Statistical analysis

The mean value and standard error from the obtained data were calculated and examined using Microsoft Excel 2010, US. Analysis of variance (ANOVA) were executed with Co-Stat Window version 6.3 to find significant differences between treatments. The mean value and standard error were calculated with standardized techniques, also least significant difference (LSD) test was performed at (± 0.05) and is shown in letters (AE).

Model calibration and evaluation

Before any model can be used confidently, appropriate validation or evaluation of the magnitude of errors that may occur as a result of their usage should be done. The experimental data at Faisalabad during Rabi season, 2020-21 were used to evaluate the model by comparing with simulation results. For model calibration and evaluation, it is indispensable to determine the genetic coefficients of the two wheat cultivars (Gandam1-17 and Anaj-17) under study. Seven wheat genetic coefficients were considered, which were derived sequentially, starting with the coefficients mainly relating with phenological development (P1V, P1D, P5, PHINT) and progressing to the coefficients primarily dealing with growth factors (G1, G2, G3) [28,32]. Model validation is a comparison between simulated and observed data. Beyond comparisons, some statistical measures are available to examine the relationship between simulated and observed values, including the correlation coefficient (r) and its square, coefficient of determination (R^2), linear regression parameters (intercept and slope) were assessed. To address the degree of dispersion and degree of association between observed and simulated data, root mean square error (RMSE), coefficient of determination (R^2), mean absolute percentage error (MAPE) and index of agreement (d-index) were used. Value of d_index as 1 represents good fitting of model while the value of d-index closes to 0 indicates bad model fitting between simulated and observed data.

$$\text{Mean Absolute Percentage Error (MAPE)} = \left[\sum_{i=1}^{n}\left[\frac{|Oi - Pi|}{Oi}\right] \times 100\right]\frac{\square}{\square_n} \quad (9)$$

$$\text{Root Mean Square Error (RMSE)} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \quad (10)$$

$$\text{d\_index} = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (11)$$

where, O_i refers to observed value; n is No. of observed values; P_i refers to predicted value; $\bar{O}$ is the mean of the observed values.

Yield loss (yield GAP) was calculated as:

$$\text{Yield GAP (\%)} = \frac{|Ypre - Yobs_i|}{Ypre} \times 100 \quad (12)$$

where, Y_{pre} is the simulated yield through model under optimal condition (150 N kg ha^{-1}), Y_{obs} is the observed yield under different treatment combination.

Results

Growth parameters

Leaf area index (LAI)

As a measure of the amount of foliage in a given area, it is also a measure of the amount of area that is prone to transpiration. Nitrogen levels, as well as wheat cultivars, have a substantial impact on the LAI as well. In the early stages of growth, LAI was boosted by increasing nitrogen levels; it reached a peak at 80 days after planting and remained constant for the next 80 to 95 days before declining until maturity. Different wheat cultivars and nitrogen levels have a considerable impact on LAI (Figure 2). N3 (150 kg N ha^{-1}) had the highest leaf area index, followed by N_4 (200 kg N ha^{-1}) (Figure 2).

Cultivars also affected significantly on LAI and the maximum value of LAI was measured on Gandam1-17 which was statistically at par in Anaj-17 (Figure 2). Anaj-17 has the lowest LAI due to genetic composition and light penetration. However, the interaction effect of nitrogen levels and wheat cultivars was found to be statistically significant. (Table S1).

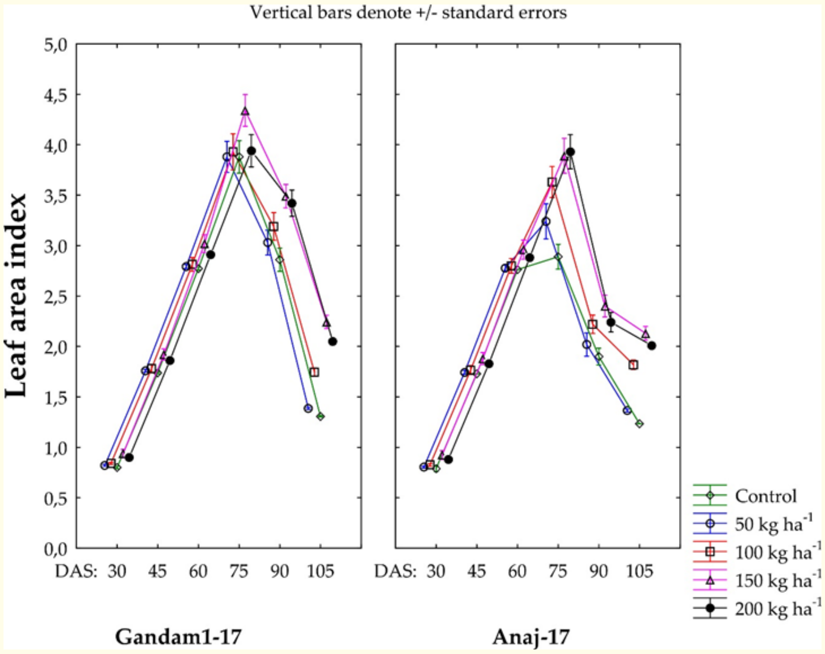

Figure 2: Effect of wheat nitrogen levels and cultivars on leaf area index. DAS stands for days after sowing.

Total dry matter production

The amount of biomass needed to supply various nutrients in the diet can be considerably affected by changes in dry matter. Table (S2) presents the results of an analysis of variance, which shows that different nitrogen levels and wheat cultivars varied significantly, although their interaction was not significant. In a comparison to the remaining nitrogen levels, the data in figure 3 suggest that total dry matter (TDM) is at its highest under nitrogen level N3 (150 kg N ha^{-1}). Wheat cultivars Gandam-17 and Anaj-17 differed in biomass due to genetic variability, while Gandam-17 had greater biomass.

Leaf area duration

Analysis of variance (Table 1) showed the highly significant difference for both wheat cultivars and nitrogen levels regarding leaf area duration (LAD). While interactive effect between wheat cultivars and nitrogen levels was found non-significant for LAD. Data indicated that maximum LAD (270.06 days) was recorded in Gandam1-17 whereas 150 kg N ha^{-1}showed maximum LAD (277.26 Days) as compared to the remaining nitrogen levels (Table 1). While shortest LAD (232.29 days) was recorded in 0 kg N ha^{-1}.

Crop growth rate

Crop growth rate (CGR) is a measure of how much weight a crop gains per square foot over time. According to the analysis of variance both wheat cultivars and nitrogen levels had a substantial impact on crop growth rate (Table 1). Despite the fact that the interaction between wheat cultivars and nitrogen levels was determined to be non-significant in the early phases, CGR was low due to a lack of leaf expansion, then it reached its peak 75 days after sowing (DAS) and then began to decline. (Table 1) shows that Gandam1-17 had the highest mean crop growth rate (9.84 g m^{-2} d^{-1}), while Anaj-17 had the lowest mean CGR (9.30 g m^{-2} d^{-1}). Nitrogen application, 150 kg N ha^{-1} demonstrated the highest CGR (11.18 mg/m2/day) that fell short of 200 kg N ha^{-1} (10.37 g m^{-2} d^{-1}). For example, the lowest mean CGR (7.88 mg/m2/day/day) was reported under an application of 0 kg N ha^{-1}. Due to the fact that most plants were healthy and strong, they may have been able to absorb water and light more effectively, which may have led to a greater CGR.

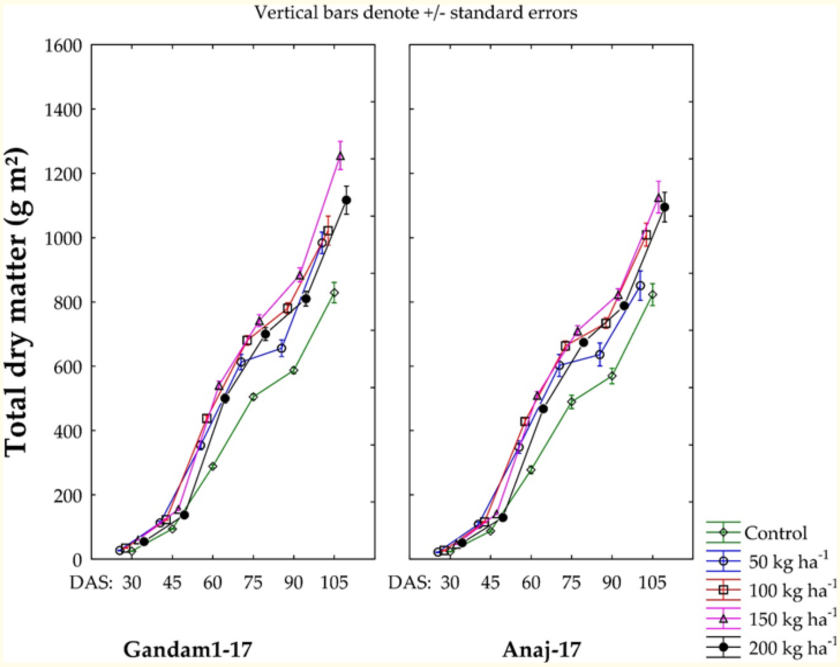

Figure 3: Effect of wheat nitrogen levels and cultivars on dry matter production. DAS stands for days after sowing.

Net assimilation rate

Nitrogen levels had a substantial impact on the net assimilation rate (NAR), while wheat cultivars had a non-significant impact on the NAR (Table 1). Carbohydrates produced by a crop plant less respiration is what is known as the net assimilation rate (NAR). A non-significant effect on NAR was also seen in the interplay of wheat cultivars and nitrogen levels. Table 1 shows that Anaj-17 had the highest NAR (6.39 g m^{-2} d^{-1}) compared to Gandam1-17 (6.16 g m^{-2} d^{-1}). NAR at 150 kg N ha^{-1}(6.61 g m^{-2} d^{-1}) was the highest, with 100 and 200 kg N ha^{-1} (6.57 g m^{-2} d^{-1} and 6.56 g m^{-2} d^{-1}) being the next highest.

Treatments	Leaf area duration	Crop growth rate	Net assimilation rate
Wheat Cultivars (C)			
Gandam1-17	270.06 A	9.84 A	6.16 B
Anaj-17	238.11 B	9.30 B	6.39 A
LSD %	6.89	0.480	0.31
Significance	**	*	NS
Nitrogen Levels (N)			
N_0 = Control	232.29 E	7.88 E	5.24 E
N_1 = 50 kg ha^{-1}	240.74 D	8.75 D	6.38 D
N_2 = 100 kg h^{-1}	253.98 C	9.67 C	6.57 B
N_3 = 150 kg ha^{-1}	277.26 A	11.18 A	6.61 A
N_4 = 200 kg ha^{-1}	266.14 B	10.37 B	6.56 C
LSD %	10.90	0.759	0.48
Significance	**	**	**
Interactions (C×N)	NS	NS	NS
Mean	254.08	9.57	6.28
CV %	3.53	6.53	6.36

Table 1: Effect of wheat cultivars and nitrogen levels on Leaf area duration, Crop growth rate and Net assimilation rate.

Data presented as means of three replicates with standard errors, means sharing same letter(s) within each parameter are statistically non-significant according to LSD Tukey test at $P < 0.05$.

Plant height

As a result of genetics and environmental factors, plant height is determined by the species under study as well as its height at the time of observation. Wheat cultivars and nitrogen levels were shown to have a substantial impact on plant height (Table 2). Wheat cultivars' interactions with nitrogen levels were determined to be insignificant. Gandam1-17 has a taller teller plant (102.81 cm) than Anaj-17 (98.05 cm). With a 150 kg N ha^{-1} application, the maximum plant height was measured (111.48 cm), while the minimum (86.20 cm) was measured with a 0 kg N ha^{-1} application at par with the 200 kg N ha^{-1} application at (107.04 cm). In order for crop plants to easily absorb nutrients, proper moisture supply was necessary for maximum plant height.

When nitrogen was administered at a rate of 140 kg ha^{-1}, plants grew taller. Differences in the varieties' genetic make-up were blamed for the height discrepancy.

Treatments	Plant height (cm)
Wheat Cultivars (C)	
Gandam1-17	102.81 A
Anaj-17	98.05 B
LSD %	4.93
Significance	*
Nitrogen Levels (N)	
N_0 = Control	86.20 E
N_1 = 50 kg ha^{-1}	93.70 D
N_2 = 100 kg h^{-1}	103.73 C
N_3 = 150 kg ha^{-1}	111.48 A
N_4 = 200 kg ha^{-1}	107.04 B
LSD %	7.79
Significance	**
Interactions (C×N)	NS
Mean	100.43
CV %	6.39

Table 2: Effect of wheat cultivars and nitrogen levels on wheat plant height.

Data presented as means of three replicates with standard errors, means sharing same letter (s) within each parameter are statistically non-significant according to LSD Tukey test at $P < 0.05$.

Yield and related trails

Number of total tillers and productive tillers

Wheat cultivars had no effect on the number of total tillers, while nitrogen levels considerably influenced the number of total tillers (Table 3). Wheat cultivars' interactions with nitrogen levels were similarly determined to be insignificant. Gandam1-17 had the most total tillers (301 m^{-2}), whereas Anaj 17 had the fewest (297 m^{-2}) total tillers. There were a greater number of total tillers in the 200 kg N ha^{-1}(338 m^{-2}) plot compared to the 0 kg N ha^{-1} plot (259 m^{-2}) (Table 3).

An important aspect of a plant's strategy is its height. To compete for light, a species' lifespan, seed mass and time to maturity all have a strong correlation with this trait. For example, cultivars and nitrogen levels were found to have a considerable impact on the number of productive tillers in Table (4.8). Wheat cultivars' interaction with nitrogen levels was determined to be non-significant. Gandam1-17 had the highest number of productive tillers (288 m^2), while Anaj-17 had the lowest number of productive tillers (274 m^2). 150 kg N ha^{-1}(315 m2) had the most productive tillers, while 0 kg N ha^{-1} had the least amount of productive tillers (244 m^2) (Table 3).

Number of grains per spike

As long as the crop had access to enough inputs (nutrients and water), it was able to produce more grains per spike. All wheat cultivars and nitrogen levels had a substantial impact on the number of grains per spike (Table 3). Wheat cultivars and nitrogen levels had no effect on grain yield per spike, according to this study. It was noted that Gandam1-17 had the most grains per spike (51) compared to Anaj-17, which had the fewest (49) (Table 3). The highest number of grains per spike (55.33) was found in treatment 150 kg N ha^{-1}(56) when compared to the rest of the fertilization treatments (Table 3).

1000-grain weight

For the evaluation of variety breeding, thousand grain weight is a critical metric. Grain yield and milling quality are directly associated, but it also has an impact on seedling vigour and growth, which indirectly affects the yield, which is an essential yield contributing element. Analysis of the data showed that wheat cultivars and nitrogen levels have a considerable impact on the weight of a thousand grains (Table 3). However, the interaction Wheat cultivars and nitrogen levels (C×N) were found non-significant (Table 3). Gandam1-17, has a higher thousand grain weight (36.11 g) than Anaj-17 (34.02 g). Only 150 kg N ha^{-1} (42.63 g) had the highest number of thousand-grain weights, while 0 kg N ha^{-1} had the lowest (24.30 g) (Table 3).

Grain yield

Grain yield in wheat and other cereals is the most essential characteristic since it is the final result of several contributing and interrelated factors. If you have a high plant density and a high tiller count and a high number of spikes per plant, you'll have a high grain yield. Wheat cultivars and nitrogen levels were found to have a substantial impact on gain yield, according to the analysis of variance table (Table 3). Grain yield was unaffected by the interplay between wheat cultivars and nitrogen levels. Anaj-17 had the lowest grain yield (3.15 ton ha^{-1}) whereas Gandam1-17 had the highest (3.38 ton ha^{-1}). In comparison to the other nitrogen treatments, 150 kg N ha^{-1} had the highest seed output (4.02 ton ha^{-1}). While the bare minimum grain production of 0 kg N ha^{-1} has been recorded (2.50 ton ha^{-1}) (Table 3).

Biological yield

In addition to grain production, farmers are concerned with strew and so biological yield is an essential consideration in crop appraisal. A plant system's entire dry matter accumulation is known as its crop biological yield. Wheat cultivars and nitrogen levels were found to have a substantial impact on biological yield in the analysis of variance (Table 3). Wheat cultivars and nitrogen levels were shown to have no effect on biological yield when combined. Gandam1-17 had the highest biological yield (10.89 ton ha^{-1}), while Anaj-17 had the lowest grain yield (10.30 ton ha^{-1}). Seed yield was highest at 150 kg N ha^{-1}, compared to other treatments, with a maximum of 12.54 ton ha^{-1}. While the bare minimum grain production of 0 kg N ha^{-1} has been recorded (8.71 kg N ha^{-1}) (Table 3).

Harvest index

Grain yield to total dry matter ratio is the harvest index. Cultivars' ability to efficiently transfer assimilates to the economic portion of a crop was measured by the harvest index. It serves as a gauge of productivity for each type of crop. HI was found to be strongly influenced by nitrogen levels (Table 3). While the main effect of cultivars and the interaction between nitrogen had no impact on harvest index. Data showed that Gandam1-17 had the highest harvest index of 30.95%, whereas Anja-17 had the lowest 30.46%. The harvest index was 32.52% higher when 200 kg N ha^{-1} was applied than when the remaining nitrogen levels were applied. The bare-bones yield was recorded as 0 kg N ha^{-1} as the bare-bones harvest index (28.77%). The more the nitrogen content, the greater the rate of growth and development; nevertheless, nitrogen concentrations above a particular point can be hazardous to plants and diminish their yield.

Treatments	Total tillers	Productive tillers	Grains per spike	1000 grain weight	Grain yield	Biological yield	Harvest index
Wheat Cultivars (C)							
Gandam1-17	301 A	288.2 A	51.47 A	36.11 A	3.38 A	10.89 A	30.95 A
Anaj-17	297 B	274 B	49.07 B	34.02 B	3.15 B	10.30 B	30.46 B
LSD %	15 C	14.57	2.42	1.85	0.19	0.51	1.45
Significance	NS	*	*	*	*	*	NS
Nitrogen Levels (N)							
N_0 = Control	259 E	244 E	40.67 E	24.30 E	2.50 E	8.71 E	28.77 E
N_1 = 50 kg ha^{-1}	286 D	268 D	51.67 C	32.80 D	2.94 D	9.46 D	31.08 C
N_2 = 100 kg h^{-1}	305 C	281.5 C	53.00 B	36.30 C	3.16 C	10.85 C	29.18 D
N_3 = 150 kg ha^{-1}	308 B	315 A	56.83 A	42.63 A	4.02 A	12.54 A	31.97 B
N_4 = 200 kg ha^{-1}	338 A	297 B	49.17 D	39.30 B	3.71 B	11.41 B	32.52 A
LSD %	24.02	23.04	3.83	2.93	0.30	0.80	2.29
Significance	*	**	**	**	**	**	**
Interactions (C×N)	NS	NS	NS	NS	NS	NS	NS
Mean	299	281.1	50.27	35.07	3.27	10.59	30.71
CV %	6.61	6.75	6.28	6.89	7.64	6.23	6.15

Table 3: Effect of wheat cultivars and nitrogen levels on yield and its related parameters.

Data presented as means of three replicates with standard errors, means sharing same letter(s) within each parameter are statistically non-significant according to LSD Tukey test at P < 0.05.

Model calibration

CERES-Wheat model necessitates the use of soil and weather management data. Cultivar coefficients must also be re-adjusted to meet the simulated and actual crop factors. For the modelling of growth and yield, the model requires seven cultivar coefficients. For accurate data modelling, the cultivars Gandam1-17 and Anja-17 must have the correct genetic coefficients. The calibrated genetic coefficients as derived by GENCALC for CERES-Wheat are given in (Table 4). Calibration of the model was successful in terms of growth and yield simulations. Data acquired during the growing season was used to calibrate the model against treatment (N level at 150 kg ha^{-1}) that produced the best results in terms of growth and yield.

Validation of model

The validation results of CERES-Wheat are described under the following subheadings

Biomass

Prediction of biomass by CERES-Wheat was satisfactory with significant R^2 (>0.90) and d-index values (around 1) for the two cultivars (Table 5). The simulated values for total biomass for Gandam1-17 was 12.995 and for Anaj-17 was 12.099 t ha^{-1}. CERES-Wheat biomass simulation results also showed that it responded well to N application rates as measured in the field experiment. Model predictions of biomass also followed a similar trend as grain yield discussed below. Deviations of predicted biomass from observed for Gandam1-17 were 2.43, 2.22, 1.86, 0.79 and 2.80% for the N0, N50, N100, N150 and N200 treatments, respectively (Table 6). In general, biomass predictions by the model were in better agreement with the observed values in Anaj-17 (MAPE = 1.9, RMSE = 19.44, d-index = 0.994). Absolute deviations of predicted from observed biomass for this cultivar were 1.29, 3.81, 1.45, 1.09 and 1.47%, respectively, for the respective N treatments (Table 5). A RMSE of 20.78 and MAPE of 2.0 was observed in the biomass predictions of the model across different N treatments and wheat cultivars (Table 5).

Cultivars	P_{mean}	O_{mean}	n	a	B	MAPE	RMSE	d-index	R^2
Gandam1-17	998.08	980.48	5	0.985	36.18	2.1	20.07	0.994	0.997
Anaj-17	1062.18	1041.26	5	0.974	43.1	1.9	19.44	0.994	0.996
Combined	1030.1	1010.9	10	0.984	35.33	2.0	20.78	0.99	0.997

Table 5: Statistical indices derived for evaluating the performance of CERES-Wheat in predicting biomass yield of different wheat cultivars.

P_{mean}: mean of predicted value, O_{mean}: mean of observed value, n: number of observations, a and b: intercept and slope of the line, MAPE: mean absolute percentage error, RMSE: root mean square error, d-index: index of agreement, R^2: coefficient of determination.

Nitrogen Levels	Cultivars	
	Anaj-17	Gandam1-17
N_0 = Control	1.29	2.43
N_1 = 50 kg ha^{-1}	3.81	2.22
N_2 = 100 kg ha^{-1}	1.45	1.86
N_3 = 150 kg ha^{-1}	1.09	0.79
N_4 = 2000 kg ha^{-1}	1.47	2.80

Table 6: Absolute per cent deviation between observed and predicted crop biomass yield at different nitrogen levels and wheat cultivars.

Grain yield

CERES-Wheat predicted satisfactory grain yield for each of the two wheat cultivars, when evaluating R^2 (degree of association) between observed and simulated values for selected variables (Table 7), grain yield has a very strong adjustment and exhibits high R^2 (>0.90), low RMSE of 0.81 and Wilmot's index of agreement (d-index) (0.99). The model predicted the final yield (product weight) which ranged between 2.36 to 4.17 t ha^{-1} and 2.44 to 4.21 t ha^{-1}

for observed and simulated data, respectively. The mean simulated value of wheat cultivar Gandam1-17 was 3.25 and for Anaj-17 was 3.44 t ha^{-1}. Grain yield simulation results showed that CERES-Wheat responded well to N application rates as measured in field experiment. In predicting grain yield, the performance of the model was best using Gandam1-17 compared to Anaj-17. Wilmot's index of agreement (d-index) values were close to 1 (>0.99) indicating good model fitting and the difference between observed and predicted grain yield is not consistent (Table 8).

Cultivars	P_{mean}	O_{mean}	n	a	B	MAPE	RMSE	d-index	R^2
Gandam1-17	3.25	3.15	5	1.009	0.03	1.9	0.69	0.996	0.99
Anaj-17	3.44	3.38	5	0.995	0.104	2.9	0.91	0.993	0.99
Combined	3.34	3.27	10	0.998	0.083	2.4	0.81	0.995	0.99

Table 7: Statistical indices derived for evaluating the performance of CERES-Wheat in predicting grain yield of different wheat cultivars.

P_{mean}: mean of predicted value, O_{mean}: mean of observed value, n: number of observations, a and b: intercept and slope of the line, MAPE: mean absolute percentage error, RMSE: root mean square error, d-index: index of agreement, R^2: coefficient of determination.

Nitrogen Levels	Cultivars	
	Anaj-17	Gandam1-17
N_0 = Control	3.37	1.29
N_1 = 50 kg ha^{-1}	3.08	1.65
N_2 = 100 kg ha^{-1}	3.52	3.06
N_3 = 150 kg ha^{-1}	1.93	0.95
N_4 = 200 kg ha^{-1}	2.43	2.33

Table 8: Absolute per cent deviation between observed and predicted grain yield.

Discussion

Nitrogen is a remarkable limiting factor for yield and yield components of wheat. Nitrogen is a key restricting component in plant growth and development, as proven by higher harvest yields following an increment in available N. Low nitrogen impacts the formation of biomass and the utilization of sun energy for plant efficiency [33]. Therefore, a deficiency of nitrogen significantly affects wheat crop performance [34]. Inadequate N fertilizer management for winter wheat production in poor countries not only decreased the nitrogen usage efficiency and economic benefits received by farmers, but also raises the risk of non-point pollution [15,35]. As a result, optimum nitrogen management with high output, low pollution, and high use efficiency is crucial to addressing these challenges and ensuring the sustainable development of winter wheat production.

Crop simulation models may help in the evaluation of nitrogen fertilizer management, improving nitrogen use efficiency, and reducing environmental contamination [36]. In this study, performance of DSSAT-CERES-Wheat model was evaluated for different wheat cultivars under various nitrogen levels in semi-arid conditions of Faisalabad.

In the field of agriculture crop simulation models have practical applications like optimization of input use, seasonal management, and spatial analysis. DSSAT model has been known to simulate wheat performance for a variety of nitrogen levels and different genotypes under diversified field conditions [37,38]. Similarly, DSSAT-CERES model has been used to simulate performance of different genotypes of maize [39,40], and various nitrogen levels for maize in semi-arid conditions of Faisalabad [41]. But the simulation for a study combining genotypes and nitrogen levels for wheat under semi-arid irrigated ecosystems of Pakistan (Faisalabad) had not been conducted before. Therefore, the current study was planned.

First of all, CERES-Wheat model was calibrated. During calibration of model, treatment having 150 kg N ha^{-1} was used for the two cultivars (Anaj-17 and Gandam1-17) as this level showed better results for yield and yield associated traits. The non-stress treatment is normally used in model calibration as some of the genetic coefficients (for example G3) in CERES-Wheat model are based on non-stress plant growth. Similar results were reported by Mubeen., *et al*. [40]; they showed that an optimum treatment irrigation at 25 mm potential soil moisture deficit (PSMD) for the two hybrids was used for model calibration as this treatment had no water stress. The calibration results showed that Absolute per cent deviation between observed and CERES-Wheat predicted crop biomass for this treatment was 1.09% and 0.79% for Anaj-17 and Gandam1-17, respectively. Similarly, the deviation for grain yield was 1.93% and 0.95% for these cultivars. The performance of CERES-Wheat was satisfactory with significant R^2 (>0.90) and d-index values (around 1) for the two cultivars regarding biomass and grain yield (Tables 5 and 7). These results are in line with Sarwar et al (2012) who reported that maximum grain yield and total dry matter were obtained in wheat when 150 kg N ha^{-1} was applied. Hammad., *et al.* [42] also found that 150 kg N ha^{-1} was the best treatment regarding yield and total dry matter in wheat.

After calibration, the DSSAT-CERES-Wheat was evaluated against all the treatments of nitrogen for the two cultivars separately. Different growth variables including time course leaf area index (LAI) and total dry matter (TDM) production and subsequently derived leaf area duration (LAD), crop growth rate (CGR) and net assimilation rate (NAR) all have their role in healthy or otherwise growth of the wheat plants. Similarly, developmental variables of yield traits including days to anthesis, number of productive tillers, number of grains per spike, 1000-grain weight and days to maturity all contribute towards the economic yield i.e. grain yield. So, in our study, all these variables were taken into consideration. Actually, the CERES-Wheat model uses all the growth and developmental stages as input in A and T files and simulates the grain yield based on all these inputs [43].

Leaf area index (LAI) is the main physiological determinant of the crop yield [44]. Regarding time course leaf area index, various nitrogen levels showed different growth pattern. Nitrogen level of 150 kg ha^{-1} (N3) showed highest LAI followed by 200 kg ha^{-1} (N4) (Figure 2A). Similarly, highest time course TDM was produced by 150 kg ha^{-1} (Fig. 3A). Among derived variables, maximum LAD (277 days) was recorded for N3 and the lowest was found for N1 i.e. 0 kg ha^{-1} (Table 1). Nitrogen application, 150 kg N ha^{-1} demonstrated the highest CGR (11.18 mg m^{-2} d^{-1}) that fell short of 200 kg N ha^{-1} (10.37 g m^{-2} d^{-1}) (Table 1). Regarding NAR, highest NAR was found at 150 kg N ha^{-1} (6.61 g m^{-2} d^{-1}), with 100 and 200 kg N ha^{-1} (6.57 g m^{-2} d^{-1} and 6.56 g m^{-2} d^{-1}) being the next highest (Table 1). Enhanced photosynthetic capacity of leaves and improved plant nutrition may be responsible for an increase in net assimilation rate. In a study conducted by Sultana., *et al*. [45], the peak LAI was the highest at 220 kg N ha^{-1} and lowest value was recorded at control (0 kg N ha^{-1}), and peak LAI was measured at booting stage. Many researchers [45-47], concluded that increases in red reflectance were associated with the decrease in chlorophyll resulting from lower N supply; decrease in NIR reflectance mostly responded to decreases in LAI and green biomass.

Regarding wheat cultivars, maximum LAI was measured for Gandam1-17 at about 75 days after sowing (Figure 2) and maximum time course TDM was found in Gandam1-17 (Figure 3). Similarly, maximum LAD (270 days), maximum CGR (9.84 g m^{-2} d^{-1}) were recorded in Gandam1-17, but NAR was higher in Anaj-17 (6.39 g m^{-2} d^{-1}) (Table 1), this was due to difference of genetic variability of different cultivars [44].

When we talk about validation of DSSAT-CERES-Wheat model for yield associated traits, it was found that the prediction of biomass was satisfactory with R2 value greater than 0.90 and d-index of about 1. Low values of RMSE (20.78) and MAPE (2.0) were observed in the biomass predictions of the model across wheat cultivars when combined together (Table 5). Similarly, absolute percent deviation ranged from 1.09 to 3.81% for Anaj-17 and this range was 0.79 to 2.80% for Gandam1-17. Similar results were found by Nasim., *et al*. [48], who reported good simulation of total dry matter by CERES-Wheat for different cultivars.

Similarly, in grain yield prediction, the model results were satisfactory. RMSE value of 0.81 and MAPE of 2.4 were observed in the grain yield predictions across the five N regimes and two wheat cultivars (Table 7). Timsina and Humphreys [49] have reviewed the performance of CERES-Wheat across several locations and reported satisfactory predictions of grain yield. Relatively good agreement between observed and simulated data for both grain yield using CERES-Wheat was reported by [21].

Degree of stress may be assessed in terms of yield losses. The higher the yield loss, the greater would be the stress and vice versa. The good simulation of the model may be evaluated based on this yield gap analysis which is calculated by taking difference between simulated yield under non-limiting conditions (taken as reference level) and observed yield under different treatment combinations

[38]. Departure of predictions from observed values were 1.29, 1.65, 3.06, 0.95 and 2.33 % for the 0, 50, 100, 150, and 200 (calibration) kg N ha^{-1} treatments, respectively, in Gandam1-17 (Table 8). Grain yields in Anaj-17, were also well predicted by the model, the deviations of simulations from the observations in this cultivar were 3.37, 3.08, 3.52, 1.93 and 2.43% for the 0, 50, 100, 150, and 200 treatments, respectively. Results showed that lower yield gap for both Gandam1-17 (0.95%) and Anaj-17 (1.93%) were obtained at nitrogen level (N3= 150 kg ha^{-1}) indicating that the CERES-Wheat model was able to simulate grain yield by best performing at this N regime.

Conclusions

Results concluded from study validate that different wheat cultivars and various nitrogen levels have a remarkable effect on crop growth and yield of the wheat crop. Gandam1-17 at 150 kg N ha^{-1} produced the highest grain yield due to high TDM production. While the remaining treatments had decreased the wheat yield and yield contributing components. So, 150 kg N ha^{-1}in combination with Gandam1-17 was found to be best for getting maximum yield. The CERES-Wheat model was assessed by difference of observed versus simulated growth and yield parameters. Mean percent difference and percent error were used to analyze the model results. They showed the good results for model simulations. For leaf area index, crop biomass and grain yield model computer-generated products were very good. This study can help farmers of the semi-arid environment to calculate the optimum different cultivars for maximum economic return from wheat.

Supplementary Materials

The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Table S1: Effect of wheat cultivars and nitrogen levels on leaf area index (Analysis of variance). Table S2: Effect of wheat cultivars and nitrogen levels on total dry matter (g m^{-2}) (Analysis of variance)

Author Contributions

Conceptualization, M.A. and A.W.; methodology, A.W.; software, A.M and A.J.; validation, A.J., Z.Q. and A.Z; formal analysis, A.J, A.W and M.A.; investigation, M.A.; resources, A.Z.; data curation, A.J. and M.A; writing-original draft preparation, M.A and A.Z.; writing-review and editing, A.J, Z.Q, M.A, E.R and M.F.S.; visualization, A.J and R.M.; supervision, A.W.; project administration, M.A.; funding acquisition, A.J and E.R. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Data Availability Statement

Not applicable.

Acknowledgments

We gratefully acknowledge Dr. Muhammad Rehan (Department of Agronomy, The University of Agriculture, Faisalabad, Pakistan) for his technical help throughout the writing of this manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Bibliography

1. Khan I., *et al*. "Partial Substitution of Chemical Fertilizers with Organic Supplements Increased Wheat Productivity and Profitability under Limited and Assured Irrigation Regimes". *Agriculture* 12 (2022): 1754.
2. Ul Haq I., *et al*. "Timing and Splitting of Nitrogen Compensated for the Loss in Grain Yield of Dual-Purpose Wheat Under Varied Cutting Heights". *Gesunde Pflanzen* (2022): 1-16.
3. Khosravi V., *et al*. "The effect of different sowing dates on yield and yield components of wheat (Triticum aestivum L.) cultivars". *International Journal of Agronomy and Plant Production* 1 (2010): 77-82.
4. Zhang Z., *et al*. "Split nitrogen fertilizer application improved grain yield in winter wheat (*Triticum aestivum* L.) via modulating antioxidant capacity and 13C photosynthate mobilization under water-saving irrigation conditions". *Ecological Processes* 10 (2021): 1-13.
5. Azam BMA and Ali E. "Effects of salt and nitrogen on physiological indices and carbon isotope discrimination of wheat cultivars in the northeast of Iran". *Journal of Integrative Agriculture* 19 (2020): 656-667.
6. Rumesh R and Rajbir Y. "Targeting nitrogen use efficiency for sustained production of cereal crops". *Journal of Plant Nutrition* 42 (2019): 1086-1113.
7. Gao X., *et al*. "Grain concentrations of protein, iron and zinc and bread making quality in spring wheat as affected by seeding date and nitrogen fertilizer management". *Journal of Geochemical Exploration* 121 (2012): 36-44.

8. Hussain MI., *et al*. "Growth, yield and quality response of three wheat (*Triticum aestivum* L.) varieties to different levels of N, P and K". *International Journal of Agriculture and Biology* 4 (2002): 362-364.

9. Hochman Z and Horan H. "Causes of wheat yield gaps and opportunities to advance the water-limited yield frontier in Australia". *Field Crops Research* 228 (2018): 20-30.

10. Rahman KA and Zhang D. "Effects of fertilizer broadcasting on the excessive use of inorganic fertilizers and environmental sustainability". *Sustainability* 10 (2018): 759.

11. Jamal A and Fawad M. "Effectiveness of phosphorous fertilizers in wheat crop production in Pakistan". *Journal of Horticultural Plant Research* 5 (2019): 25-29.

12. Yousaf M., *et al*. "The effect of nitrogen application rates and timings of first irrigation on wheat growth and yield". *International Journal of Agriculture Innovations and Research* 2 (2014): 645-665.

13. Shiferaw B., *et al*. "Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security" 5 (2013): 291-317.

14. Trost BPA., *et al*. "Effects of irrigation and nitrogen fertilization on the greenhouse gas emissions of a cropping system on a sandy soil in Northeast Germany". *European Journal of Agronomy* 81 (2016): 117-127.

15. Tan Y., *et al*. "Effects of optimized N fertilization on greenhouse gas emission and crop production in the North China Plain". *Field Crops Research* 205 (2017): 135-146.

16. Santis MAD GM., *et al*. "Impact of nitrogen fertilisation strategies on the protein content, gluten composition and rheological properties of wheat for biscuit production". *Field Crops Research* 254 (2020): 107829.

17. Abedi T., *et al*. "Effect of organic and inorganic fertilizers on grain yield and protein banding pattern of wheat". *Australian Journal of Crop Science* 4 (2010): 384-389.

18. Shahzad K and Akmal M. "Yield performance of wheat under split n application rates and timing". *Sarhad Journal of Agriculture* 33 (2017): 350-356.

19. Usman K., *et al*. "Impact of tillage and nitrogen on cotton yield and quality in a wheat-cotton system, Pakistan". *Archives of Agronomy and Soil Science* 60 (2014): 519-530.

20. Booltink H., *et al*. "Tools for optimizing management of spatially-variable fields". *Agricultural Systems* 70 (2001): 445-476.

21. Singh AK., *et al*. "Evaluation of CERES-Wheat and CropSyst models for water-nitrogen interactions in wheat crop". *Agricultural Water Management* 95 (2008): 776-786.

22. Wajid A., *et al*. "Crop models: Important tools in decision support system to manage wheat production under vulnerable environments". *Agriculture* 11 (2021): 1166.

23. Mohanty M., *et al*. "Ecosystems; environment. Simulating soybean–wheat cropping system: APSIM model parameterization and validation" 152 (2012): 68-78.

24. Confalonieri R., *et al*. "The CropSyst model to simulate the N balance of rice for alternative management". *Agronomy for Sustainable Development* 26 (2006): 241-249.

25. Jones JB. "Laboratory guide for conducting soil tests and plant analysis". CRC press (2001).

26. Jamal A., *et al*. "Performance of Wheat (*Tricticum avestium* L.) as influenced by application of single super phosphate alone and in combination with different organic fertilizers in calcareous soil of Swabi, Pakistan". *Kahramannaraş Sütçü İmam univ doğa bilim derg* 22 (2019): 14-18.

27. Saeed MF., *et al*. "Optimizing phosphorus levels in wheat grown in a calcareous soil with the use of adsorption isotherm models". *Journal of Soil Science and Plant Nutrition* 21 (2021): 81-94.

28. Hunt L., *et al*. "GENCALC: Software to facilitate the use of crop models for analyzing field experiments". *Agronomy Journal* 85 (1993): 1090-1094.

29. Ritchie J and Otter S. "Description and performance of CERES-wheat: A user-oriented wheat yield model. USDA-ARS, Grassland". *Soil and Water Research Laboratory, Temple, TX* (1984).

30. Ritchie J., *et al*. "Cereal growth, development and yield". In Understanding options for agricultural production; Springer (1998): 79-98.

31. Hunt L and Pararajasingham S. "CROPSIM-WHEAT: A model describing the growth and development of wheat". *Canadian Journal of Plant Science* 75 (1995): 619-632.

32. Hunt L and Boote K. "Data for model operation, calibration, and evaluation. In Understanding options for agricultural production; Springer (1998): 9-39.

33. Heinemann AB., *et al*. "Canovas Efficiency of solar radiation use on wheat productivity due to nitrogen fertilization Solar radiation use efficiency on the wheat grain yield as a function of nitrogen fertilizer". *Bras J Agric Environ Engg -Agriambi* (2006).

34. Sarwar M., *et al*. "Comparison of Bt and non-Bt cotton (*Gossypium hirsutum* L.) cultivars for earliness indicators at different sowing dates and nitrogen levels". *Journal of Agriculture Research* (2012): 50.

35. Si Z., *et al*. "Optimizing nitrogen application for drip-irrigated winter wheat using the DSSAT-CERES-Wheat model". *Agricultural Water Management* 244 (2021): 106592.

36. Zhang D., *et al*. "DSSAT-CERES-Wheat model to optimize plant density and nitrogen best management practices". *Nutrient Cycling in Agroecosystems* 114 (2019): 19-32.

37. Khan GR., *et al*. "Split Nitrogen Application Rates for Wheat (*Triticum aestivum* L.) Yield and Grain N Using the CSM-CERES-Wheat Model". *Agronomy* 12 (2022): 1766.

38. Pokhariyal S., *et al*. "Yield Gap Analysis under Different Water and Nitrogen Management Practices in Wheat Crop using CSM-CROPSIM-CERES-Wheat Model in Tarai Region of Uttarakhand". *International Journal of Current Microbiology and Applied Sciences* 9 (2020): 317-324.

39. Mubeen M., *et al*. "Evaluating CSM-CERES-Maize Model for Irrigation Scheduling in Semi-arid Conditions of Punjab, Pakistan". *International Journal of Agriculture and Biology* (2013): 15.

40. Mubeen M., *et al*. "Application of CSM-CERES-Maize model in optimizing irrigated conditions". *Outlook on Agriculture* 45 (2016): 173-184.

41. Khaliq T., *et al*. "Modeling nitrogen use efficiency of maize cropping systems in Pakistan". In Proceedings of the Proceedings of the International Annual Meeting of ASACSSA-SSSA (2007): 4-8.

42. Hammad HM., *et al*. "Comparative effects of organic and inorganic fertilizers on soil organic carbon and wheat productivity under arid region". *Communications in Soil Science and Plant Analysis* 51 (2020): 1406-1422.

43. Pathak H., *et al*. "Simulation of Nitrogen Balance in Rice–Wheat Systems of the Indo-Gangetic Plains". *Soil Science Society of America Journal* 70 (2006): 1612-1622.

44. Mubeen M., *et al*. "Evaluating different irrigation scheduling criteria for autumn-sown maize under semi-arid environment". *Pakistan Journal of Botany* 45 (2013): 1293-1298.

45. Sultana SR., *et al*. "Normalized difference vegetation index as a tool for wheat yield estimation: a case study from Faisalabad, Pakistan". *The Scientific World Journal* (2014).

46. Fernandez S., *et al*. "Radiometric characteristics of Triticum aestivum cv, Astral under water and nitrogen stress". *International Journal of Remote Sensing* 15 (1994): 1867-1884.

47. Penuelas J., *et al*. "Cell wall elasticity and water index (R970 nm/R900 nm) in wheat under different nitrogen availabilities". *International Journal of Remote Sensing* 17 (1996): 373-382.

48. Nasim W., *et al*. "Simulation of different wheat cultivars under agro-ecological condition of Faisalabad-Pakistan". *Crop and Environment* 1 (2010): 44-48.

49. Timsina J and Humphreys E. "Performance of CERES-Rice and CERES-Wheat models in rice–wheat systems: a review". *Agricultural Systems* 90 (2006): 5-31.