ELEVATION OF WHEAT CULTIVARS AT VARIOUS LEVELS OF NITROGEN THROUGH FIELD EXPERIMENTATION AND MODELING APPROACH IN PUNJAB, PAKISTAN

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ABSTRACT: The present study was conducted to evaluate the growth of wheat cultivars at different nitrogen (N) levels through experimental and crop simulation model in Sialkot District of Punjab, Pakistan. The data was collected from the fields as well as the weather and soil data obtained from the relevant departments. The experiment was conducted for two wheat cultivars with four treatments of N i.e. 0, 55, 110, 220 kg N per hector. Overall, the results indicated that the field level observed data showed significantly positive correlation with the model simulated growth and yield variables. The findings of this study showed that out of the two wheat cultivars i.e. Faisalabad-2008 showed earlier anthesis and maturity as compared to the Sehar-2006, however, the wheat yield, leaf area index, and harvest index was higher for Sehar-2006. From these results, it can be concluded that Sehar-2006 has more productivity and must be encouraged as compared to Faisalabad-2008.

Keywords: Anthesis; climate; food security; harvest; nitrogen; wheat yield.

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INTRODUCTION

Wheat is the key cereal crop of Pakistan covering an area of nine million hectares and contributes 10 % in agriculture sector and 2% in Gross Domestic Production (GDP) (Pakistan Economic Survey, 2017; Yu *et al*., 2017; Government of Pakistan (GOP), 2019). The total cultivation and production area of wheat in Pakistan is highly inconsistent mainly because of two main factors i.e. climatic challenges such as temperature and shift in the rainfall patterns (GoP, 2013). The provincial wheat production area during the year 2016-2017 was highest for Punjab i.e. 6.75 million hectares, followed by Sindh (1.17 M Ha), Khayber Pakhtun Khawa (KPK) (0.74 M Ha) and Baluchistan (0.39 M Ha). Overall wheat contributes 10 % in agriculture sector and 2% in (GDP) (Pakistan Economic Survey, 2017). According to the United State Department of Agriculture (USDA) report (2017) during the year 2017-2018 the wheat, area has decreased mainly due to the dry conditions and low soil moisture contents during the months of September to December. This is particularly in rain-fed areas where the rains are recorded to be less. However, the production is expected to be higher despite of decrease in production area by the use of fertilizers. Wheat flour contributes 72 % of Pakistan's daily caloric intake with per capita wheat consumption of around 124 kg per year, one of the highest in the world. During 2016, domestic wheat prices remained stable and price of the price wheat flour in 2016 was almost the same as in 2015.

The input data required to run the Decision Support System for Agro-technology Transfer (DSSAT) models include daily weather data, i.e., maximum and minimum temperature, rainfall, and solar radiation; soil characterization, including its physical, chemical, and morphological properties for each soil horizon; cultivar coefficients (genotype and phenotype); and crop management information such as plantation/ sowing dates, number and quantity of irrigation application, row and plant spacing, rates, dates and amounts of fertilizer. The model can also calculates the soil N balance as well as N leeching and uptake by the plant (Ahmad *et al*., 2015: Godwin and Singh 1998). Globally a wide range of crop simulation models is used for wide range of applications to assess alternative crop management options (Jones *et al*. 2003; Hoogenboom *et al*. 2000). Crop Simulation Model (CSM) is a dynamic, process-oriented model that stimulates crop growth, development, and yield for a wide range of food and other crops, including rice, wheat and maize (Ahmad *et al*. 2011). The DSSAT model has been adopted as research tool for the evaluation of performance of various cropping patterns, production techniques and managing practices (Jones *et al*., 2003; Shelia *et al*., 2018).

The excessive consumption of N fertilizer is globally a crucial factor for wheat productivity and its sustainable production from both economic and environmental perspectives (Yazdanpanah *et al*., 2016; Zhao *et al*., 2016). It has been observed that Pakistan stands forth in N fertilizer usage however; the mean yield in terms of N use efficiency is decreasing (Rahim *et al*., 2020). N stress is considered as one of the primary driver behind Pakistan Rice-wheat yield gaps which leads to increase in N-fertilizer use (Khaliq *et al*., 2019). However, the increase in nitrogen leaching (mainly in the form of nitrate) in ground water lead to the contamination of drinking water aquifers whereas, leaching in surface water may cause eutrophication and other disturbance in ecosystems. There is less available information and guidance on acceptable N-leaching concentrations in Pakistan, however, the ground water nitrate is above permissible limits for human consumption in 70% of shallow and deep wells of Southern Punjab (Khan *et al*., 2019; Donald, S., 2021). Therefore, there is a dire need to increase N management practices to enhance the efficiency and decrease impacts on soil and environment such as water leaching. This research has been conducted with the objective of evaluating the effects of different concentrations of N fertilizer on two wheat cultivars in Punjab, Pakistan and evaluation of their output through both experimental and simulation model.

METHODOLOGY

Study Area: Punjab is a major wheat production region of Pakistan with 75.5% of farmland area i.e. 6.96 M ha (Pakistan Statistical Bureau, 2019). The wheat-rice cropping system predominates in this region and the winter wheat crop, known as “Rabi crop.” is sown during November and December and harvested in April or May. The present study was conducted in the Sialkot District of Punjab located around a latitude of 32.381° N, a longitude of 74.49° E, and at an elevation of 249 m above sea level with a total area of 3,016 km^2 (GoP, 2017). There are four municipalities (Tehsils) in Sialkot and 152 villages. The land is generally plain and fertile for agriculture. The majority of the area is rural, i.e., 74.2%, and only 25.8% is urban. The dominant crop in the region is wheat, grown on approximately 209,000 ha and with an annual average total production of 536,000 Mt (GoP, 2019). The weather pattern in this region varies from hot and humid during the summer to cold during the winter, with an average annual precipitation of 1,000 mm. This study area was selected because climate change projections indicate a high vulnerability to extreme weather events such as flash floods, extreme heat waves and changes in precipitation patterns (Bashir and Schilizzi, 2015; Ahmed *et al*., 2015).

Soil Data: The soil data was collected from the Soil Fertility Lab, Lahore. This area falls under the Sialkot series containing brown to dark brown silty clay. The drainage potential is moderately well with moderately high runoff potential and fertility level as 1. The chemical characteristics of top three layers of soil are presented in Table 1.

Design of Field experiment: The field experiment was conducted in plots with four rows and each row was sub divided into eight sub plots to plant two wheat cultivars i.e. Faisalabad-2008 and Sehar-2006 with different N concentration in each sub-plot. The row space was 30 cm. dry seeds of both wheat cultivars were sowed on same date i.e. 15th Nov. 2018 in already prepared soil. Three flood irrigations were applied on dates 21st Dec. 2018, 29th Jan. 2019, and 21st Feb., 2019 with 100 mm. Urea fertilizer was applied in different concentrations i.e. N1 (0 N kg ha^{-1}), N2 (55 N kg ha^{-1}), N3 (110 N kg ha^{-1}) and N4 (220 N kg ha^{-1}). In N2, N3 and N4 the urea was applied in in three equal quantities on 25th Nov, 2018, 20th Dec., 2018, and 24th Jan., 2019.

Table 1: Chemical characteristics of soil.

Depth (cm)	pH (Sat. Paste)	$CaCO_3$ (%)	Organic Matter (%)	CEC (dSm^{-1})	HCO_3^{-1} ($meqL^{-1}$)	Ca+2Mg+2 ($meqL^{-1}$)	Cl^{-1} ($meqL^{-1}$)	SO_4^{-2} ($meqL^{-1}$)
0-15	7.0	0.00	0.81	24.9	1.6	6.4	0.8	7.3
15-26	7.0	0.00	0.40	12.9	1.4	4.4	0.9	3.8
26-43	7.3	0.50	0.30	20.1	1.8	2.8	0.8	1.5

Crop Development Observations: After sowing of seeds daily observations were made and seedling emergence was recorded for each treatment and average days to emergence and average days of physiological maturity of these plants were calculated from the sowing date. The harvested plants were taken and dried in oven at 70°C, weighted and converted into kg ha^{-1}. The wheat grains from the crop were separated and dried to calculate the total grain yield and converted into kg ha-1. The harvest index (HI) is the ratio of grain yield and total dry matter yield as adopted by Hunt (2012). The leaf area was measured using the leaf area meter (Model Licor 3100, LI-COR inc. Lincoln, NE) and LAI was calculated by using the formula as adopted by Breda (2003).

$$HI=\frac{Grain\ Yield}{Total\ Dry\ Matter}\ X100$$

$$LAI = \frac{Leaf\ Area}{LAnd\ Area}.$$

Experimental Data collection: A list of wheat farmers in the four municipalities in the Sialkot District was obtained from the local Agriculture Office. The farmers that were available during this time period were randomly selected from 13 different villages from the four municipalities, including four from Daska, two from Pasrur, two from Sambrial, and five from Sialkot 5 (Figure 1). A representative sample of farmers were chosen from landowners who had more than ten years of farm experience. The questionnaires were written in the local language so that the farmers could fully understand and respond to all the questions. A total of 185 questionnaires were distributed in person (45-46 questionnaires in each municipality) between September and November of 2018. We selected this time period for data collection because it coincided with the preparatory and sowing stages for wheat and thus farmers were easily approachable during the sowing phase. When surveys were distributed, the purpose of conducting this study and questions were briefly explained in the local language. For those farmers who were illiterate, the questions from the questionnaire were discussed through an interview by a data collector. The questionnaires were collected in person the following day, with some flexibility in the return date. The return rate for questionnaires was 81%, i.e., the total questionnaires that were returned was 150. After rejecting the invalid questionnaires (N= 22) and incomplete questionnaires (N = 28), the remaining questionnaires (N= 100) were analyzed.

Meteorological Data: The weather station in Sialkot is the only weather station in the study area and is located around a latitude of 74.53 °E, a longitude of 32.50 °N and at an elevation of 2,560 m. Long-term historical weather data for the period from 1988 to 2018 for minimum and maximum temperature and precipitation were obtained from the Punjab Meteorological Department to analyze climate change trends.

Crop Growth Model: The DSSAT Cropping System Model (CSM)-CERES-Wheat requires input files i.e. X file containing experimental file including treatments, farm level practices, crop management such as irrigation and fertilizer application, and simulation controls, the weather file contained weather station data for the year 2018-2019 i.e. Temperature maximum and minimum (°C), solar radiations (MJ m-2 day-1), rainfall (mm), S-File containing soil physical and chemical characteristics, A-file containing the filed data with final observations and T file containing data with time course (Hoogenboom *et al*., 2017; Basso *et al*., 2016; Peng *et al*., 2018).

Model Calibration and evaluation: Calibration and evaluation are key steps in application of CSM-CERES-Wheat model. Model calibration requires the field experiment based results. The vegetative and phonological wheat coefficients were find out starting from P1V (days, optimum vernalizing temperature), P1D (Photoperiod Response), P5 (Grain filling), and PHINT (interval between successive leaf tip appearance), whereas the growth coefficients were G1 (Kernel# per unit canopy weight at anthesis), G2 (Standard canopy size), G3 (Standard, non-stressed mature weight). Two types of wheat cultivars i.e. Faislabad-2008 and Sehar-2006 were selected for this study. These cultivars were selected on the bases of high percentage of farmers growing these varieties. Faislabad-2008 is grown by 51% of the farmers under 34% of total area sown by wheat, which is the highest, and Sehar-2006 is grown by 10.8% of the farmers under 6.5% of wheat cultivation area. Moreover, the Faisalabad-2008 has highest adaptation in Punjab than other cultivars i.e. 83.12% during the year 2013-2014, whereas Sehar-2006 has 20.76%, which determines farmers are adopting cultivation of these cultivars over others (Iqbal *et al*., 2016). These coefficients of both cultivars are presented in table below:

Table 2: Coefficient Values of Wheat Cultivars.

Cultivar Type	P1V	P1D	P5	G1	G2	G3	PHINT
Faisalabad-2008	22	41	596	31	28	1.3	70
Sehar-2006	11	45	476	37	24	2.0	66

RESULTS

Weather/ Climate variables: The weather pattern for the study duration indicate that mean monthly maximum solar radiations were in the month of September i.e. 20.47 MJ m^{-2} day^{-1} and minimum where in January i.e. 8.65 MJ m^{-2} day^{-1}. The mean monthly maximum temperature was observed in September and minimum in January i.e. 34.44 °C and 16.88 °C respectively. The maximum mean monthly rainfall was during the month of January i.e. 1.92 mm and three months i.e. November, December, and April were with minimal (0 mm) rainfall (Figure 2).

Days to Anthesis: The comparison of observed and simulated results for days to anthesis showed a positive correlation for both cultivars (Figure 3). It can be observed from the results that comparatively wheat cultivar Faisalabad-2008 showed early anthesis as compared to Sehar-2006.

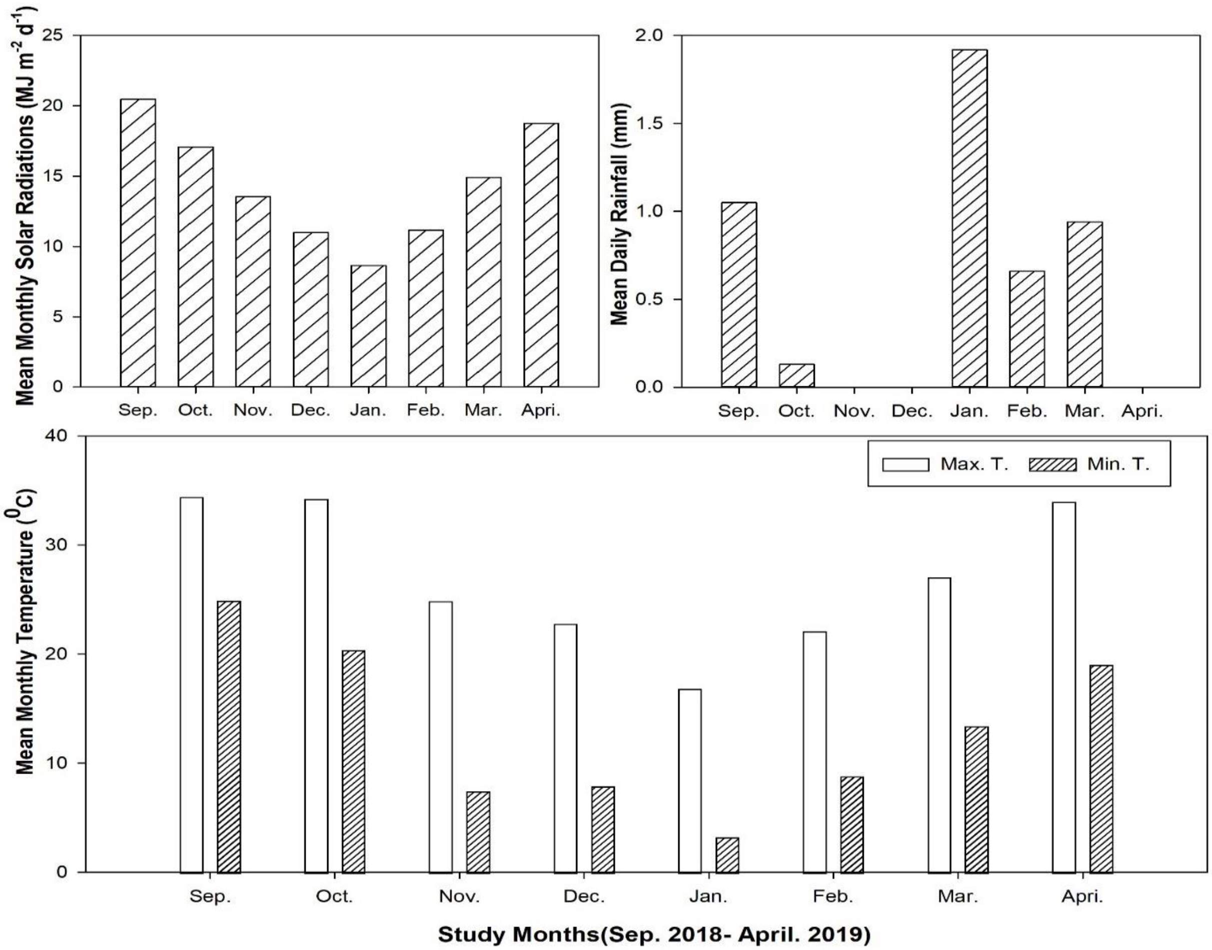

Figure 2: Meteorological parameters for the wheat growth season (2018-2019), Sialkot, Pakistan

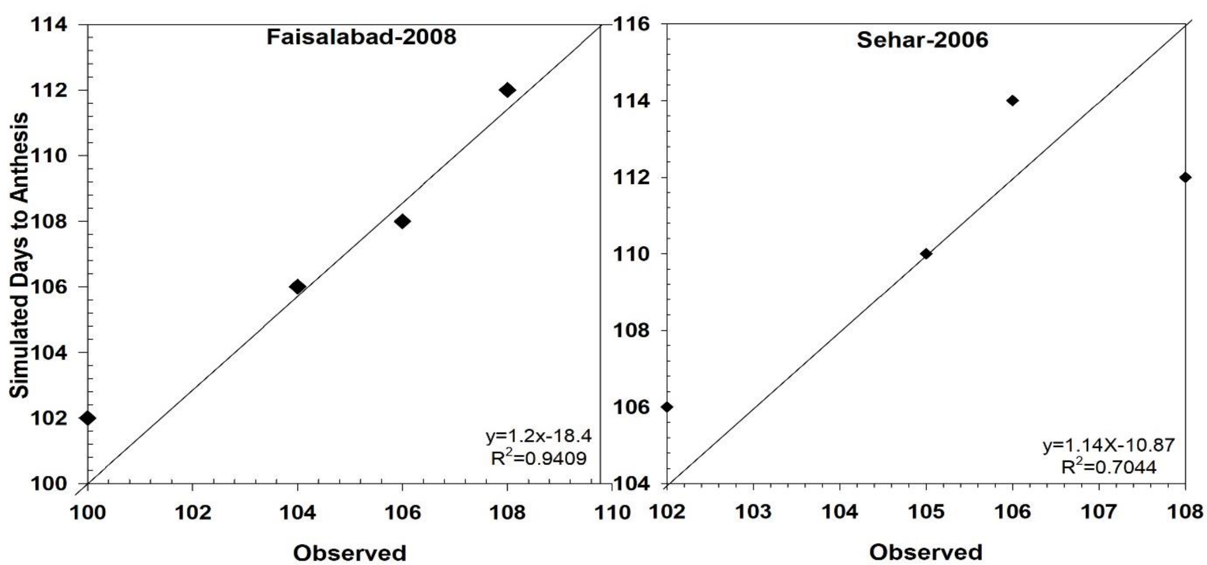

Figure 3: Comparison of Days to Anthesis

Days to Maturity: The comparison of observed and simulated results for days to maturity of wheat cultivars Faisalabad-2008 and Sehar-2006 showed a positive correlation for both cultivars. It can be observed from the results that comparatively wheat cultivar Faisalabad-2008 showed early maturity as compared to Sehar-2006.

Wheat Production: The comparison of observed and simulated results for wheat production (kg/ha) showed a positive correlation for both cultivars. It can be observed from the results that comparatively wheat cultivar Sehar-2006 showed more productivity as compared to Faisalabad-2008.

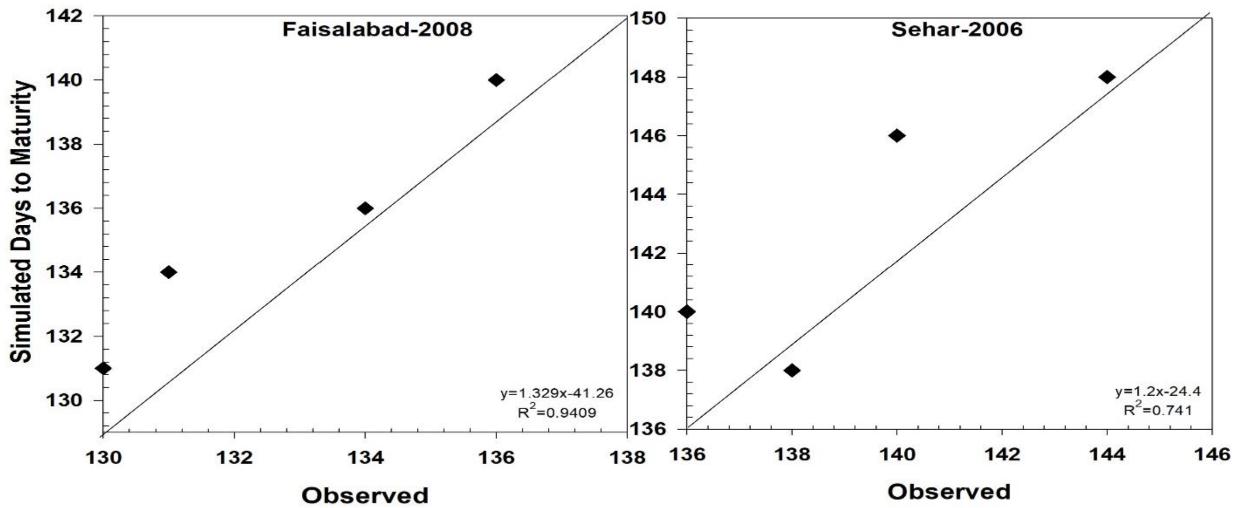

Figure 4: Comparison of Days to Maturity

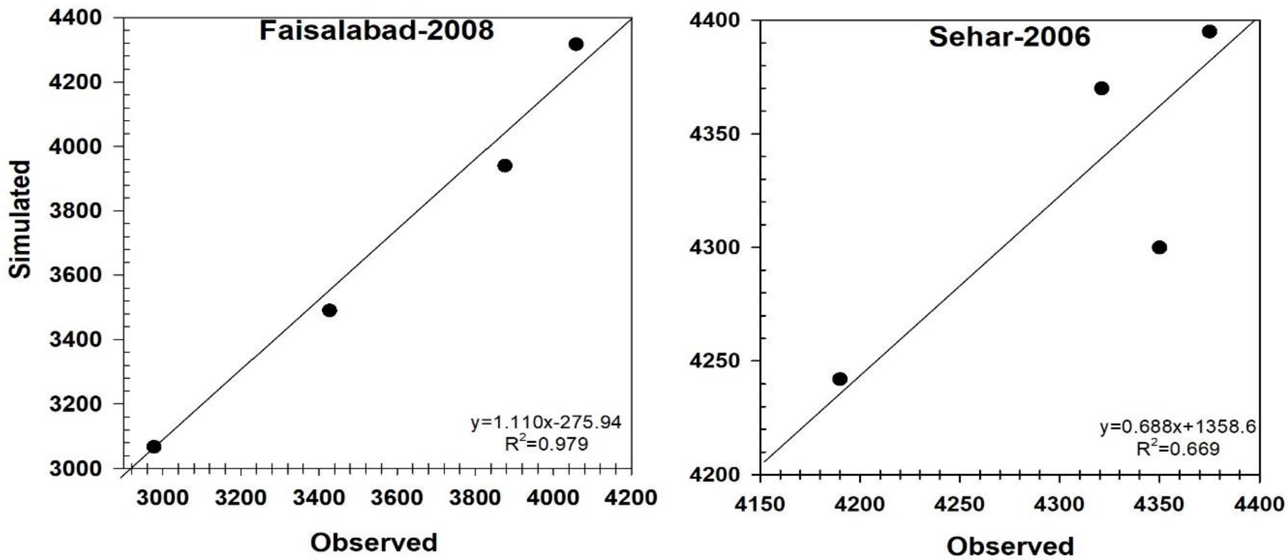

Figure 5: Comparison of Wheat yield (Kg ha^{-1})

Maximum Leaf Area Index: The comparison of observed and simulated results for Maximum Leaf Area Index (MLAI) showed a positive correlation for both cultivars. It can be observed from the results that comparatively wheat cultivar Sehar-2006 showed higher LAI as compared to Faisalabad-2008. The MLAI was observed in Sehar-2006 i.e. 5.94.

Harvest Index: The comparison of observed and simulated results for Harvest Index (HI) showed a positive correlation for both cultivars. It can be observed from the results that comparatively wheat cultivar Sehar-2006 showed higher HI as compared to Faisalabad-2008. The maximum HI was observed in Sehar-2006 i.e. 0.56.

Nitrogen Treatments: The result of wheat simulation under four different N treatments indicated that with increase in N application there was increase in all the variables i.e. yield, grain number per meter square, HI and MLAI, for both wheat cultivars i.e. Faisalabad-2008 and Sehar-2006. Less variation was found between both cultivars, moreover, it was found that the cultivar Faisalabad-2008 showed higher productivity (5959 kg ha^{-1}) as compared to Sehar-2006 (5465 kg ha^{-1}) at 220 kg N application. The highest grain number were for cultivar Faisalabad-2008 (21283/m^2) and Sehar-2006 (22771/m^2) at 220 kg N application and lowest for Faisalabad-2008 (10226/m^2) and Sehar-2006 (11375/m^2) at 0 kg N application. The results indicated that the HI for both cultivars was maximum at N-55 kg i.e. 0.59 and 0.57 for Faisalabad-2008 and Sehar-2006 respectively and at higher concentrations of N the HI decreased. The maximum LAI for Faisalabad-2008 (7.2) and Sehar-2006 (6.4) was observed at N 110 kg and N 220 kg respectively.

Nitrogen Leaching and uptake: The results indicated that the N- leaching both wheat cultivar was maximum at Treatment 2 i.e. 55 kg Nha^{-1} i.e. Faisalabad-2008 (20.85 kg ha^{-1}) and Sehar-2006 (21.01 Kg ha^{-1}). The lowest leaching of 2.36 and 2.40 N kg ha^{-1} for Faisalabad-2008 and Sehar-2006 respectively was observed with no application of N. Similarly, the N uptake by wheat cultivars (Faisalabad-2008) was highest for 220 $kgNha^{-1}$ and 160.53 $kgNha^{-1}$ (Sehar-2006), and lowest at no application of N i.e. Faisalabad-2008 (59.46 $kgNha^{-1}$) and Sehar-2006 (56.21 $kgNha^{-1}$).

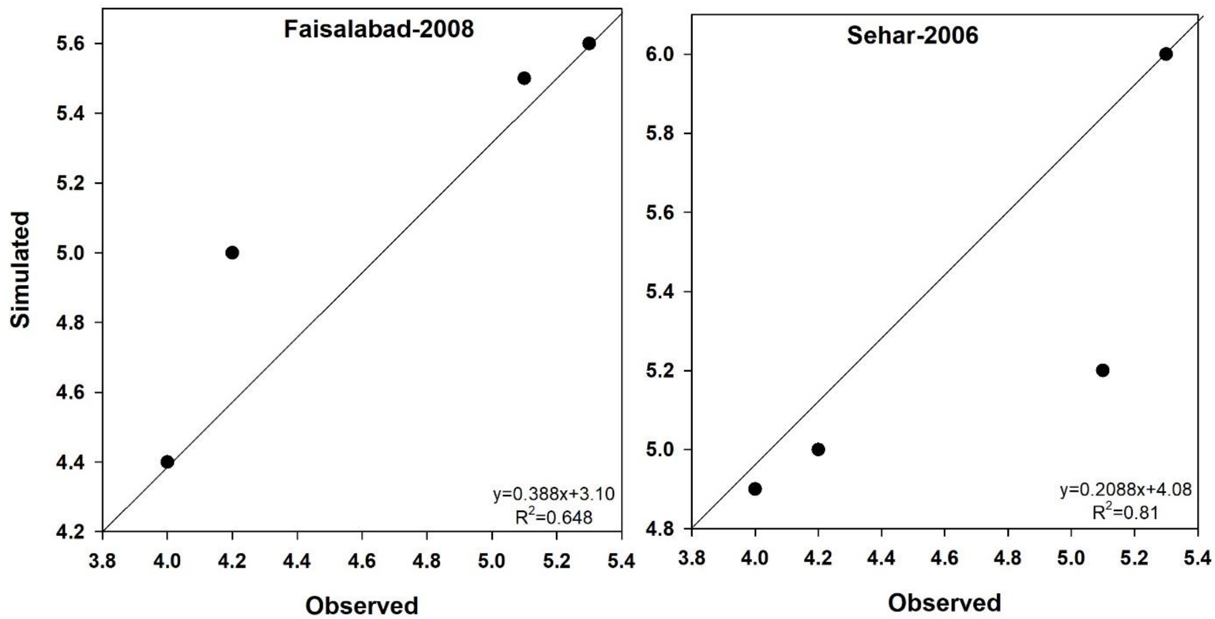

Figure 6: Comparison of Maximum Leaf Area Index

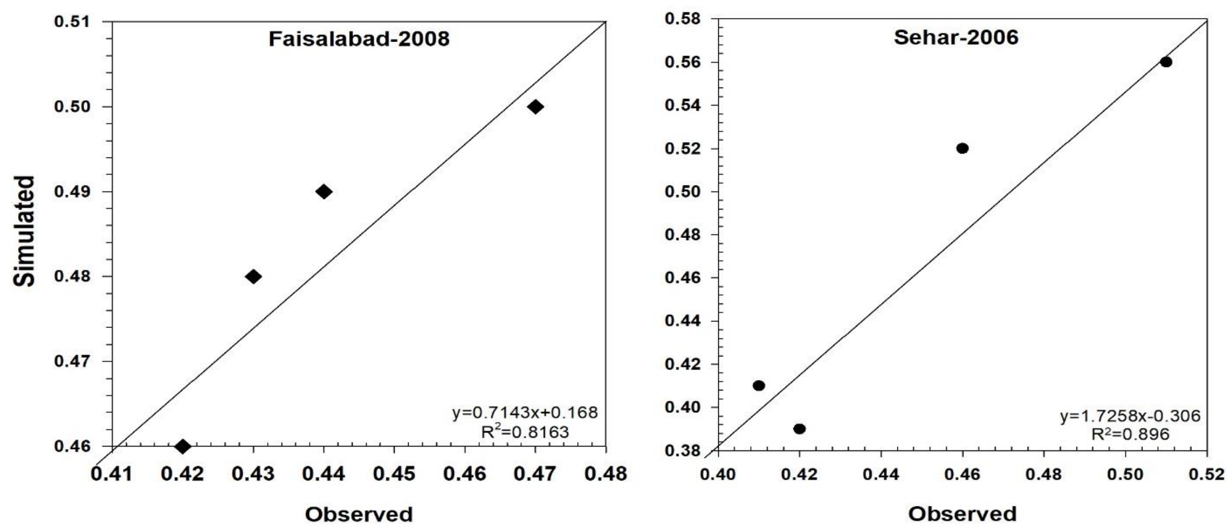

Figure 7: Comparison of harvest index

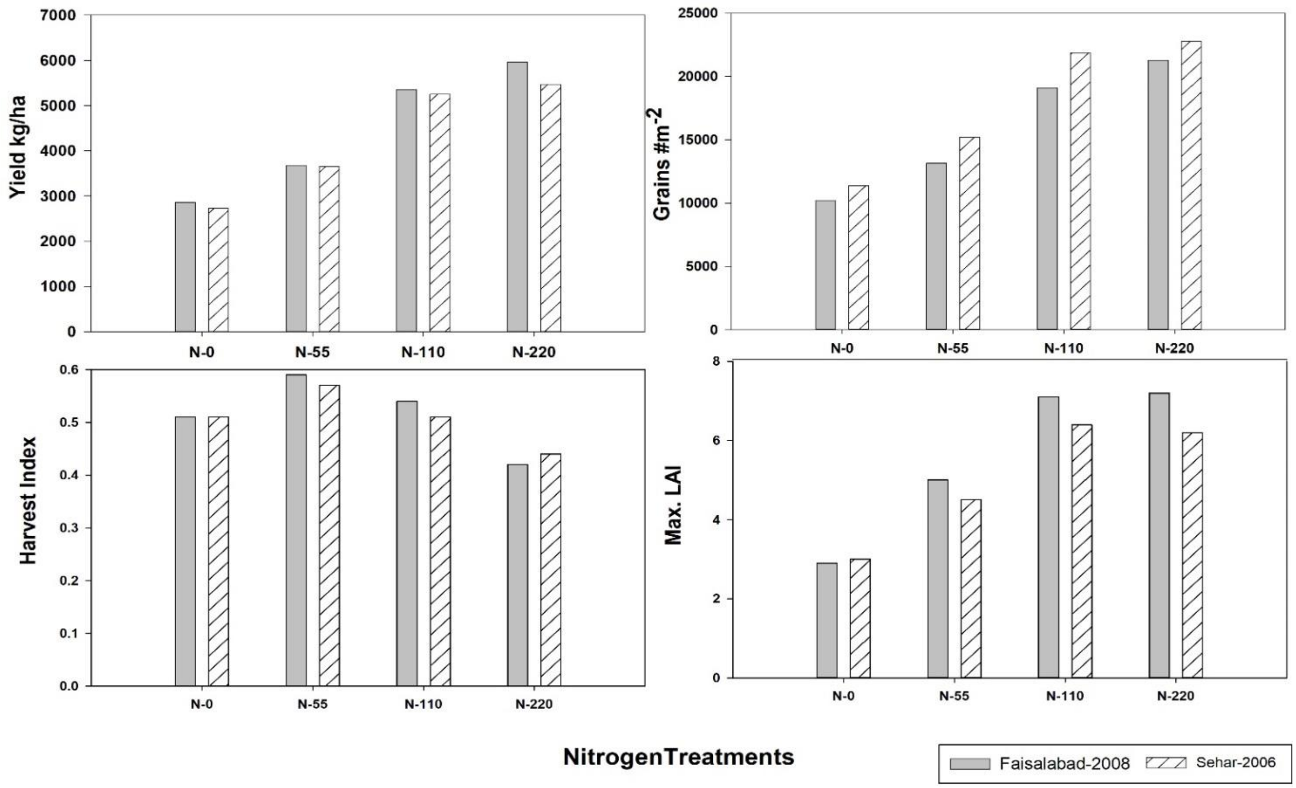

Figure 8: Simulation of Wheat Cultivars variables at different N- treatments

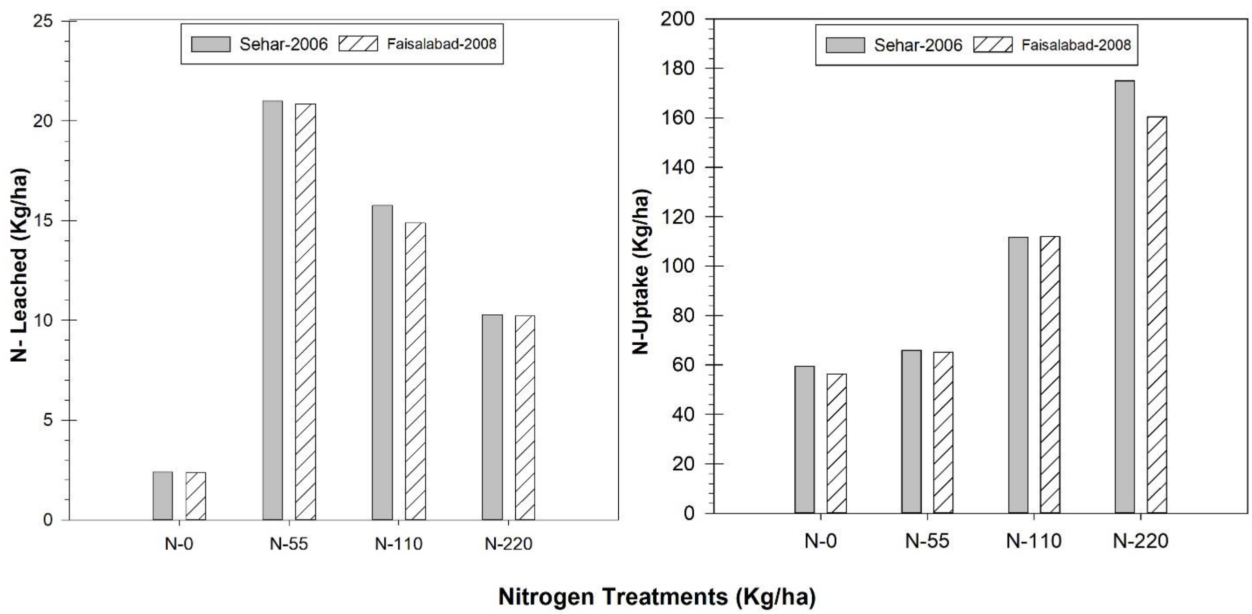

Figure 9: Simulation of Wheat Cultivars Nitrogen Leaching and uptake at different N- Levels

DISCUSSION

The overall weather trend in study area during the Rabi season 2018-19 was suitable for wheat growth. The highest solar radiations and maximum temperature during the month of September to November are suitable for sowing and emergence. The report by National Agromet Centre (2014-15) mentioned that high temperature and no rainfall during the months of sowing helps in early emergence of wheat. Similarly, the rainfall during the months of January- March are highly favorable for wheat as during this the wheat crops shooting, heading, milking to wax maturity is occurring. The National Agro met Centre (2014-15) mentioned that the optimum temperature of wheat is 30-32°C while the biological zero is 0-5 °C. The wheat cultivar Faisalabad-2008 showed early anthesis and maturity as compared to Sehar-2006 with a difference of 4 and 8 days respectively. However, the wheat yield was higher for Sehar-2006 i.e. 4242-4370 kg/ ha (Simulated) and 4190-4375 kg ha^{-1} (Observed) as compared to Faisalabad-2008 i.e. 3067-4317 kg ha^{-1} (Simulated) and 2978-4058 kg ha^{-1} (Observed). These results indicates that although the Faisalabad-2008 showed early emergence and crop maturity still Sehar-2006 has higher wheat yield and productivity. The positive correlation of observed and simulated values indicate highly adoptability of the model under present environmental and climatic conditions. The findings of Latif *et al*. (2017) found that in PunjabFaisalabad-2008 is most popularly cultivated wheat variety sown at an area of 34 % whereas; Sehar-2006 has a popularity of 10.8% sown on area of 6.5%. Moreover, the findings of Ali *et al*. (2017) suggested that Faisalabad-2008 must be encouraged as it is more disease (rust) resistant (2.2%) as compared to the other common wheat cultivars i.e. Sehar-2006 (31%), Inqilab-91 (40%), Millat-2001 (25%). Economically the adaptation of farmers to the Faisalbad-2008 has more economical benefits as compared to Sehar-2006 and other cultivars. According to the findings of Latif *et al*. (2017) during the Rabi season 2011-12 to 2012-13 Faisalabad 2008 gave 172.08% more economical benefits followed by 183.72% in year 2012-13 to 2013-14, whereas the Sehar-2006 showed 16% and 20.76% economical change during the same years. According to the studies it has been observed that about 90% of agricultural land in Pakistan is deficient in soil N and phosphorous, also 50% Punjab’s soil has lesser concentrations of Potassium and other essential micronutrients compared to the recommended concentrations.

In general, 90% agricultural soil of Pakistan is deficient in N and phosphorous, and 50% of soil has lesser potassium and other micronutrients than the recommended value. Results of present study suggested that amount of N in all soil samples was less than the recommended amount for healthy growth of plants.

Conclusion: From the present study, it can be concluded that the output of crop simulation models are positively correlated to the observed field values, indicating the model adoptability for further studies. The application of N concentrations indicated an increase with increase in crop growth variables and in overall wheat yield. The Sehar-2006 showed more wheat yield and grain number per m^2 as compared to the Faisalabad-2008, however the cultivar Faisalabad-2008 has early emergence, maturity and other growth variables like LAI and HI were higher as compared to Sehar-2006. The increase in N application increased the nitrogen leaching and plant uptake. Overall, Faisalabad-2008 must be encouraged in Punjab to increase the wheat productivity.

Conflict of Interest: The authors proclaim no conflict of interest.

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