Effects of Nitrogen Rate, Ratio, and Timing on Agronomic Parameters of Winter Wheat

Muhammad Saleem Kubar[1], Kashif Ali Kubar[2], Mehar un Nisa Narejo[3], Shafique Ahmed Memon[4], Abdul Hafeez Mastoi[2], Habib Rehman Lakho[2], Bakhtiyar Ali[2], Abdul Wahab[5], Zuhaib Saleem Memon[6]

[1]Department of Crop Cultivation and Farming System, College of Agronomy, Shanxi Agriculture University, Jinzhong, 030801, Shanxi P.R. China.

[2]Faculty of Agriculture, Lasbela University of Agriculture, Water and Marine Sciences, Uthal 90150, Balochistan-Pakistan.

[3]Department of Crop Physiology, Faculty of Crop Production, Sindh Agriculture University, Tandojam, Sindh, Pakistan.

[4]Department of Entomology, Faculty of Crop Protection, Sindh Agriculture University, Tandojam, Sindh, Pakistan.

[5]Directorate of Agriculture Research Zehri Khuzdar, Balochistan.

[6] Department of Soil Science, Sindh Agriculture University, Tandojam, Sindh, Pakistan.

*** Correspondence:** msaleemkubar@yahoo.com, kashifkubar@luawms.edu.pk

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Efficient nitrogen (N) fertilizer management is pivotal for enhancing agronomic indices while ensuring sustainable agricultural practices. This study explored the effects of different nitrogen levels (0, 75, 150, 225, and 300 kg N ha^{-1}), application ratios 5:5 (50% + 50%) and 6:4 (60 + 40%) and timing (jointing, flowering, and grain filling stages) on agronomic parameters of winter wheat. The results revealed that the 225 kg N ha^{-1} treatment at a 6:4 ratio performed significantly better than other treatments across growth parameters. At this optimal rate and ratio, plant height, aboveground dry biomass (AGDB), leaf dry weight, and stem dry weight were significantly higher compared to lower (75 kg N ha^{-1}) or excessive (300 kg N ha^{-1}) applications. Plant height exhibited an increasing setup up to 27.30% at jointing, 24.34% at flowering, and 33.13% at grain filling under 225 kg N ha^{-1} at 6:4. Aboveground biomass followed a similar trend, achieving a 66.90% increase at jointing under 225 kg N ha^{-1}, while leaf and stem dry weights reflected the vigorous contribution of nitrogen rates and ratios, particularly at jointing and flowering stages. Leaf area dynamics and leaf area index (LAI) further validated these findings, peaking at the flowering stage for 225 kg N ha^{-1} at 6:4. The results emphasize the importance of optimizing N fertilizer rates, ratios, and application timing to improve crop growth dynamics and productivity. The results provide appropriate evidence for sustainable nitrogen management, application of nitrogen at 225 kg N ha^{-1} and a 6:4 ratio as an effective approach to maximize agronomic performance in winter wheat while mitigating

environmental impacts. These results contribute novel perspectives to nitrogen use efficiency and influence practical recommendations for precision agriculture.

Keywords: Nitrogen, Ratios, Rates, Dry biomass, Fresh biomass, Growth stages

Introduction:

Crop production is expected to increase significantly in 21st-century agriculture, driven by a growing global population, which is predicted to reach 9.4 billion people by 2050 [1][2]. Wheat provides over 20% of human calories, making it one crucial dietary source. Thus, there is a dire need to increase wheat yield. Since the 1960s, harvest index has been considered a key factor to enhance grain production, It measures the quantity of total dry matter distributed to harvested grains [3][4][5]. Many studies highlight that increases in the harvest index (HI), rather than increases in dry matter (DM), are currently the primary drivers of future gains in wheat production. Generally, the remobilization of stem and leaf dry matter (DM) along with the absorption of photosynthetic products supplies the necessary nutrients for grain filling [6][7][8]. The response to nitrogen availability was uniform across both older and newer maize hybrids, with the disparity in dry matter accumulation between maize cultivated under elevated and reduced nitrogen conditions attributed to consistently higher leaf carbon exchange rates and chlorophyll content throughout the grain-filling phase [9]. Grain and total dry matter yield show considerable positive responses to N rates, according to [10][11][5] reported that winter wheat treated with 112 kg of nitrogen per hectare (N ha^{-1}) produced 30% more dry matter compared to the unfertilized crop. Three nitrogen fertilizer rates, specifically 0, 45, and 90 kg N ha^{-1}, were evaluated in a pot trial, yielding an increase of 34 kg dry matter for each additional 1 kg N ha^{-1} [12][13]. Consequently, the findings of these studies show that nitrogen fertilizer is essential to the state's effective winter wheat farming.

According to many scholars, the relative shortage of nitrogen required for optimal production may be mitigated by having greater aboveground biomass [14][15][16][17][18]. The formation of biomass, however, requires adequate leaf area (LAI), which is greatly influenced by nitrogen rates, total dry matter, and associated parameters, including the obliteration coefficient and captured photosynthetic active radiation [19]. In agriculture and environmental research, leaf area index and canopy analysis are crucial variables that are frequently used as reference plant indices for tracking crop growth, forecasting grain output, and improving crop management techniques [20][21][17]. Dry matter buildup in crops occurs as a result of photosynthetic production, which is heavily influenced by the properties of the canopy leaves. The main factors influencing matter accumulation and grain yield are leaf area, its duration, and the photosynthetic rate [22][23][24].

Nitrogen (N) management is a critical factor in winter wheat production, influencing crop growth, development, and ultimately, grain yield. The effects of nitrogen rate, ratio, and timing on agronomic parameters of winter wheat have been extensively studied [1][6][5]. Optimizing N application is essential for maximizing wheat productivity while minimizing environmental impacts. Research has shown that N rate, ratio, and timing can significantly impact wheat growth and yield [11][18]. For example, excessive N application can lead to lodging and reduced grain quality [25], while inadequate N can limit yield potential [26]. Understanding the interactions between N management and wheat agronomic parameters is crucial for developing effective N management strategies.

This study is significant as it investigates the impact of nitrogen fertilizer rates on wheat yield, dry matter accumulation, and leaf area index, addressing the pressing need to increase wheat production to meet the demands of a growing global population. By exploring the effects of different nitrogen fertilizer rates on wheat growth and productivity, this research will contribute to the development of more efficient and sustainable agricultural practices. The findings of this study will have implications for improving crop management techniques, predicting grain output, and promoting environmental sustainability in agriculture, ultimately enhancing food security and supporting the livelihoods of millions of people dependent on wheat production.

Objectives:

The main objectives of this study are stated below:

1. To evaluate the impact of varying nitrogen fertilizer levels, application ratios (5:5 and 6:4), and timing (jointing, flowering, and grain filling stages) on key agronomic indices such as plant height, aboveground dry biomass, leaf area, and leaf area index in winter wheat under field conditions.
2. To identify the optimal nitrogen management strategy, including rate, ratio, and application timing, that maximizes winter wheat growth and yield while minimizing the adverse effects of over-fertilization, thereby promoting sustainable and efficient agricultural practices. By investigating these objectives, this research not only advances our understanding of nitrogen dynamics in winter wheat but also provides practical, actionable insights for achieving higher crop productivity and sustainability, while addressing critical challenges such as nitrogen overuse and environmental conservation.

Materials and Methods:

Experimental Locations:

Field experiments for this study were conducted at Shanxi Agricultural University's Taigu experimental agricultural station in Shanxi Province, China (N 37°25', E 112°33') (Figure 1) The research area experiences temperate continental monsoon weather, characterized by mean annual temperatures of 13°C or 12°C, mean annual rainfall ranging from 442 mm to 600 mm, potential evapotranspiration levels of 1840.2 mm and 1872.2 mm, and sunshine durations of 2672 hours and 2697 hours at the Taigu base, respectively. The area under investigation, characterized by a semiarid climate typical of the Northeast Loess Plateau, consists of a hilly arid field that receives 60% to 70% of its annual rainfall during the seasonal months, particularly throughout the fallow season from July to August. The soil in the established field exhibits a pH of 7.7 and contains 51.12 mg kg^{1} of available nitrogen, 19.34 mg kg^{1} of available phosphorus, and 7.7 mg kg^{1} of surface organic matter. Figure 2 represents the flow chart of the research methodology, and Figure 3 presents the monthly average rainfall, the number of rainy days, and the minimum, maximum, and mean temperatures.

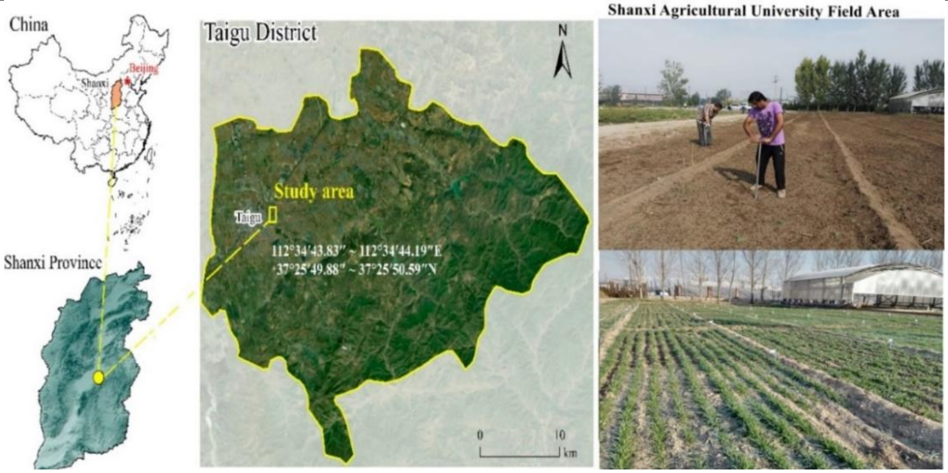

Figure 1. Experimental area of the study

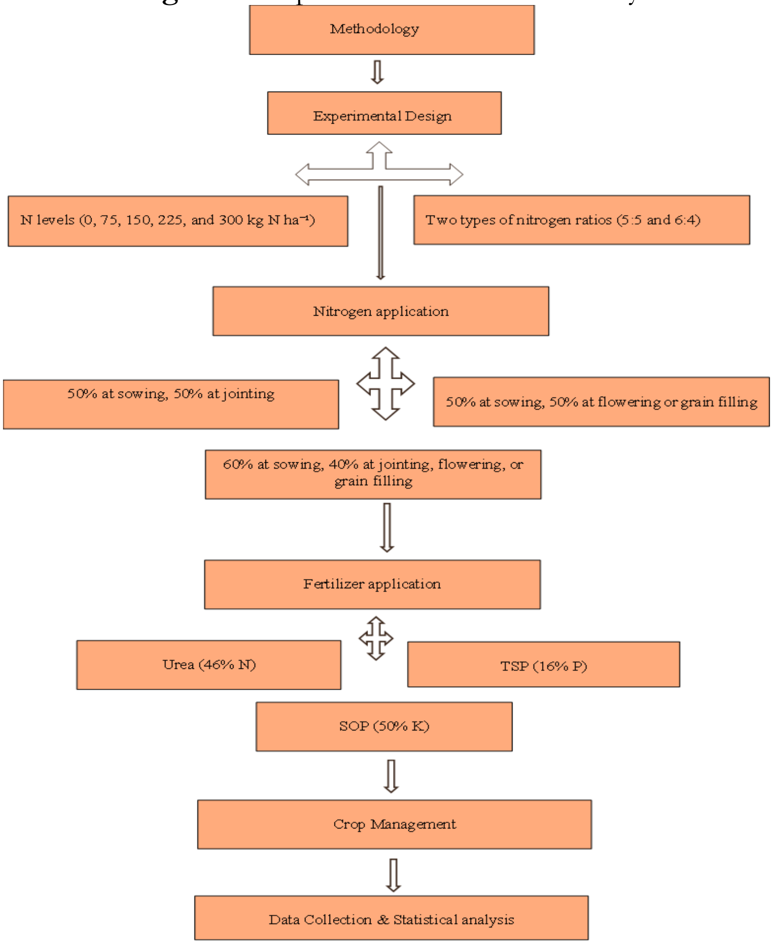

Figure 2: Flow chart of research methodology

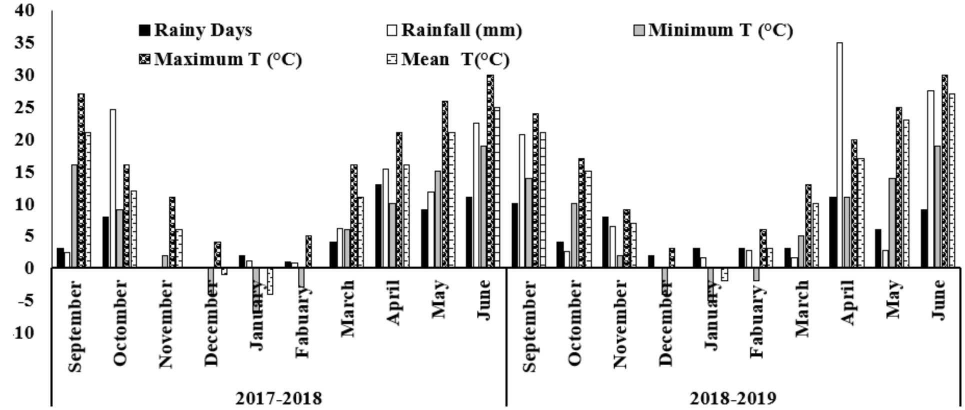

Figure 3. Monthly rainy day, rainfall, minimum temperature, maximum temperature, and mean temperature of 2017-2018 to 2018-2019 at Shanxi Agricultural University.

Treatment Detail:

The trials were conducted using a split-plot design, with three repeats. Main plots consisted of total nitrogen (N) levels, including control (no fertilizer applied), 75, 150, 225, and 300 kg N ha^{-1}. Subplots contained two types of nitrogen ratios: one is 5:5 (50%, 50%), and another is 6:4 (60%, 40%). The subplots were arranged according to different nitrogen application timing ratios to assess their impact at various growth stages. For the 5:5 ratio (50%:50%), nitrogen was applied in three distinct patterns: 50% at the jointing stage and 50% at the following stage (50%:50%:0%:0%), labeled as 5+5; 50% at the jointing stage and 50% at the flowering stage (50%:0%:50%:0%), also labeled as 5+5; and 50% at the jointing stage with the remaining 50% applied at the grain filling stage (50%:0%:0%:50%), again labeled as 5+5. Similarly, for the 6:4 ratio (60%:40%), nitrogen was distributed as follows: 60% at the jointing stage and 40% immediately after (60%:40%:0%:0%), labeled as 6+4; 60% at the jointing stage and 40% at the flowering stage (60%:0%:40%:0%), labeled as 6+4; and 60% at the jointing stage with 40% applied at the grain filling stage (60%:0%:0%:40%), also labeled as 6+4. These treatments allowed for a detailed evaluation of nitrogen timing and its effects on crop performance. Nitrogen fertilizer was applied both as a basal dose and as top dressing at different growth stages of winter wheat using two distinct methods. In the first method, 50% of the nitrogen was applied at sowing and the remaining 50% at the jointing stage. The second method involved splitting the nitrogen application with 50% at sowing and 50% at later stages, specifically either at the flowering stage or during the grain filling stage. The second method involves applying 60% at sowing time, followed by 40% at the jointing stage, 60% at sowing time, followed by 40% at the flowering stage, and 60% at sowing time, followed by 40% at the grain filling stage, respectively. The experimental plots measured 12 m² each (3 m × 4 m), and each treatment was arranged with three replications to ensure reliability and statistical validity of the results. A total of 75 plots were utilized in the experiment, where urea (46 %) served as the nitrogen source and was applied before the planting of the crop. Phosphorus was applied in the form of triple super phosphate (16%) at a rate of 120 kg per hectare, while potassium was applied as potassium chloride (50%) at a rate of 60 kg per hectare during the planting period. The experimental investigation involved cultivating the Jintai 182 variety before winter wheat sowing, with a sowing rate of 95 kg ha^{-1}. Plants were collected on June 15 and June 21, 2019, after winter wheat was planted on September 31, 2017, and October 1, 2018. Data was gathered during the 20–25-day field gap in March, April, and May.

Winter wheat treatment schedules and nitrogen fertilizer ratios were shown (Table 1). Using Shanxi province's traditional methods, all other agricultural operations, including weed management, irrigation, disease and pesticide application, and crop growth stage and demand, were completed constantly according to schedule

Table 1. Nitrogen fertilizer ratios and application timing of winter wheat

Ratio	Label	Sowing	Jointing	Flowering	Filling
0	0	0	0	0	0
	5+5	50%	50%	0	0
5+5	5+5	50%	0	50%	0
	5+5	50%	0	0	50%
	6+4	60%	40%	0	0
6+4	6+4	60%	0	40%	0
	6+4	60%	0	0	40%

Growth and Biomass Characteristics:

A sample of winter wheat was obtained from the location where the photosynthetic rate was assessed. Winter wheat samples, each 20 cm in length, were collected from every plot. The collected trials were swiftly returned to the research laboratory for measurement. Above-ground biomass, comprising leaves, stems, and spikes, was systematically segregated. Measure the fresh weight (g) of a winter wheat plant using an electronic balance, then convert this measurement to winter wheat per unit area (kg N ha^{-1}). Winter wheat plants were placed in a Kraft paper bag and subjected to an oven temperature of 105 °C for 30 minutes. The material was then subjected to baking at 80 °C for 24 hours until a constant weight was attained. The weight (g) of the dried wheat was converted into above-ground biomass, encompassing leaves, stems, and spikes dry weight biomass per unit area (DWB, kg m^{-2}) using the standard dry weight method [5].

Plant height (cm): The heights of three plants were measured in centimeters from the base to the tip, and the average height was calculated thereafter.

Leaf Area Index: The Leaf Area Index (LAI) of winter wheat was evaluated under different nitrogen ratios and application timings across various treatments during the jointing, flowering, and grain-filling stages in both years. To achieve this objective, 20 cm winter wheat plants were collected from the main rows of all sub-blocks, ensuring a minimum interval of one rhythm from the previous sampling. We measured the leaf distance of winter wheat plants using a ruler to adjust the leaf area. Leaf area was previously calculated by multiplying leaf length and width by a constant of 0.75, reflecting the proportion of the winter wheat leaf zone to the ground zone. Leaf area duration (LAD) was determined by computing the following the equation.

$$\text{LAD} = \frac{\text{LAI1} + \text{LAI2 x 2}}{\text{T2} - \text{T1}}$$

Where, L_1 = LAI at 1^{st} stage, L_2 = LAI at 2^{nd} stage T_2 and T_1 = Time intervals between 1^{st} and 2^{nd} stage in days

Statistical Analysis:

This study presents the data as the mean of three replicates. Data analysis was conducted using Analysis of Variance (ANOVA) within a randomized block design framework. The significance of each source of variation was evaluated using the F-test. For post hoc mean separation, Duncan's Multiple Range Test (DMRT) was applied at a significance level of $P < 0.05$. All statistical analyses were performed using SAS software version 9.3 (SAS Institute, Cary, North Carolina, USA). Treatments were assessed for significant differences utilizing the least significant difference (LSD P< 0.05 method. The Shapiro-Wilk test was performed to assess the normality of variance before the ANOVA analysis. Microsoft Excel 2013 was used for data computation, and graphical illustrations were created using Origin 8.5. Statistical evaluations were conducted with SPSS version 19.0, while advanced statistical tests and analyses were carried out using SAS version 9.3.

Results and Discussion:

Impact of Nitrogen Management on Plant Height*:*

The size of winter wheat plants is primarily determined by the genetic makeup of the variety, although it is also influenced by the quality and quantity of inputs applied. Among various growth parameters, plant height is of particular significance and is often correlated with grain yield. The results on the variability in plant height of winter wheat variety Jintai 182, influenced by soil nitrogen application (Table 2), indicate that the height of Jintai 182 was increased by the addition of nitrogen in varying amounts. In the calculation, it was observed that as the amount of topdressing fertilizer was increased, the plant height decreased; however, the N ratio of 6:4 was higher than that of the 5:5 ratios under middle fertility conditions during the years 2017-2018 and 2018-2019. The average plant height of winter wheat at various growth stages in both high and low-productivity environments ranged from 23.34% to 27.30% during jointing, 23.39% to 24.34% at flowering, and 33.13% to 19.46% at the grain-filling stage. These measurements were taken under the treatment of 225 kg N ha^{-1} with a 6:4 nitrogen ratio, in comparison to the 5:5 ratio. Additionally, when nitrogen fertilizer was applied in plots at the jointing stage, comparisons were made with applications of 150 and 300 kg N ha^{-1}, respectively. The optimal outcomes were observed with the application of 225 kg N ha-1 at a 6:4 ratio across various growth stages, yielding results ranging from 59.85 to 63.57 at jointing, 98.42 to 89.65 at flowering, and 105.42 to 99.13 during the grain filling stage. This was particularly evident when nitrogen was applied at the jointing stage over both years, in comparison to the 150 and 300 kg N ha^{-1} treatments, respectively. Furthermore, our findings indicate that there are variations in decrease and increase across different growth stages, influenced by various treatments and ratios. Overall, minimal results were observed at the treatment levels of 300 and 75 kg N ha^{-1} in comparison to the CK plots. Variance analysis indicated that the nitrogen application rate and ratios significantly influenced plant height, and the interaction between nitrogen treatments and ratios was also noteworthy (Table 11. The above results suggest that excessive application of nitrogen fertilizer, along with additional basal and topdressing nutrients, can lead to excessive plant elongation, increased stem length, and even a reduction in grain number. The results indicated that both the quality and quantity of nitrogen fertilizer play a crucial role in promoting healthy plant growth. Crops sown with lower quantities of nitrogen were unable to achieve their full growth potential or yield.

'5+5 and 6+4' signifies 50% and 50%, as well as 60% and 40% respectively. JS refers to the jointing stage, FS denotes the flowering stage, and GFS indicates the grain-filling stage. Mean values in a separate column that share similar letters are not significantly different at $p < 0.05$. The values represent the mean ± standard error (SE).

Influence of Nitrogen Management on Plant Above-Ground Dry Biomass:

During the different growth stages, the aboveground biomass exhibited distinct dynamic changes across the various treatments and nitrogen ratios (Table 3). Throughout the various growth stages, the aboveground dry biomass (AGDB) increased as the nitrogen supply improved, with values ranging from 22.62% to 66.90%, 44.24% to 49.35%, and 16.36% to

27.45% under the 6:4 ratio compared to the 5:5 ratio. These changes were observed with a treatment of 225 kg N ha¹ at the jointing, flowering, and filling stages across individual years, in contrast to the 300 kg N ha¹ and 150 kg N ha¹ treatments. This was particularly noted when nitrogen was applied at the jointing stage, with minimal variances observed among the treatments and ratios in both years compared to CK, as a result. The changes in ratios and treatments were observed to culminate at the end of the growth period. The maximum AGDB was achieved with 225 and 300 kg N ha^{-1} of nitrogen at the high and low ratios and treatments, respectively. The variance analysis results indicated that nitrogen treatment significantly influenced plant dry biomass, and the interaction between nitrogen treatments and the ratio was also noteworthy (Table 2). These outcomes were concerning during the grain filling period, likely due to the winter wheat spikelets filling under nitrogen-poor conditions rather than nitrogen-rich conditions.

Table 2. Effect of nitrogen fertilizer management on plant height (cm) of winter wheat

N rates (kg ha-1)	The ratio of fertilizer	Timing of fertilizer	2017-2018			2018-2019		
			JS	FS	GFS	JS	FS	GFS
Ck	0	0	48.52±2.21d	79.76±1.65d	79.18±1.76d	49.94±2.24d	72.10±1.34d	82.98±1.55d
	5+5	JS	51.90±1.30d	82.93±3.66d	83.94±1.12d	51.04±1.22d	74.94±2.76d	86.46±2.87c
	5+5	FS	51.32±1.09d	82.87±2.65d	82.05±1.76d	51.84±1.89d	73.90±2.81d	84.90±1.54c
	5+5	GFS	50.58±1.22d	82.83±2.32dc	81.90±1.65d	51.75±1.65d	75.94±2.43c	87.15±1.21c
75	6+4	JS	53.51±0.76d	89.48±2.67c	86.47±0.76c	54.45±1.21c	79.78±2.36c	89.18±3.72c
	6+4	FS	52.44±3.54d	85.84±1.70c	86.38±0.93c	54.40±165c	77.33±2.65c	90.33±1.87b
	6+4	GFS	51.84±1.21d	85.75±1.09c	84.70±2.67c	54.72±2.76c	83.93±2.65b	93.14±1.76b
	5+5	JS	54.42±1.43c	92.00±1.12b	91.99±1.43b	58.83±2.65b	83.09±2.65b	92.38±1.22b
	5+5	FS	54.21±1.54c	89.55±1.23c	90.74±1.76b	54.94±1.65c	80.93±2.22b	90.05±1.65b
	5+5	GFS	53.35±2.21c	89.34±2.65c	88.57±2.76b	55.31±1.76c	82.83±3.67b	94.11±1.87b
150	6+4	JS	55.92±2.34b	91.23±2.23b	100.55±3.23a	54.10±1.81c	84.17±2.73b	94.10±1.65b
	6+4	FS	53.60±1.67c	87.60±0.78c	93.22±2.76b	56.26±1.21c	80.11±1.65b	93.28±1.87b
	6+4	GFS	53.43±3.72c	87.68±0.89c	93.76±2.98b	56.97±1.54c	81.48±1.09b	92.90±1.80b
	5+5	JS	56.77±1.54b	96.55±1.76a	102.75±1.21a	60.24±3.87a	85.73±0.89b	94.49±1.33b
	5+5	FS	50.73±1.21c	94.11±1.54a	99.66±1.43b	54.98±3.32c	82.21±0.72b	87.67±2.34c
	5+5	GFS	50.54±1.23c	89.51±1.65b	94.08±1.65b	57.28±1.65b	83.91±1.76b	92.33±2.76b
225	6+4	JS	59.85±1.63a	98.42±1.21a	105.42±2.21a	63.57±1.65a	89.65±1.67a	99.13±2.98a
	6+4	FS	55.53±1.54b	94.75±1.21a	101.38±1.67a	61.66±1.56a	88.83±1.50a	97.73±2.25a
	6+4	GFS	51.33±2.78c	93.19±1.69b	100.51±3.76a	61.18±1.22a	84.83±1.76a	91.09±1.09b
	5+5	JS	55.03±1.54b	92.95±2.76b	90.03±2.32b	55.65±1.87c	78.61±1.76b	86.68±2.12c
	5+5	FS	50.62±1.21c	90.49±1.23b	88.80±2.65c	56.95±1.23c	76.37±2.65b	86.40±1.79c
	5+5	GFS	50.05±0.78c	87.06±1.54c	87.65±2.78c	58.76±1.78b	78.76±2.76b	88.15±2.61c
300	6+4	JS	52.72±1.07c	88.06±1.65c	91.68±2.87b	58.25±1.78b	85.35±2.09b	90.60±1.23b
	6+4	FS	52.55±1.81c	85.85±1.55c	88.97±1.21c	54.19±1.23c	81.29±1.20c	89.57±1.09c
	6+4	GFS	51.69±2.63c	84.37±2.21c	88.65±1.21c	55.14±1.23c	82.83±2.65c	88.42±1.23c

Table 3. Effect of nitrogen fertilizer management on above-ground biomass (g kg^{-1}) winter wheat

N rates (kg ha-1)	The ratio of fertilizer	Timing of fertilizer	2017-2018			2018-2019		
			JS	FS	GFS	JS	FS	GFS
Ck	0	0	14.50±0.87d	39.10±0.29d	64.22±0.34d	8.50±0.27d	39.77±0.83d	54.24±0.26d
75	5+5	JS	16.56±0.91b	42.34±0.16d	68.25±0.75b	11.22±0.21c	40.67±0.22d	63.59±0.43b
	5+5	FS	17.20±0.72a	44.73±0.32c	71.19±0.56a	11.20±0.76c	47.73±0.16c	65.19±0.42b
	5+5	GFS	15.29±0.97c	39.88±1.05d	64.66±0.33c	9.29±0.65d	42.88±0.35d	57.66±0.76c
	6+4	JS	16.41±0.34b	43.38±1.57c	69.31±0.29b	10.41±1.09c	46.38±1.05c	63.31±0.12b

	6+4	FS	17.13±0.71a	47.31±0.12c	67.91±0.82b	12.53±0.43b	50.31±0.09b	61.91±0.16b
	6+4	GFS	15.58±0.56c	44.66±0.59c	65.74±0.37b	12.25±0.11b	47.66±0.64c	59.74±0.29c
150	5+5	JS	16.49±1.05b	47.26±1.89c	65.17±0.93b	10.49±0.19c	50.26±0.47b	59.17±1.09c
	5+5	FS	17.43±0.46a	40.70±0.50d	70.47±0.27a	11.43±1.24c	41.70±0.23d	64.47±0.85b
	5+5	GFS	14.79±0.28d	41.43±0.16d	71.35±0.59a	8.79±0.16d	44.43±0.16c	65.35±0.45b
	6+4	JS	16.69±1.64b	48.30±0.46c	64.87±1.63c	13.02±0.09a	51.30±0.65b	56.87±0.21c
	6+4	FS	16.27±1.24b	45.48±0.03c	66.50±0.08c	10.27±0.22c	48.48±1.12c	60.50±0.65b
	6+4	GFS	15.89±0.88b	44.24±1.80c	65.26±0.25b	9.89±0.71d	47.24±0.11c	59.26±0.22c
225`	5+5	JS	16.59±0.62b	50.51±0.20b	72.62±1.25a	12.59±1.07b	52.84±0.76b	66.62±1.23a
	5+5	FS	16.42±0.92b	49.18±0.34c	70.69±0.32a	11.09±0.65c	54.51±0.27b	64.03±0.43b
	5+5	GFS	15.25±1.11c	46.63±0.10c	67.90±0.92b	11.92±0.76c	49.63±0.09b	60.90±0.52b
	6+4	JS	17.78±0.20a	56.40±0.33a	74.73±0.25a	14.12±0.63a	59.40±0.17a	69.13±0.46a
	6+4	FS	17.64±0.52a	54.65±0.61a	73.81±0.62a	12.52±0.44b	56.32±0.12a	68.48±0.76a
	6+4	GFS	14.89±0.76d	48.20±0.86c	68.99±1.07b	10.89±0.16c	50.54±0.84b	60.33±0.92b
300	5+5	JS	16.39±0.65b	47.59±0.34c	67.41±2.60b	12.39±0.43b	50.59±0.65b	58.08±0.10b
	5+5	FS	14.75±0.94d	47.42±0.18c	64.58±0.92d	11.41±0.11c	50.42±0.12b	57.58±0.6b
	5+5	GFS	15.09±1.40c	43.28±0.75d	64.59±1.26d	9.09±0.62d	46.28±0.19c	54.59±0.26d
	6+4	JS	17.09±1.05a	49.67±0.51b	66.51±0.06c	13.09±0.71b	52.67±1.20b	60.51±0.32b
	6+4	FS	17.37±1.11a	44.21±0.84c	68.80±0.93b	11.70±1.03c	47.21±1.05c	62.80±0.29b
	6+4	GFS	15.77±1.68c	44.71±1.79c	63.47±2.30c	9.77±0.27d	47.71±0.19c	57.47±0.88c

Table 4. Effect of nitrogen fertilizer management on leaf dry biomass (g kg^{-1}) of winter wheat

N rates (kg ha^{-1})	The ratio of fertilizer	Timing of fertilizer	2017-2018			2018-2019		
			JS	FS	GFS	JS	FS	GFS
Ck	0	0	2.38±0.60d	7.67±0.44d	6.67±0.37d	3.38±0.11d	6.67±0.43d	10.05±0.56d
75	5+5	JS	4.28±0.45b	8.19±0.64d	7.19±0.49d	5.28±0.21b	7.19±0.03d	10.31±0.33d
	5+5	FS	2.59±0.74d	8.63±0.42d	7.63±0.33d	3.59±0.09c	7.63±0.41d	13.74±0.04c
	5+5	GFS	3.76±0.50c	8.91±0.61d	7.91±0.76d	4.76±0.19c	7.91±0.64d	11.63±0.62c
	6+4	JS	3.92±0.27c	8.43±1.77d	7.43±0.42d	4.92±0.45c	7.43±0.67d	12.04±0.64c
	6+4	FS	3.99±0.71c	9.60±0.75c	8.60±1.45d	4.99±0.52c	8.60±1.34c	10.50±0.60d
	6+4	GFS	2.59±1.02d	10.59±0.73b	9.59±0.86c	3.59±0.56d	9.59±1.74b	11.51±1.42c
150	5+5	JS	3.84±0.95c	11.81±0.75b	10.81±0.70b	4.84±0.07c	10.81±0.34b	15.12±0.24b
	5+5	FS	4.16±0.66b	8.87±1.07d	7.87±1.56d	5.16±0.63b	7.87±0.43d	14.74±0.50b
	5+5	GFS	3.07±0.53c	9.21±1.74c	8.21±1.60d	4.07±0.46	8.21±0.16c	10.19±0.82d
	6+4	JS	2.86±0.69d	9.15±0.88c	8.15±0.24d	3.86±1.09d	8.15±0.34c	14.40±0.54b
	6+4	FS	4.83±0.46b	10.12±1.73b	9.12±0.90c	5.83±0.76b	9.12±0.13b	14.40±0.23b
	6+4	GFS	3.70±0.38c	9.28±0.27c	8.28±1.12c	4.70±0.33c	8.28±0.34c	11.26±0.39c
225	5+5	JS	5.80±0.29b	11.88±0.43b	10.88±0.29b	6.80±1.16b	10.88±0.71b	16.17±0.02a

	5+5	FS	5.39±1.33b	10.98±0.54b	9.98±1.85c	6.39±0.35b	9.98±0.45b	14.80±0.06b
	5+5	GFS	4.52±0.66b	11.67±0.46b	10.67±0.81b	5.52±0.29b	10.67±0.67b	15.02±0.23b
	6+4	JS	6.92±0.91a	12.66±0.64a	11.66±1.03a	7.92±0.76a	11.66±0.24a	17.31±0.20a
	6+4	FS	6.26±1.12a	12.08±1.39a	11.08±0.5a7	7.26±0.12a	11.08±0.65a	15.51±0.05b
	6+4	GFS	5.62±1.28b	11.72±0.82b	10.72±0.07b	6.62±0.28b	10.72±0.02b	15.45±0.20b
300	5+5	JS	3.76±0.35b	10.58±1.15b	9.58±0.34c	4.76±0.45c	9.58±1.07b	14.16±0.32c
	5+5	FS	4.33±0.85b	9.65±0.88c	8.65±1.94d	5.33±0.71b	8.65±1.24c	13.59±0.71c
	5+5	GFS	3.92±0.72b	10.71±1.78b	9.71±0.20c	4.92±0.04c	9.71±0.50c	13.82±0.27c
	6+4	JS	3.27±1.28c	11.02±0.49b	10.02±0.10b	4.27±0.15c	10.02±0.23b	15.35±0.42b
	6+4	FS	3.85±0.44c	9.96±0.37c	8.96±0.22d	4.85±0.24c	8.96±0.14c	11.53±0.59c
	6+4	GFS	4.06±027b	10.34±0.79b	9.34±0.15c	5.06±0.61b	9.34±0.10c	13.57±0.65c

Table 5. Effect of nitrogen fertilizer management on stem dry weight (g kg^{-1}) of winter wheat

N rates (kg ha^{-1})	The ratio of fertilizer	Timing of fertilizer	2017-2018			2018-2019		
			JS	FS	GFS	JS	FS	GFS
Ck	0	0	5.22±0.32d	14.17±0.59d	12.15±0.51d	6.22±0.21d	13.17±0.15d	14.15±0.12d
75	5+5	JS	6.30±0.15b	16.37±0.17d	16.90±0.15c	7.30±0.32b	15.37±0.22d	18.90±0.09c
	5+5	FS	6.93±0.25b	17.65±0.07c	12.84±0.12d	7.93±0.29b	16.65±1.07c	14.84±0.10d
	5+5	GFS	7.51±1.27a	14.63±0.02d	16.13±0.09c	8.51±0.8a	13.63±0.17d	18.13±0.21c
	6+4	JS	5.88±0.43d	20.72±0.11b	16.03±0.45c	6.88±0.02c	19.72±0.05b	18.03±0.16c
	6+4	FS	5.75±0.54d	20.83±0.32b	18.26±0.04b	6.75±0.11c	19.83±0.32b	20.26±0.65b
	6+4	GFS	6.42±0.44b	19.74±0.76b	13.14±0.11d	7.42±0.65b	18.74±0.15c	15.14±0.43d
150	5+5	JS	6.46±1.01b	20.38±0.45b	15.29±0.72c	7.46±0.43b	19.38±0.11b	17.29±0.04c
	5+5	FS	6.12±1.06b	18.17±0.11c	12.57±1.17d	7.12±0.02b	17.17±0.02c	14.57±0.09d
	5+5	GFS	5.52±0.66d	17.73±0.72c	19.18±0.59a	6.52±0.15c	16.73±0.22c	21.18±0.11a
	6+4	JS	6.36±1.03b	17.74±0.37c	19.36±0.62a	7.36±0.09b	16.74±0.23c	21.36±0.15a
	6+4	FS	6.19±0.89b	21.39±0.94a	15.55±0.55c	7.19±0.23b	20.39±0.65b	17.55±1.05c
	6+4	GFS	5.50±0.17d	21.52±0.75a	13.41±0.08d	6.50±0.54c	20.52±0.15b	15.41±0.09d
225	5+5	JS	7.47±0.67a	22.76±0.08a	17.62±0.54b	8.47±0.34a	21.76±0.14a	19.62±0.62b
	5+5	FS	6.10±0.34b	19.46±1.17b	17.00±0.42b	7.10±0.07b	18.46±0.21b	19.00±0.43b
	5+5	GFS	5.66±1.01d	16.21±0.09c	16.88±0.13c	6.66±0.65c	15.21±0.17d	18.88±0.54c
	6+4	JS	7.95±0.34a	25.68±0.32a	20.35±0.04a	8.95±0.11a	24.68±0.02a	22.35±0.65a
	6+4	FS	6.72±0.29b	23.38±0.55a	18.66±0.59b	7.72±0.23b	22.38±0.15a	20.66±0.02b
	6+4	GFS	6.62±0.18b	22.38±0.35a	18.00±0.43b	7.62±0.08b	21.38±0.34a	20.00±0.23b
300	5+5	JS	6.41±0.92b	17.89±1.06c	17.58±0.32b	7.41±0.39b	16.89±0.11c	19.58±0.16b
	5+5	FS	5.51±0.63d	19.55±0.72b	17.81±0.62b	6.51±1.01c	18.55±0.15c	19.81±0.04b
	5+5	GFS	6.52±0.56b	14.22±1.04d	15.69±0.03c	7.52±0.09b	13.22±0.72d	17.69±0.17c
	6+4	JS	6.17±1.39b	17.84±0.53c	18.88±0.32b	7.17±0.27b	16.84±0.01c	20.88±0.16b

	6+4	FS	5.57±0.87d	18.44±0.60c	13.77±0.12d	6.57±0.23c	17.44±0.25c	15.77±0.64d
	6+4	GFS	5.89±1.10d	16.56±0.80c	18.92±0.09b	6.89±0.02c	15.56±0.21d	20.92±0.09b

Table 6 Effect of nitrogen fertilizer management on spike dry weight (g kg^{-1}) of winter wheat

N rates (kg ha^{-1})	The ratio of fertilizer	Timing of fertilizer	2017-2018		2018-2019	
			FS	GFS	FS	GFS
Ck	0	0	12.12±0.49d	17.05±0.00d	13.12±0.20d	19.05±0.02d
75	5+5	JS	15.04±2.85c	17.83±1.89d	16.04±0.65c	19.83±0.43d
	5+5	FS	20.26±0.78a	18.88±0.65d	21.26±1.09a	20.88±0.24c
	5+5	GFS	11.49±0.94d	17.14±0.60d	12.49±0.12d	19.14±0.68d
	6+4	JS	17.65±1.09b	20.94±1.48c	18.65±1.79b	22.94±1.09b
	6+4	FS	16.95±2.58c	19.54±1.92c	17.95±0.43b	21.54±2.68b
	6+4	GFS	13.33±3.01d	20.29±1.16c	14.33±0.32c	22.29±0.05b
150	5+5	JS	18.23±0.24b	18.62±0.93d	19.23±0.65b	20.62±0.88b
	5+5	FS	14.74±1.98d	22.73±0.28b	15.74±2.09c	24.73±0.56b
	5+5	GFS	12.98±2.11d	19.69±1.87c	13.98±0.61d	21.69±0.54b
	6+4	JS	18.23±0.58b	25.89±0.72b	19.23±0.34b	27.89±0.44b
	6+4	FS	15.68±1.87c	20.53±1.45c	16.68±0.25c	22.53±0.50b
	6+4	GFS	14.44±1.12d	19.61±0.85c	15.44±0.19c	21.61±0.02b
225	5+5	JS	19.39±0.31b	26.94±0.21a	20.39±0.65b	28.94±0.27a
	5+5	FS	13.60±1.86d	24.81±2.61b	14.60±0.05c	26.81±1.01a
	5+5	GFS	17.40±1.86b	19.78±1.60c	18.40±0.65b	21.78±0.31b
	6+4	JS	21.89±0.58a	29.26±0.51a	22.89±1.09a	31.26±0.31a
	6+4	FS	18.71±1.68b	27.76±0.34a	19.71±0.48b	29.76±0.37a
	6+4	GFS	16.17±0.25c	24.94±0.62b	17.17±0.34b	26.94±0.45b
300	5+5	JS	13.65±1.18d	22.49±0.15b	14.65±0.39c	24.49±0.65b
	5+5	FS	17.65±0.24b	22.24±0.23b	18.65±0.16b	24.24±0.45b
	5+5	GFS	13.13±1.49d	22.83±0.65b	14.13±0.05c	24.83±0.34b
	6+4	JS	15.17±0.65c	27.40±0.55a	16.17±0.31c	29.20±0.32a
	6+4	FS	13.10±1.03d	25.04±0.39b	14.10±0.43c	27.04±0.21b
	6+4	GFS	15.94±0.96c	21.70±0.44b	16.94±1.87c	23.70±0.05b

Table 7 Effect of nitrogen fertilizer management on leaf area (cm^2 $plant^{-1}$) of winter wheat

N rates (kg ha-1)	The ratio of fertilizer	Timing of fertilizer	2017-2018			2018-2019		
			JS	FS	GFS	JS	FS	GFS
Ck	0	0	805.1±4.2d	1530.9±4.4d	954.72±4.5d	905.1±6.7d	1630.9±5.6d	1054.2±2.8d
75	5+5	JS	1086.8±9.5c	1681.4±4.3d	982.17±2.5d	1186.8±3.5b	1781.4±3.9d	1082.7±2.6d
	5+5	FS	794.9±2.2d	1819.1±3.76c	901.63±4.7d	1228.2±4.6b	1919.0±6.3b	1001.3±4.6d
	5+5	GF	1147.2±5.7c	1830.8±7.6c	1141.62±5.3b	1247.2±7.5b	1930.8±4.1b	1241.2±5.3b
	6+4	JS	1194.4±4.3c	1910.4±7.7b	1173.13±7.9b	1294.4±6.8b	2010.4±4.7b	1273.3±6.9b
	6+4	FS	1059.4±5.9c	1718.8±3.5c	1146.91±2.8b	1159.4±6.6b	1818.8±7.7c	1246.1±7.5b
	6+4	GF	1002.0±3.3c	1553.8±4.6d	1180.95±4.7b	1102.0±5.2b	1653.8±3.8d	1280.5±4.2b
150	5+5	JS	1370.1±9.2b	2277.8±5.3b	1131.89±9.6b	1470.1±7.4a	2377.8±7.6a	1231.9±7.3b
	5+5	FS	1075.5±4.6c	2322.0±3.2a	1089.24±6.6c	1175.5±9.7b	2422.0±2.7a	1189.4±3.6c
	5+5	GF	998.5±4.6d	1730.6±3.6c	1106.92±5.9b	1098.5±6.5c	1830.6±8.7c	1206.9±4.7b
	6+4	JS	1253.5±11.6b	2308.1±7.6b	986.16±4.9d	1353.5±7.2b	2408.1±9.5a	1086.1±4.2d
	6+4	FS	994.9±11.5d	1952.7±7.6b	1250.27±3.5b	1094.9±5.7c	2052.7±3.3b	1350.2±3.2b
	6+4	GF	1114.9±7.4c	1930.8±5.6b	1152.43±7.7b	1214.9±3.4b	2030.8±2.3b	1252.4±7.9b
225	5+5	JS	1281.8±6.5b	2350.4±4.7a	1350.25±3.8b	1381.8±3.9b	2450.4±5.7a	1450.2±4.5b
	5+5	FS	1055.2±4.6c	2014.4±2.76b	1516.97±7.6a	1155.2±7.0b	2114.4±7.9b	1616.9±4.6a
	5+5	GF	1069.1±4.3c	1590.4±4.7d	1218.48±5.6b	1169.7±3.7b	1690.4±4.8d	1318.4±7.7b
	6+4	JS	1453.5±6.6a	2425.4±3.1a	1518.06±6.4a	1553.5±7.2a	2525.4±5.7a	1618.0±2.6a
	6+4	FS	1141.2±3.4c	1926.3±9.3b	1505.90±3.5a	1241.2±7.8b	2026.3±8.5b	1605.0±7.8a
	6+4	GF	1131.8±3.4c	1974.9±2.5b	1383.17±6.7b	1231.8±4.6b	2074.9±3.3b	1483.1±3.5b
300	5+5	JS	1176.8±5.4c	1914.8±9.4b	1507.35±9.7a	1276.8±4.5b	2014.8±7.7b	1607.5±2.2a
	5+5	FS	1061.5±9.5c	1818.8±3.7c	1141.16±4.5b	1161.5±7.9b	1918.8±9.2b	1241.6±2.7b
	5+5	GF	1081.6±4.6c	1950.8±4.6b	1102.15±5.1b	1181.6±4.7b	2050.8±4.1b	1202.5±6.5b
	6+4	JS	1061.1±6.3c	1953.3±3.7b	1106.46±6.6b	1161.1±4.4b	2053.3±3.6b	1206.6±6.7b
	6+4	FS	999.0±6.3d	1862.9±5.6c	980.25±8.4d	1099.5±7.3c	1962.0±3.4b	1080.5±7.7d
	6+4	GF	969.1±6.3d	1955.4±4.7b	1014.24±7.3c	1069.7±3.5c	2055.4±7.1b	1114.4±4.8c

Table 8 Effect of nitrogen fertilizer management on leaf area index of winter wheat

N rates (kg ha-1)	The ratio of fertilizer	Timing of fertilizer	2017-2018			2018-2019		
			JS	FS	GFS	JS	FS	GFS
Ck	0	0	2.01±0.12d	3.83±0.25d	2.39±0.08d	2.26±0.08d	4.08±0.21d	2.64±0.10d
75	5+5	JS	2.72±0.10b	4.20±0.10c	2.46±0.10d	2.97±0.05c	4.45±0.23c	2.71±0.09c
	5+5	FS	1.99±0.92d	4.55±0.14c	2.25±0.60d	3.07±0.15b	4.80±0.02c	2.50±0.32d
	5+5	GFS	2.87±0.06b	4.58±0.13c	2.85±0.11c	3.12±0.12b	4.83±0.17c	3.10±0.15b

	6+4	JS	2.99±0.04b	4.78±0.19b	2.93±0.16c	3.24±0.21b	5.03±0.14b	3.18±0.33b
	6+4	FS	2.65±0.06b	4.30±0.08c	2.87±0.31c	2.90±0.04c	4.55±0.16c	3.12±0.05b
	6+4	GFS	2.51±0.15b	3.88±0.11d	2.95±0.24c	2.76±0.06c	4.13±0.09c	3.20±0.11b
150	5+5	JS	3.43±0.26a	5.69±0.05b	2.83±0.20c	3.68±0.05b	5.94±0.09b	3.08±0.05b
	5+5	FS	2.69±0.12b	5.81±0.61b	2.72±0.03c	2.94±0.16c	6.06±0.20a	2.97±0.12c
	5+5	GFS	2.50±0.33b	4.33±0.20c	2.77±0.09c	2.75±0.12c	4.58±0.09c	3.02±0.09b
	6+4	JS	3.13±0.11a	5.77±0.17b	2.47±0.05c	3.38±0.06b	6.02±0.21a	2.72±0.10c
	6+4	FS	2.49±0.03c	4.88±0.25b	3.13±0.08b	2.74±0.05c	5.13±0.12b	3.38±0.26b
	6+4	GFS	2.79±0.13b	4.83±0.09b	2.88±0.29c	3.04±0.25b	5.08±0.11b	3.13±0.20b
225	5+5	JS	3.20±0.04a	5.88±0.17a	3.38±0.16b	3.45±0.01b	6.13±0.10a	3.63±0.19b
	5+5	FS	2.64±0.09b	5.04±0.14b	3.79±0.16a	2.89±0.21c	5.29±0.11b	4.04±0.04a
	5+5	GFS	2.67±0.21b	3.98±0.09d	3.05±0.08b	2.92±0.34c	4.23±0.05c	3.30±0.05b
	6+4	JS	3.63±0.18a	6.06±0.42a	3.80±0.08a	3.88±0.12a	6.31±0.07a	4.05±0.07a
	6+4	FS	2.85±0.06b	4.82±0.16b	3.76±0.20a	3.10±0.10b	5.07±0.22b	4.01±0.24a
	6+4	GFS	2.83±0.05b	4.94±0.04b	3.46±0.23b	3.08±0.05b	5.19±0.10b	3.71±0.06b
300	5+5	JS	2.94±0.03b	4.79±0.40b	3.77±0.09a	3.19±0.03b	5.04±0.21b	4.02±0.23a
	5+5	FS	2.65±0.06b	4.55±0.09b	2.85±0.13c	2.90±0.11c	4.80±0.01c	3.10±0.23b
	5+5	GFS	2.70±0.12b	4.88±0.19b	2.76±0.09c	2.95±0.14c	5.13±0.19b	3.01±0.09b
	6+4	JS	2.65±0.07b	4.88±0.07b	2.77±0.08c	2.90±0.17c	5.13±0.06b	3.02±0.07b
	6+4	FS	2.50±0.07b	4.66±0.17b	2.45±0.17d	2.75±0.04c	4.91±0.16c	2.70±0.17c
	6+4	GFS	2.42±0.05c	4.89±0.09b	2.54±0.23c	2.67±0.11c	5.14±0.09b	2.79±0.04c

Table 9. Effect of nitrogen fertilizer management on leaf area duration (days cm) of winter wheat

N rates (kg ha^{-1})	The ratio of fertilizer	Timing of fertilizer	2017-2018			2018-2019		
			JS	FS	GFS	JS	FS	GFS
Ck	0	0	43.80±1.66d	62.14±1.72d	40.23±2.95d	47.55±1.88d	57.14±2.55d	36.36±1.65d
75	5+5	JS	51.90±0.23c	66.59±2.02c	52.03±4.35b	55.65±2.23c	61.59±1.56c	46.41±2.54c
	5+5	FS	49.01±0.73d	68.02±5.52c	44.47±4.36d	59.01±3.82c	63.02±1.21c	39.59±1.67d
	5+5	GFS	55.84±0.62b	74.29±2.45b	54.22±6.45b	59.59±.1.98c	69.29±1.69c	48.59±1.65c
	6+4	JS	58.23±0.95b	77.10±2.69b	50.33±3.12b	61.98±2.13b	72.10±1.65b	44.70±1.33c
	6+4	FS	52.07±1.71c	71.63±4.95b	53.41±1.71b	55.82±2.76c	66.63±1.54c	47.79±1.45c
	6+4	GFS	49.50±4.33d	68.38±3.33c	54.08±5.00b	53.25±3.87c	60.04±1.76c	53.45±2.23b
150	5+5	JS	68.40±0.50a	85.23±2.70b	54.48±0.76b	72.15±1.67a	80.23±1.65b	48.86±3.65c
	5+5	FS	63.71±1.61b	85.30±0.67b	49.11±5.90c	67.46±1.43b	80.30±1.54b	43.48±2.93c
	5+5	GFS	51.18±5.14c	70.95±6.30b	52.72±6.00b	54.93±3.65c	65.95±1.43c	47.09±1.68c
	6+4	JS	66.78±2.56a	82.36±1.70b	49.80±5.97c	70.53±1.78b	77.36±1.33b	44.18±3.42c
	6+4	FS	55.26±2.15b	80.07±2.39b	47.37±1.67c	59.01±0.78c	75.07±2.98b	41.75±1.76c

	6+4	GFS	57.09±1.88b	77.06±5.41b	44.10±1.42c	60.84±2.34b	72.06±5.65b	38.48±1.76d
225	5+5	JS	68.11±0.43a	92.52±2.42a	48.27±0.67c	71.86±1.54a	87.52±2.43b	42.65±1.87c
	5+5	FS	57.57±1.01b	88.30±2.36b	62.96±3.82a	61.32±1.54b	83.30±3.50b	57.34±1.66a
	5+5	GFS	49.86±1.68d	70.21±1.90b	57.59±5.32b	53.61±2.76c	65.21±1.67c	51.97±1.65b
	6+4	JS	72.74±2.16a	98.59±2.27a	56.66±2.10b	76.49±1.76a	93.59±1.54a	51.04±1.74b
	6+4	FS	57.52±3.77b	85.80±3.57b	54.11±0.67b	61.27±1.65b	80.80±1.54b	48.49±1.55c
	6+4	GFS	58.24±1.39b	83.94±1.70b	57.23±2.37b	61.99±2.65b	78.94±1.65b	51.61±3.54b
300	5+5	JS	57.96±0.70b	85.55±0.76b	45.75±3.75c	61.71±4.43	80.55±1.76b	40.12±4.76c
	5+5	FS	54.00±2.80b	73.99±4.57b	52.41±5.71b	57.75±3.33c	68.99±1.65c	46.78±3.76c
	5+5	GFS	56.85±0.72b	76.33±2.22b	43.89±5.19d	60.60±1.67b	71.33±1.89b	38.27±2.65d
	6+4	JS	56.53±2.30b	76.50±4.04b	44.53±4.80d	60.28±1.32b	71.50±2.66b	38.90±2.45d
	6+4	FS	53.65±0.56b	71.06±1.38b	42.58±3.84d	57.40±1.66c	66.06±2.60c	34.46±2.65d
	6+4	GFS	54.84±1.21b	74.25±2.81b	47.79±3.94c	58.59±1.78c	69.25±1.78c	42.16±2.16c

Table 10 Effect of nitrogen fertilizer management on plant height (cm) of winter wheat

N rates (kg ha-1)	The ratio of fertilizer	Timing of fertilizer	2017-2018			2018-2019		
			JS	**FS**	**GFS**	**JS**	**FS**	**GFS**
Ck	0	0	48.52±2.21d	79.76±1.65d	79.18±1.76d	49.94±2.24d	72.10±1.34d	82.98±1.55d
	5+5	JS	51.90±1.30d	82.93±3.66d	83.94±1.12d	51.04±1.22d	74.94±2.76d	86.46±2.87c
	5+5	FS	51.32±1.09d	82.87±2.65d	82.05±1.76d	51.84±1.89d	73.90±2.81d	84.90±1.54c
	5+5	GFS	50.58±1.22d	82.83±2.32dc	81.90±1.65d	51.75±1.65d	75.94±2.43c	87.15±1.21c
75	6+4	JS	53.51±0.76d	89.48±2.67c	86.47±0.76c	54.45±1.21c	79.78±2.36c	89.18±3.72c
	6+4	FS	52.44±3.54d	85.84±1.70c	86.38±0.93c	54.40±165c	77.33±2.65c	90.33±1.87b
	6+4	GFS	51.84±1.21d	85.75±1.09c	84.70±2.67c	54.72±2.76c	83.93±2.65b	93.14±1.76b
	5+5	JS	54.42±1.43c	92.00±1.12b	91.99±1.43b	58.83±2.65b	83.09±2.65b	92.38±1.22b
	5+5	FS	54.21±1.54c	89.55±1.23c	90.74±1.76b	54.94±1.65c	80.93±2.22b	90.05±1.65b
	5+5	GFS	53.35±2.21c	89.34±2.65c	88.57±2.76b	55.31±1.76c	82.83±3.67b	94.11±1.87b
150	6+4	JS	55.92±2.34b	91.23±2.23b	100.55±3.23a	54.10±1.81c	84.17±2.73b	94.10±1.65b
	6+4	FS	53.60±1.67c	87.60±0.78c	93.22±2.76b	56.26±1.21c	80.11±1.65b	93.28±1.87b
	6+4	GFS	53.43±3.72c	87.68±0.89c	93.76±2.98b	56.97±1.54c	81.48±1.09b	92.90±1.80b
	5+5	JS	56.77±1.54b	96.55±1.76a	102.75±1.21a	60.24±3.87a	85.73±0.89b	94.49±1.33b
	5+5	FS	50.73±1.21c	94.11±1.54a	99.66±1.43b	54.98±3.32c	82.21±0.72b	87.67±2.34c
	5+5	GFS	50.54±1.23c	89.51±1.65b	94.08±1.65b	57.28±1.65b	83.91±1.76b	92.33±2.76b
225	6+4	JS	59.85±1.63a	98.42±1.21a	105.42±2.21a	63.57±1.65a	89.65±1.67a	99.13±2.98a
	6+4	FS	55.53±1.54b	94.75±1.21a	101.38±1.67a	61.66±1.56a	88.83±1.50a	97.73±2.25a
	6+4	GFS	51.33±2.78c	93.19±1.69b	100.51±3.76a	61.18±1.22a	84.83±1.76a	91.09±1.09b
	5+5	JS	55.03±1.54b	92.95±2.76b	90.03±2.32b	55.65±1.87c	78.61±1.76b	86.68±2.12c

	5+5	FS	50.62±1.21c	90.49±1.23b	88.80±2.65c	56.95±1.23c	76.37±2.65b	86.40±1.79c
	5+5	GFS	50.05±0.78c	87.06±1.54c	87.65±2.78c	58.76±1.78b	78.76±2.76b	88.15±2.61c
300	6+4	JS	52.72±1.07c	88.06±1.65c	91.68±2.87b	58.25±1.78b	85.35±2.09b	90.60±1.23b
	6+4	FS	52.55±1.81c	85.85±1.55c	88.97±1.21c	54.19±1.23c	81.29±1.20c	89.57±1.09c
	6+4	GFS	51.69±2.63c	84.37±2.21c	88.65±1.21c	55.14±1.23c	82.83±2.65c	88.42±1.23c

Impact of Nitrogen Fertilizer Management on Leaf Dry Weight:

The N treatment rates and ratios significantly influenced the leaf dry weight over two years (Table 4). The results demonstrated that winter wheat plants under various treatments and ratios achieved their maximum leaf dry biomass when provided with appropriate nitrogen supply rates and timing, respectively. During the same period, there were no notable differences in the primary leaf dry weight between the two distinct ratios. All growth stages of leaf dry weight components were significantly influenced by nitrogen treatments and ratios (Table 4). The largest average range in variation was 225 kg N ha^{-1} under the 6:4 ratios compared to the 5:5 ratio across all growth stages in both years. This occurred when nitrogen was applied at the jointing stage, as opposed to the flowering and grain filling stages, with variations of approximately 74.81% and 72.23%, respectively, followed by the application of 300 kg N ha^{-1} at the grain filling stage in both years. The differences between treatments were observed at the 0.05 probability level. The analysis of variance indicated that nitrogen level had a significant effect on leaf dry weight, whereas the nitrogen ratio did not show a significant effect. Additionally, the interaction between nitrogen level and nitrogen ratio was also found to be non-significant (Table 4). The leaf dry weight also affected the number of leaf area components and the capacity of the leaf area index.

'5+5 and 6+4' signifies 50% and 50%, as well as 60% and 40% respectively. JS refers to the jointing stage, FS denotes the flowering stage, and GFS indicates the grain-filling stage. Mean values in a separate column that share similar letters are not significantly different at $p < 0.05$. The values represent the mean ± standard error (SE).

'5+5 and 6+4' signifies 50% and 50%, as well as 60% and 40% respectively. JS refers to the jointing stage, FS denotes the flowering stage, and GFS indicates the grain-filling stage. Mean values in a separate column that share similar letters are not significantly different at $p < 0.05$. The values represent the mean ± standard error (SE).

Effect of Nitrogen Management on Stem Dry Weight:

The dynamics of stem dry biomass per plant across the treatments and ratios were influenced by nitrogen timing, resulting in increases of 52.29-43.89%, 81.22-87.39%, and 67.48-57.95% under the treatment of 225 kg ha^{-1} at a ratio of 6:4 (Table 5). The sole exception noted was the stem dry biomass of winter wheat at the 225 kg N ha^{-1} treatment. The dynamics of stem dry biomass offered a thoughtful analysis of the results from nitrogen treatments and ratios across various N timing scenarios. In response to nitrogen fertilizer and ratios, SDB production showed significant improvement with the 225 kg N ha^{-1} treatment under the 6:4 ratio. This application occurred at the jointing stage during the 2017-18 and 2018-19 periods. Additionally, the application of up to 300 kg N ha^{-1} over the two years revealed the most notable differences, particularly between the CK and 225 kg N ha^{-1} treatments. Averaged across the treatments and ratio, the highest values of 25.68 and 24.68 (g) were recorded at 225 kg N ha^{-1} during the flowering stage in both years, compared to 150 and 300 kg N ha^{-1} under the 6:4 ratio when nitrogen was applied at the jointing stage. Analysis of variance indicated that nitrogen levels significantly influence stem dry weight at the 0.01 or 0.05 probability levels. The nitrogen treatments, their ratios, and the interaction between treatments and ratios exhibited significant effects, with F values of 83.51***, 12.85***, and 9.38***, respectively (Table 11).

Impact of Nitrogen Fertilizer on Spike Dry Weight:

Spike dry weight of winter wheat significantly increased with the increase of nitrogen rates and ratios (Table. 6). When 225 kg N ha-1 was applied at the jointing stage in both years, plants in different growth stages grew by 53.88 to 60.30%, 80.61 to 74%, and 71.6 to 64.09 % more than they did in the control group (CK). The best results were seen when 225 kg N ha^{-1} was used in a 6:4 ratio instead of a 5:5 ratio during the grain-filling stage. The same was true when nitrogen fertilizer was added during the jointing stage as a camper during the flowering and filling stages over two years, instead of 150 kg N ha^{-1} and 300 kg N ha^{-1}, respectively. The variance analysis showed that the nitrogen level and nitrogen ratio had a significant effect on the spike dry weight of winter wheat at the 0.01 or 0.05 probability levels. The interaction between the treatment and ratio also had a significant effect (Table 6).

'5+5 and 6+4' signifies 50% and 50%, as well as 60% and 40% respectively. JS refers to the jointing stage, FS denotes the flowering stage, and GFS indicates the grain-filling stage. Mean values in a separate column that share similar letters are not significantly different at $p < 0.05$. The values represent the mean ± standard error (SE).

'5+5 and 6+4' signifies 50% and 50%, as well as 60% and 40% respectively. JS refers to the jointing stage, FS denotes the flowering stage, and GFS indicates the grain-filling stage. Mean values in a separate column that share similar letters are not significantly different at $p < 0.05$. The values represent the mean ± standard error (SE).

Effect of Nitrogen Fertilizer Management on the Dynamics of Leaf Area:

Leaf area (cm²) increased across different growth stages, from jointing to grain filling stages (Table 7). The leaf area (cm²) increased by 80.58-71.68%, 58.42-54.84%, and 59.00-53.41% over two years under the treatment of 225 kg N ha¹ with a 6:4 ratio, compared to the 5:5 ratio. Nitrogen applied at the jointing stage resulted in greater leaf area increase compared to the flowering and grain filling stages, as compared to the control (CK), respectively. N treatments and ratios presented a significant impact on leaf area cm during the growing season. Overall, the highest leaf area cm was achieved in the flowering stage under the treatment of 225 kg N ha^{-1} with the 6:4 ratio, compared to the 5:5 ratio and nitrogen application at the jointing stage. Variance analysis showed that nitrogen application rate and ratios had a significant effect on the leaf area, and the interaction of nitrogen treatments and ratios was also significant.

Effect of Nitrogen Fertilizer on the Dynamics of Leaf Area Index:

The dynamics of leaf area index (LAI) across various growth periods exhibited increases of 80.59-71.68%, 58.22-54.65%, and 58.98-53.40% under the treatment of 225 kg N ha^{-1} with a ratio of 6:4 (Table 8). The dynamics observed in the 225 kg N ha^{-1} treatments were notably different from those in the 150 kg N ha^{-1} and 300 kg N ha^{-1} treatments. The peak value of LAI plant^{-1} was lowest in the CK treatment and significantly higher in the 225 kg N ha^{-1} treatment under the 6:4 ratio compared to the 5:5 ratio at the flowering stage, when nitrogen was applied at the jointing stage, in comparison to the flowering and filling stages over two years. The highest means were observed in the treatments of 150 and 300 kg N ha^{-1}. The average concluded years and treatments indicate that the extreme LAI in the nitrogen treatments and ratios were as follows: CK: 3.83-4.08 at the flowering stage; 75 kg N ha^{-1} yields 4.78-5.03 at flowering under a 6:4 ratio; 150 kg N ha-1 results in 5.71-6.06 at flowering under a 5:5 ratio; 225 kg N ha^{-1} produces 6.06-6.31 at the flowering stage under a 6:4 ratio; and 300 kg N ha^{-1} achieves 4.88-5.13 at flowering under a 6:4 ratio, respectively. The plants achieved their maximum LAI just before the flowering stage. The dynamics of the leaf area indicated the varied growth periods of winter wheat under different treatments and ratios. The objective of nitrogen treatments and ratios revealed that the average leaf area index across treatments and ratios was significantly lower during the jointing and filling stages in the first year. The differences between treatments were observed at the 0.05 probability level. The analysis of variance indicated that nitrogen level had a significant adaptive effect on the leaf area index. In contrast, the nitrogen ratio exhibited a non-significant effect, while the interaction between nitrogen level and nitrogen ratio was found to be significant (Table 8).

'5+5 and 6+4' signifies 50% and 50%, as well as 60% and 40% respectively. JS refers to the jointing stage, FS denotes the flowering stage, and GFS indicates the grain-filling stage. Mean values in a separate column that share similar letters are not significantly different at $p < 0.05$. The values represent the mean ± standard error (SE).

'5+5 and 6+4' signifies 50% and 50%, as well as 60% and 40% respectively. JS refers to the jointing stage, FS denotes the flowering stage, and GFS indicates the grain-filling stage. Mean values in a separate column that share similar letters are not significantly different at $p < 0.05$. The values represent the mean ± standard error (SE).

Effect of Nitrogen Fertilizer on Leaf Area Duration:

The results indicated that the application of various treatments, ratios, and nitrogen timings for winter wheat significantly affected leaf area duration (LAD) during both the 2018-2019 and 2019-2020 seasons (Table 9). The LAD increased with rising nitrogen levels from the jointing to grain-filling stage, showing a change from 66.06% to 60.85% and from 58.65% to 63.78% at the jointing and flowering stages under the treatment of 225 kg N ha^{-1} with a 6:4 ratio. During the grain-filling stage, the LAD ranged from 56.50% to 57.69% under the same treatment but with a 5:5 ratio. The results indicated that LAD values exhibited significant levels among the ratios during the jointing and flowering stages in 2017-2018. The highest results were recorded at the flowering stage, ranging from 98.59 to 93.59 under the treatment of 225 kg N ha^{-1} with a 6:4 ratio, compared to a 5:5 ratio when nitrogen fertilizer was applied at the jointing stage, in comparison to the flowering and filling stages over two years, respectively. Furthermore, the treatment of 150 kg N ha^{-1} with a ratio of 5:5 is superior to the treatment of 300 kg N ha^{-1} with the same ratio during the jointing to grain filling stage. In comparison, the treatment of 75 kg N ha^{-1} is more effective than the control treatment. Nevertheless, minimal results were noted at the jointing stage within the CK plots. The differences between treatments were observed at the 0.05 probability level. The analysis of variance indicated that nitrogen level had a significant adaptive effect on leaf area duration. In contrast, the effect of nitrogen ratio was non-significant, and the interaction effect between nitrogen level and nitrogen ratio also proved to be non-significant.

Plant Height as Affected by Nitrogen Management:

The results regarding plant height of winter wheat variability Jintai 182 as influenced by soil nitrogen practical (Table 10) show that the plant height of Jintai 182 improved with the application of nitrogen amounts under the nitrogen proportion. In the calculation, with the increase in the amount of topdressing fertilizer, the plant height decreased, but the N ratio of 6:4 was higher than that of the 5:5 ratio in the middle fertility situation throughout 2017-2018 and 2018-2019. The average plant height of winter wheat at different growth periods below the high and low productiveness surroundings were 23.34 to 27.30% at jointing, 23.39 to 24.34% flowering and 33.13 to 19.46% at grain filling stage under the treatment 225 kg N ha^{-1} of ratio 6:4 as compare to 5:5 and when the nitrogen fertilizer applied in plots at the jointing stage, as compare of 150 and 300 kg N ha^{-1}, respectively. The maximum results were perceived at the treatment of 225 kg N ha^{-1} ratio of 6:4 at the different growth stages ranged from 59.85 to 63.57 at jointing, 98.42 to 89.65 at flowering, and 105.42 to 99.13 at grain filling stage, when nitrogen application was applied at the jointing stage time, in both years as compared to 150 and 300 kg N ha^{-1} respectively. Moreover, our results show that decrease increase, decrease in increase with the different growth stages in different treatments and ratios. However, overall minimum results were observed at the treatment of 300 and 75 kg N ha^{-1} as compared to the CK plots. Variance analysis showed that nitrogen application rate and ratios had a significant effect on the plant height, and the interaction of nitrogen treatments and ratios was also significant.

'5+5 and 6+4' signifies 50% and 50%, as well as 60% and 40% respectively. JS refers to the jointing stage, FS denotes the flowering stage, and GFS indicates the grain-filling stage. Mean values in a separate column that share similar letters are not significantly different at $p < 0.05$. The values represent the mean ± standard error (SE).

'5+5 and 6+4' represents 50% + 50% and 60% +40%. JS: Jointing stage; FS: Flowering stage; GFS: Grain filling stage. This means values in a separate column followed by similar letters are not significantly different at $p < 0.05$. The values are the mean ± SE.

Table 11 Significance of F-value from analysis of variance of various parameters of winter wheat as affected by nitrogen management

Parameter	N-rates (N)	Ratios (R)	N × R
Plant height	539.57***	39.90 ***	6.77 ***
Plant dry biomass	191.36***	22.08***	17.46 ***
Leaf dry weight	38.69 ***	1.07NS	1.42NS
Stem dry weight	83.51***	12.85 ***	9.38***
Spike dry weight	10.02 ***	2.90**	1.77 *
Leaf area	54.50 ***	11.84 **	3.13 **
Leaf area index	58.40***	1.51NS	5.79***
LAD	22.64***	0.47NS	1.46NS

Note: *, **, and *** indicate significance levels at alpha 0.05, 0.01, and 0.001, respectively, as determined by the honestly significant difference (HSD) test. 'NS' denotes non-significance.

Discussion:

Dry Biomass and Leaf Area Index as Affected by Nitrogen Management:

The dry biomass and leaf area index (LAI) of the winter wheat crop demonstrated significant differences ($p < 0.05$) from the jointing to the grain filling periods, corresponding to varying rates and ratios of nitrogen. The application of nitrogen markedly improved the dry biomass and leaf area index of winter wheat throughout all growth stages. The application of nitrogen at a rate of 225 kg N ha^{-1} with a 6:4 ratio, in comparison to a 5:5 ratio, resulted in significant improvements in above-ground biomass, as well as leaf, stem, and spike dry biomass. Specifically, the above-ground biomass increased by 16.36-27.45% during the grain-filling stage, leaf biomass by 74.81-72.23% at grain-filling, stem biomass by 81.22-87.39% at flowering, and spike biomass by 71.61-64.09% at the grain-filling stage, compared to the control over two years. Previous research indicated that a suitable LAI was recommended to be between 5 and 7 during the flowering stage [27][28]. Research indicates that when the Leaf Area Index (LAI) reaches approximately 3, the capture of Photosynthetically Active Radiation (PAR) approaches 90%; any subsequent increase in LAI would be ineffective [29][5]. The effect on the LAI arises from the fact that an extreme LAI can reduce light concentration and/or alter light quality at inappropriate levels within the canopy, particularly where tiller shoots and new tillers are located [15]. The leaf area index showed improvement below the fertilization level of 225 kg N ha^{-1} during the flowering growth stage, specifically under the 6:4 ratio, when nitrogen was applied at the jointing period. An LAI of 5 to 7 was attained under suitable nitrogen supply conditions of 180 kg N ha^{-1} during the jointing to heading stage, indicating that the optimal leaf biomass portion of AGB could be a crucial factor in yield determination. In our study, the average highest above-ground biomass, including leaf, stem, and spike dry biomass, was measured as follows: above-ground biomass ranged from 74.73 to 69.13 g kg^{-1}, leaves from 11.66 to 17.31 g kg^{-1}, stems from 25.68 to 24.68 g kg^{-1}, and spikes from 29.26 to 31.26 g kg^{-1}. These measurements were taken during the flowering and grain-filling growth stages at a nitrogen application rate of 225 kg N ha^{-1} with a ratio of 6:4, respectively. A further study corroborating our findings demonstrated that the leaf biomass component of aboveground biomass increased positively with nitrogen supply, with the ratio being marginally higher during the heading development stage [30]. In the flowering stage, the highest average LAI values of 6.06-6.31 and 5.81-6.06 were recorded under nitrogen applications of 225 and 150 kg N ha^{-1}, respectively. This was observed when nitrogen was applied at the jointing stage for the 6:4 ratio and at the flowering stage for the 5:5 ratio, across both years, in comparison to the 75 and 300 kg N ha^{-1} treatments. The interaction between N fertilizer rates and N ratios significantly affected dry biomass and LAI. Research has demonstrated that there are significant correlations between growth rate and grain yield in corn crops [31][32][29].

Our findings showed that different N rates and ratios had a notably favorable impact on dry biomass and LAI values, which may be because the winter wheat crop captured sunlight. In contrast to the jointing stages of the winter wheat crop, we found that the influence was more noticeable throughout the blooming and grain-filling growing stages. Our findings confirm [33][34] that higher values of leaf area and LAI have been linked to higher values of dry matter production as a result of improved nitrogen supply. A better nitrogen supply typically leads to larger leaf areas, which enhance light absorption and promote carbon fixation. By tracking the cell proliferation in grain crops, another study demonstrates that shadowing environmental factors can also limit leaf growth [35][36]. Furthermore, an increase in the leaf area index during the blooming growth stage indicates the ideal leaf development, which facilitates improved solar absorption and use. This arrangement may result from the grain crop's canopy shrinking and mature leaves senescing [37][38]. In contrast to the control, we found that winter wheat crops with nitrogen rates of 150 and 225 kg N ha^{-1} achieved higher LAI. This could be explained by longer periods of green leaf area and delayed shoot senescence.

LAI and leaf area duration are directly correlated [5]. The size and duration of the leaf area are largely included in LAD, which is the fundamental component of LAI and the development period [39]. Our findings showed that different rates and timings had a notably good effect on the duration of leaf area and the values of the leaf area index, which may be because the winter wheat crop captured sunlight. Compared to other developing stages of the winter wheat crop, we found that the effect was more noticeable while the crop was at the blooming stage. When cultivar Yizheng was treated with 225 and 300 kg N ha^{-1}, Wang et al. 2018 found that the cultivar's maximum leaf area duration was larger during the grain-filling stage than during the jointing stage [40][29] Nonetheless, there was little difference in LAD between tests and growth phases. Furthermore, a rise in LAD during the flowering growth stage indicates ideal leaf growth, which supports better solar absorption and consumption. Our findings are consistent with those of Tiryakioglu et al., 2015 who found that the cultivars with the highest LAD values were man's-97, which ranged 87 cm^2 ms^{-1} and get-75, which ranged 61 cm^2 ms^{-1} during the first year, and a man's-97, which ranged 46 cm2 ms^{-1} and get-75, which ranged 72 cm^2 ms^{-1} during the second year [41][42] Amanos-97 had the lowest figure for both years (37 -30 cm^2 ms^{-1}). Rather than their senescence, the genotypes' leaf area values were more frequent determinants of leaf area longevity. Senescence flag leaf senescence began immediately before anthesis during the grain filling cycle, which largely influenced the relationships between leaf area and LAD. When treatment 225 kg N ha^{-1} (1/3 nitrogen at V2, 1/3 nitrogen at V16, and 1/3 nitrogen at R1 stage) was applied, the crop reached its maximum LAD (243.4 days) [43][44]. An increase in N rates showed that the leaf area crop's duration was extended by up to 258.4 days using a rate of 250 kg N ha^{-1}, followed by treatments of 300 and 200 kg N ha^{-1}. The length of the leaf area rose gradually until the crop reached maturity. We found that winter wheat crops treated with 150 and 225 kg N ha^{-1} of nitrogen had higher LAI than the control, which may be related to the longer duration of green leaf area and delayed shoot senescence. Overall, a higher nitrogen application rate resulted in better tissue development and plant growth, which raises nitrogen concentration in leaves and raises the leaf area index. The same is true when comparing nitrogen to potassium and phosphorus.

Conclusion:

The application of nitrogen fertilizer had a significant effect on winter wheat grain production, plant height, dry biomass, and LAI and LAD characteristics. Because N concentration improved, the nitrogen application was better corresponding with the plant's N demand during the optimal development stage. During the jointing, flowering, and grain-filling stages of winter wheat, nitrogen fertilizer at 225 kg N ha-1 in a 60% + 40% ratio greatly increased the plant height, dry biomass, leaf area, LAI, and LAD. This was in contrast to a 50% + 50% ratio. Additionally, it was found that plant height, total dry biomass, LAI, and LAD were positively and significantly correlated with winter wheat grain output. Applying nitrogen fertilizer in various ratios at the appropriate growing stage is an efficient way to increase grain yield by choosing the best and most sustainable N timings and N rates. This allows for the classification of the optimal and sustainable rate of nitrogen fertilization.

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