Effect of Irrigation and Nitrogen Topdressing at Different Leaf Ages on the Length and Growth of Wheat Leaves, Leaf Sheaths, and Internodes

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Abstract: The lengths of leaves, leaf sheaths, and internodes are the main factors affecting individual plant types. An ideotype is a basis for developing a high-yielding population structure. Water and nitrogen (N) fertilizer can directly affect the growth of a plant’s organs. To evaluate the effects of irrigation and nitrogen application on the length and growth of wheat leaves, leaf sheaths, and internodes, we carried out a 5 year field experiment in the high yield wheat fields of the North China Plain. Five treatments (T2–T6) were applied, and irrigation was carried out in springtime at the appearance of the second leaf (T2), the third leaf (T3), the fourth leaf (T4), the fifth leaf (T5) and the sixth leaf (T6). The results showed that the irrigation and N topdressing periods had different effects on the leaves, leaf sheaths, and internodes. The lengths of the upper three leaves gradually increased with the progression of the irrigation and N topdressing. The increases in the lengths of the leaf sheath were similar and followed the irrigation and N topdressing pattern at four stages of leaves in the spring: n-1, n-2, n-3 and n-4. The most effective growth of the internodes was achieved by irrigation and N topdressing at the n + 2 and n + 3 stages. The vertical spacing among the upper three leaves increased with irrigation and N topdressing at the appearance of the top second (or flag) leaf. Differences in temperature and precipitation over the years either weakened or enhanced the differences in the plants’ organ lengths with the different treatments. However, the orders of treatments did not alter organ length in different years. Earlier irrigation and N topdressing treatments (T2, T3, and T4) showed an inhibitory effect on the leaves and leaf sheaths during the early growth stage. The inhibitory effect was more evident in the later-emerged leaves and leaf sheaths than in those that emerged earlier. However, irrigation and N fertilization increased the final length of the organs by improving the growth rate during the rapid incremental phase (RIP) and the slow incremental phase (SIP). Although the most significant extensions of the lengths of leaves, leaf sheaths, and internodes were achieved by irrigation and N topdressing before the organs entered the RIP, the specific growth stages were different among the three organs. These results can provide a reference for directly regulating the development of wheat organs and constructing an ideotype.

Keywords: irrigation period; N topdressing period; organ length; organ building process; plant-type regulation

1. Introduction

Wheat is one of the most important food crops globally, and its yield directly affects food security. Breeding a high-quality population structure is fundamental in achieving high wheat yields [1–3]. The plant type is the basis for a high-quality population structure [4–6]. The lengths of the internodes, leaves, and leaf sheaths are the main factors affecting individual plant types of wheat. Therefore, accurately regulating the growth of...
internodes, leaves, and leaf sheaths is very important in developing an ideal wheat plant type and a high-quality population structure.

The leaf is the most critical photosynthetic organ [7]. The leaf size at each growth stage and each leaf position directly affects the total canopy light interception and the vertical distribution of light within the canopy. Therefore, it is important to accurately regulate the size of the leaf at each leaf position [8–10]. Irrigation at different growth periods could effectively regulate the leaf size of winter wheat [11–13]. Previous studies have found that spring irrigation can promote leaf elongation; the earlier the irrigation, the greater the promoting effect on leaves [14]. The advance of the irrigation period from the jointing stage (Feekes 6.0 [15]; the phenological division of this paper is referred to in the literature.) to the regreening stage (Feekes 4.0) can increase the length of the upper three leaves [14]. On the premise that jointing water has been irrigated, the irrigation in the regreening stage will increase the area of the upper three leaves [11]. Zhang [16] and Xu et al. [17] found that, compared with irrigation at jointing stage, irrigation treatment at the upstanding stage (Feekes 5.0) also promoted the length of the upper three leaves. Previous studies focused mainly on the effect of nitrogen (N) topdressing on the wheat leaf’s canopy leaf area index [18–21]. There is little available information about the role of N on leaf growth.

The length of each internode and leaf sheath determines the vertical distance among leaves and, therefore, affects the vertical distribution of light within the canopy [22–24]. Many studies analyzed the combined effects of changing the irrigation and the timing of N topdressing on the internode length. Zhou et al. [25] showed that the basal first internode increased significantly when irrigation and N topdressing application timing were raised from the jointing stage to the upstanding stage. The effect was reduced when irrigation and N were applied at the regreening stage. Zhang et al. [26] showed that the length of the basal first internode was longer when irrigation and N were applied at the jointing stage rather than in the upstanding stage. There are few studies on the effects of changing irrigation and nitrogen on internode length. Ma et al. [27] reported that a water deficit before flowering reduced the length of the basal first and second internodes. Zhang et al. [28] showed that N topdressing at the regreening stage promoted the growth of the first and second internodes, compared with N topdressing at the jointing stage. Changes to irrigation or the N topdressing stage could affect the internode length of wheat. However, studies on irrigation or N topdressing on leaf sheath length have rarely been reported.

There are relatively stable internal relationships between leaf positions and the leaves and internodes during plant growth. The extension periods are common to leaf n, leaf sheath n-1, and internode n-2 [29]. Thus, irrigation at targeted leaf ages is conducive to the directional control of specific leaf layers and/or internodes. The effects of irrigation and fertilization at different leaf ages on the regulation of leaves, leaf sheaths, and internodes in barley [30] and spring wheat [31] have been studied previously. However, there are few systematic studies on the effects of irrigation and fertilization at different leaf ages on the individual organs of winter wheat. Zhu et al. [32] reported the regulatory impact of irrigation and fertilization on leaves, internodes, and leaf sheath lengths in the 1970s. They concluded that the maximum length in leaf n + 2, leaf sheath n + 1, and internode n-2 were observed when irrigation and N topdressing were supplied at leaf n. Thereafter, there have been only a few unsystematic reports about the effects of irrigation and N topdressing at different leaf ages on a particular organ of wheat. Yang et al. [33] studied only the influence of irrigation at different leaf ages on internode length in a single-year experiment. Their results showed that the basal first internode was longer with irrigation at the spring 3 leaf age, and the basal second internode was longer at the spring 4 leaf age. No significant differences were observed between the two treatments in the basal third, fourth, and fifth internodes. Wang et al. [34] also studied the effect of irrigation and N topdressing at different leaf ages on the basal first, second, and third internodes. Their study showed that the basal first internode was longer with treatments at the spring 3 leaf age, and both the basal second and third internodes were longer with treatment at the spring 5 leaf age. Their study was also a single-year experiment. Lv et al. [35] studied the
effect of irrigation and N topdressing on the basal first and second internodes in a two-year experiment. Their results showed that irrigation and N topdressing at the spring 4 leaf age had a more significant extension on the basal second internode.

In summary, the irrigation and fertilization period significantly affected wheat growth. However, there are few systematic studies on the regulation effects of irrigation and N topdressing at different leaf ages on various organs of winter wheat. In addition, previous experimental periods were short, and the consistency of the studies’ results under other climatic conditions could not be determined. Since the studies conducted more than 40 years ago by Zhu et al. [32], soil fertility, climatic conditions, and wheat variety characteristics have changed considerably. Therefore, to precisely regulate each organ’s growth and to develop an ideal plant type, it is necessary to systematically study the effect of irrigation and N topdressing at different leaf ages on various wheat organs in modern high-yielding fields.

Previous studies have been carried out on crop organ development [36–39]. Fournier et al. [40] and Zhu et al. [41] studied the growth of maize leaves, leaf sheaths, and internodes. Li et al. [42] investigated the differences in leaf and internode growth in different winter wheat varieties. Dornbusch et al. [38] investigated the effects of different varieties, planting densities, and sowing times on the leaf lengths, leaf sheath lengths, and internode lengths of winter wheat. Xue et al. [43] simulated the growth process of sorghum internodes using a logistic model. Zou et al. [44] used a logistic model to simulate the growth of winter wheat and maize plant height under mulch. Tan et al. [45] and Chen et al. [44,46] concluded that the development of winter wheat leaves, leaf sheaths, and internodes showed an “S” curve, and the growth process simulated by the logistic model was consistent with the growth dynamics of winter wheat organs. However, the effect of irrigation and N topdressing periods on organ development in winter wheat has not been previously reported.

Plant type refers to the spatial distribution of plants and the appearance and growth of a variety under specific environmental conditions. Plant type includes leaf size, internode length, and the distance between leaves. The study of plant morphology is important for utilizing and improving field microclimate, improving light energy utilization, and crop yield. Therefore, we conducted a five-year field experiment in the high-yielding wheat fields of North China, studying the effect of different irrigation and nitrogen topdressing periods on the growth of leaves, leaf sheaths, internodes, and leaf ear spacing of winter wheat. The aim of the study was to provide a theoretical basis and a technical reference for more accurately regulating organ growth and constructing ideal plant types using irrigation and N topdressing. The study also aimed to provide a reference for screening ideal plant type varieties via reasonable water and fertilizer management.

2. Materials and Methods
2.1. Experimental Site

Field experiments were conducted in five winter wheat growing seasons, from 2012 to 2014 and 2018 to 2021, in Gaocheng District, Shijiazhuang City, Hebei Province, China (38°03′ N, 114°53′ E). The local climate is that of a warm temperate continental monsoon. The rainfall for the five wheat seasons was 139.5 mm, 52.5 mm, 112.4 mm, 131.3 mm, and 84.4 mm, and the average temperature was 8.31 °C, 10.27 °C, 10.24 °C, 11.06 °C, and 10.57 °C, respectively (Figure 1). Winter wheat is usually sown in early October in this area. Winter wheat enters the overwintering period (Feekes 3.0) [15] in late November or early December and enters the regreening period (Feekes 4.0) in late February or early March of the following year. Six leaves and five internodes usually occur after the regreening stage. In the winter wheat irrigated areas of the North China Plain, irrigation and N topdressing are generally carried out simultaneously in the spring to improve the efficiency of N fertilizer utilization.
The soil texture of the test field was loam. The average soil bulk density in the 0 m to 2 m layer was 1.47 g·cm⁻³, and the maximum field capacity was 28.0%. The 5 year average of the soil organic matter in the 0 cm to 20 cm soil layer—total N, available N, rapidly available phosphorus, and rapidly available potassium—was 14.1 g·kg⁻¹, 1.3 g·kg⁻¹, 130.1 mg·kg⁻¹, 30.5 mg·kg⁻¹, and 120.3 mg·kg⁻¹, respectively.

2.2. Experimental Design

In this experiment, the fields were irrigated twice each wheat growing season. The first irrigation and the N topdressing were carried out simultaneously, and various treatments were carried out at different leaf ages in the springtime. The second irrigation was carried out at the flowering stage. In the 2012 to 2013 and 2013 to 2014 wheat seasons, five treatments (T₂–T₆) were applied, and the first irrigation was carried out in springtime at the appearance of the second leaf (T₂), third leaf (T₃), fourth leaf (T₄), fifth leaf (T₅), and sixth leaf (T₆). In the wheat seasons from 2018 to 2019 and 2019 to 2020, only T₃, T₄, T₅, and T₆ treatments were applied. In the wheat season from 2020 to 2021, on the basis of the original T₂–T₆ treatment, no irrigation and no nitrogen topdressing treatment (W₀) were added. The dates of the first spring irrigation and N topdressing for each treatment are shown in Table 1. A flow meter dispensed precisely 60 mm of water for each irrigation.

### Table 1. Date of irrigation and topdressing of different treatments in each growing season.

| Growing Season | Variety       | Regreening | T2  | T3  | T4  | T5  | T6  | Anthesis |
|----------------|---------------|------------|-----|-----|-----|-----|-----|----------|
| 2012–2013      | Shixin828     | 27/2       | 18/3| 30/3| 8/4 | 15/4| 23/4| 13/5     |
| 2013–2014      | Shixin828     | 25/2       | 17/3| 25/3| 31/3| 6/4 | 11/4| 2/5      |
| 2018–2019      | Gaoyou2018    | 23/2       | —   | 22/3| 30/3| 7/4 | 13/4| 10/5     |
| 2019–2020      | Gaoyou2018    | 25/2       | —   | 20/3| 26/3| 1/4 | 11/4| 2/5      |
| 2020–2021      | Gaoyou2018    | 20/2       | 3/3 | 16/3| 27/3| 4/4 | 9/4 | 5/5      |

T₂, T₃, T₄, T₅, and T₆ refer to the first irrigation and nitrogen topdressing at the appearance of the second, third, fourth, fifth, and sixth spring leaf, respectively. T₂ was not set in growing seasons from 2018 to 2019 or 2019 to 2020.

This experiment was established as a randomized design, with a plot consisting of three replicates per treatment. The plot area was 8 m × 9 m = 72 m². The planting material was a semi-winter wheat variety with high tillering ability, which is widely grown in Hebei Province. The sowing date was from 6 October to 9 October, row spacing was 15 cm, and the seedling density ranged from 3 × 10⁶·hm⁻¹ to 3.15 × 10⁶·hm⁻¹. In each winter wheat growing season, 240 kg·hm⁻¹ N, 120 kg·hm⁻¹ P₂O₅, and 150 kg·hm⁻¹ K₂O were applied. The fertilizers used were urea (containing 46% of N), diammonium phosphate (containing 18% of N, P₂O₅ 46%), and potassium chloride (containing 60% of K₂O). The N was applied with 50% as base fertilizer and 50% as topdressing with the first spring irrigation, and the P and K were used as base fertilizers.
2.3. Sampling and Measurement

2.3.1. Organ Length

A ruler was used to measure the organ lengths. The leaf length was the distance from the leaf ear to the leaf tip; the internode length was the distance between two adjacent nodes; the leaf sheath length was the distance between the adherent nodes of the leaf sheath and the leaf auricle; and leaf auricle spacing was the distance between the auricle of two adjacent leaves. The leaf length was measured at the end of elongation. The internode length, leaf sheath length, and leaf auricle spacing were measured at the anthesis stage. Twenty plants were measured for each plot.

2.3.2. Monitoring and Analysis of the Organ Growth Process

The lengths of the leaves, leaf sheaths, and internodes were measured every 3 days with a straightedge, starting from the regreening period in the growing season from 2020 to 2021. Fifteen plants were measured for each plot. The measured organ lengths were the actual lengths after dissection. Monitoring ended at the end of the elongation of all organs.

When an organ length reached 1 mm or more, the organ started to elongate. The growth process of each organ showed a slow–fast–slow S-shape. Therefore, a sigmoid curve in SigmaPlot 12.5 was utilized to fit the growth process of each organ. The characteristic parameters were calculated using the curve equation. The effects of irrigation and N topdressing at different leaf ages on organ growth were analyzed. The expression of the sigmoid curve equation is as follows:

\[ Y = \frac{K}{1 + \exp\left(-\frac{x - x_0}{b}\right)} \]

Liu et al. and Zou et al. [47–49] showed how the above equation is transformed. The characteristic parameters of the organ growth process were calculated and used to divide the organ developmental process into three stages: the gradual incremental phase (GIP), the rapid incremental phase (RIP), and the slow incremental phase (SIP). The transformed equation is as follows:

\[ Y = \frac{K}{1 + A \times \exp(-Bx)} \]

\[ A = \exp\left(x_0/b\right) \]

\[ B = 1/b \]

In the above equation, x is the number of days after regreening, Y is the length of each organ after regreening, K is the uppermost asymptote implying the upper limit of crop growth (cm), and b are the coefficients for the initial stage and the accretion rates, respectively. K, x₀, and b are the parameters of the fitted equation. The characteristic parameters are derived from the first-order and second-order derivatives of the equation:

\[ t_1 = \left(\ln A - 1.317\right)/B \]

\[ t_2 = \left(\ln A + 1.317\right)/B \]

\[ t_3 = -\ln(1/99/A)/B \]

\[ D_1 = t_1 - t_0 \]

\[ D_2 = t_2 - t_1 \]

\[ D_3 = t_3 - t_2 \]

\[ D = t_3 - t_0 \]

\[ w_1 = K/(1 + A \times \exp(-Bt_1)) \]

\[ w_2 = K/(1 + A \times \exp(-Bt_2)) \]

\[ w_3 = K/(1 + A \times \exp(-Bt_3)) \]
where \( t_0 \) is the time when the organ starts to elongate, \( t_1 \) is the end time of the GIP, \( t_2 \) is the end time of the RIP, \( t_3 \) is the end time of the SIP, \( D_1 \) is the duration of the GIP, \( D_2 \) is the duration of the RIP, \( D_3 \) is the duration of the SIP, \( D \) is the total organ build time, \( w_1 \) is the growth at the end of the GIP, \( w_2 \) is the growth at the end of the RIP, \( w_3 \) is the growth at the end of the SIP, \( V_1 \) is the growth rate in the GIP, \( V_2 \) is the growth rate in the RIP, and \( V_3 \) is the growth rate in the SIP.

2.3.3. Soil Surface Temperature

Temperature loggers (automatic optic sensors HOBO; Onset Computer Co., Bourne, MA, USA) were placed 3 cm below the surface of each treatment, and temperatures were recorded at 30-min intervals.

2.4. Statistical Analyses

Statistical analyses were carried out with SPSS 24.0 (SPSS Inc., Chicago, IL, USA). Differences were significant using the least significant differences test at a 0.05 probability level. Figures were created using SigmaPlot 12.5 (Systat Software Inc., San Jose, CA, USA) and Microsoft 2019 (Microsoft, Redmond, WA, USA).

3. Results

3.1. Effect of Timing of Irrigation and N Topdressing on the Length and Growth of the Leaf

3.1.1. Leaf Length

In the 5 year trial, the length differences among the treatments L2, L3, L4, L5, and L6 varied by 0.79 to 10.61%, 5.35 to 11.34%, 8.77 to 33.47%, 20.85 to 63.24%, and 34.50 to 66.23%, respectively (Figure 2). These length differences indicated that irrigation and N topdressing at different leaf ages had a smaller effect on L2 and L3 and a more significant impact on the upper three leaves. The ANOVA results (Table 2) showed significant effects of treatments and years on the upper three leaf lengths. The lengths of the upper three leaves (L4, L5, and L6) in different treatments showed a trend of \( T_2 > T_3 > T_4 > T_5 > T_6 \), which indicated that the delay in the irrigation and nitrogen recovery period could reduce the length of the leaves. Although the changing trend of leaf length among the treatments was generally consistent every year, the difference in magnitude among the treatments varied considerably. Therefore, the effect of the interactions between years and treatments on most leaves were significant.

3.1.2. The Growth of the Leaf

Figure 3 shows that the leaf developmental process presented a slow–fast–slow “S”-shape. Simulations were performed with sigmoid curves, and all \( R^2 \) values were greater than 0.99. Earlier irrigation and N topdressing treatments (\( T_2, T_3, \) and \( T_4 \)) showed inhibitory effects during the early stages of L3, L4, L5, and L6 growth. This effect was more evident in the later-emerged leaves than in those leaves that emerged earlier. However, earlier irrigation and N topdressing treatments improved the growth rate during the mid-stage and the late stage of the leaves. The later irrigation and N topdressing treatments, \( T_5 \) and \( T_6 \), did not significantly inhibit the leaves at the early growth stage. The leaf lengths of the leaves in the early irrigation and N topdressing treatments exceeded those of the late treatments, until the growth process of L4, L5, and L6 reached approximately two-thirds of the total length.
varied considerably. Therefore, the effect of the interactions between years and treatments on most leaves were significant.

Figure 2. Leaf length for different treatments in each wheat growing season. L2–L6 represent the second leaf to the sixth leaf in springtime, and the sixth leaf is the last. T2, T3, T4, T5, and T6 refer to the first irrigation and nitrogen topdressing at the appearance of the second, third, fourth, fifth, and sixth spring leaf, respectively. T2 was not set in the growing seasons from 2018 to 2019 and 2019 to 2020, and W0 was set only in the growing season from 2020 to 2021.

Table 2. Analysis of variance (ANOVA) for the effects of different irrigation, N topdressing treatments, and year on the length of each organ.

| Organs | Treatments | Years | Years × Treatments |
|--------|------------|-------|--------------------|
| L2     | NS         | **    | *                  |
| L3     | **         | **    | NS                 |
| L4     | **         | **    | **                 |
| L5     | **         | **    | **                 |
| L6     | **         | **    | *                  |
| S2     | NS         | **    | NS                 |
| S3     | NS         | **    | NS                 |
| S4     | **         | **    | **                 |
| S5     | **         | **    | **                 |
| S6     | **         | **    | NS                 |
| I1     | **         | **    | NS                 |
| I2     | **         | **    | NS                 |
| I3     | **         | **    | *                  |
| I4     | **         | **    | **                 |
| I5     | **         | **    | NS                 |
| L3–L4  | **         | **    | **                 |
| L4–L5  | **         | **    | NS                 |
| L5–L6  | **         | **    | *                  |

* and ** indicate significant effects at $p < 0.05$ and $p < 0.01$, respectively; NS indicates no significant impact. L2–L6 represent the second leaf to the sixth leaf in springtime; S2–S6 represent the second leaf sheath to the sixth leaf sheath in springtime; I1–I5 represent the first internode to the fifth internode in springtime. L3–L4, L4–L5, and L5–L6 represent the spacing from the third leaf auricle to the fourth leaf auricle, from the fourth leaf auricle to the fifth leaf auricle, and from the fifth leaf auricle to the sixth leaf auricle, respectively.
Figure 3. Growth process of each leaf in the growing season from 2020 to 2021. L3–L6 represent the third leaf to the sixth leaf in springtime.

Table 3 shows that the end time of the GIP, the RIP, and the SIP on L3–L6 leaves advanced with a delay in the irrigation and nitrogen topdressing period. Early irrigation and N topdressing significantly prolonged the duration of the GIP and the TIP of the leaves. Early irrigation and N topdressing had a minor effect on the duration of the RIP and the SIP of the upper three leaves, but significantly increased the growth rate in the RIP and the SIP. This indicates that early irrigation and N topdressing could prolong the developmental time of the leaves and improve the growth rate during the mid-stage and the late stage.

3.2. Effect of Timing of Irrigation and N Topdressing on the Length and Development of the Leaf Sheath

3.2.1. Leaf Sheath Length

The ANOVA showed that the years and treatments had a significant effect on the length of S4, S5, and S6 (Table 2). The detailed length difference in S4 showed T2 and T3 > T5, T6, and W0. In S5, the length difference showed T2, T3, and T4 > T5, T6, and W0. In S6, T2, T3, T4, and T5 were greater than T6 and W0 (Figure 4). This indicated that irrigation and N topdressing at spring leaf ages of n-1, n-2, n-3, or n-4 had a noticeable stimulation effect on the length of Sn. Sn’s length difference among Tn-1, Tn-2, Tn-3, and Tn-4 was negligible. Although the changing trend of leaf sheath length among the treatments was similar in different years, the difference in magnitude varied. Therefore, there were significant interaction effects on some leaf sheaths, based on treatments and years.
Table 3. Characteristic parameters of the growth process of each leaf in the growing season from 2020 to 2021.

| Leaf | Treatment | The End Time of Each Phase (d) | Duration of Each Phase (d) | Growth Rate of Each Phase (cm/d) |
|------|-----------|-------------------------------|---------------------------|---------------------------------|
|      |           | GIP  | RIP  | SIP  | GIP  | RIP  | SIP  | TIP  | GIP  | RIP  | SIP  |
| L3   | T₂        | 18.36a| 26.47a| 36.57a| 14.36a| 8.11a| 10.10a| 32.57a| 0.31a| 1.48b| 0.41b|
|      | T₃        | 18.39a| 25.95b| 35.36b| 14.39a| 7.56b| 9.41b| 31.37b| 0.30a| 1.57a| 0.44a|
|      | T₄/T₅/T₆/W₀| 18.15a| 25.03c| 33.58c| 14.15a| 6.88c| 8.56c| 29.58c| 0.28b| 1.59a| 0.44a|
| L4   | T₂        | 27.46a| 35.35a| 45.17a| 14.46a| 7.89a| 9.82a| 32.17a| 0.36a| 1.83a| 0.51a|
|      | T₃        | 27.35a| 34.96a| 44.43ab| 14.35a| 7.60a| 9.47a| 31.43ab| 0.35b| 1.80a| 0.50a|
|      | T₄        | 26.23b| 33.99b| 43.67b| 13.23b| 7.77a| 9.67a| 30.67b| 0.34bc| 1.58b| 0.45b|
|      | T₅/T₆/W₀  | 25.48c| 32.94c| 42.23c| 12.48c| 7.46c| 9.29a| 29.23c| 0.33c| 1.49b| 0.42b|
| L5   | T₂        | 37.31a| 43.44a| 51.07a| 15.31a| 6.13b| 7.63b| 29.07a| 0.33a| 2.24a| 0.63a|
|      | T₃        | 36.77b| 43.04a| 50.86a| 14.77a| 6.28b| 7.82b| 28.94a| 0.32b| 1.69b| 0.48b|
|      | T₄        | 35.34c| 42.30b| 50.94a| 13.34c| 6.95a| 7.41b| 28.96b| 0.31b| 1.58b| 0.48b|
|      | T₅        | 34.68d| 41.04c| 51.37a| 12.68d| 7.77a| 7.41b| 28.96b| 0.30b| 1.49b| 0.42b|
|      | T₆/W₀     | 34.65d| 40.56c| 47.91b| 12.65d| 7.35b| 7.29a| 25.91a| 0.28d| 1.65b| 0.46b|
| L6   | T₂        | 43.52a| 49.53a| 57.01a| 18.52a| 6.01b| 7.48b| 32.01a| 0.21a| 1.80a| 0.51a|
|      | T₃        | 43.37a| 49.33a| 56.74a| 18.37a| 5.96b| 7.41b| 31.74a| 0.21a| 1.78ab| 0.50ab|
|      | T₄        | 42.85a| 49.11a| 56.91a| 17.85a| 6.26b| 7.79b| 31.91a| 0.22a| 1.70ab| 0.48ab|
|      | T₅        | 40.49b| 47.61b| 56.46a| 15.49b| 7.11a| 8.66a| 31.46a| 0.20a| 1.23c| 0.34c|
|      | T₆        | 40.46b| 46.65bc| 54.36b| 15.46bc| 6.20b| 7.71b| 29.36b| 0.20a| 1.32bc| 0.37bc|
|      | W₀        | 39.22b| 45.35c| 52.97b| 14.22b| 6.13b| 7.63b| 27.97b| 0.19a| 1.59abc| 0.45abc|

GIP, the gradual incremental phase; RIP, the rapid incremental phase; SIP, the slow incremental phase; TIP, the total incremental phase. Different letters within a column show significantly different at p = 0.05 (LSD).

Figure 4. Leaf-sheath length for different treatments in each wheat growing season. S₂–S₆ represent the second leaf sheath to the sixth leaf sheath in springtime. T₂ was not set in the growing seasons from 2018 to 2019 or 2019 to 2020, and W₀ was set only in the growing season from 2020 to 2021.

3.2.2. The Growth of the Leaf Sheath

As shown in Figure 5, the growth process of the leaf sheaths also presented “S”-shaped curves. Simulations were performed with sigmoid curves, and all the R² values were above 0.98. Compared with the Tₙ and W₀ treatment, Tₙ₋₁, Tₙ₋₂, Tₙ₋₃, and Tₙ₋₄ showed an
inhibitory effect during the early stage of the Sn building process. The inhibitory effect was more evident in the later-emerged leaf sheaths than in those that emerged earlier. However, the inhibitory effect impacted the growth rate during the mid-stage and late stage of the leaf sheath. The leaf sheath lengths from the early irrigation and N topdressing treatments gradually exceeded those from the late treatments, until the leaf sheath lengths reached approximately 75% of the total length.

Figure 5. Growth process of each leaf sheath in the growing season from 2020 to 2021. S3–S6 represent the third leaf sheath to the sixth leaf sheath in springtime.

Compared with the Tn and W0 treatments (Table 4), the Tn-1, Tn-2, Tn-3, and Tn-4 treatments resulted in a significant increase in Sn and prolonged the GIP of Sn, but had a negligible effect on the duration of the RIP and the SIP. Meanwhile, they significantly increased the growth rate during the RIP and the SIP of Sn, but slightly decreased the growth rate during the GIP. This indicated that irrigation and N topdressing at spring leaf ages of n-1, n-2, n-3, or n-4 mainly increased Sn length by improving its growth rate during the RIP and the SIP.

3.3. Effect of Timing of Irrigation and N Topdressing on the Length and Growth of Internodes
3.3.1. Internode Length

The ANOVA, as demonstrated by Table 2, showed that both treatments and years had significant effects on the internode length of I1–I5. Significant interaction effects between the two factors on I4 and I5 were observed. Figure 6 shows that I1 was longer in the T3 and T4 treatments, I2 was longer in the T4 and T5 treatments, I3 was longer in the T5 and T6 treatments, and I4 was longer in the T6 treatment. These results indicated that irrigation and N topdressing at spring leaf ages of n + 2 or n + 3 had a more significant promotion
on the length of In (n = 1, 2, 3, 4). However, a unique tendency occurred in I5: T₃ and T₄ produced a greater length in I5, whereas T₆ had the shortest I5.

Table 4. Characteristic parameters of the growth process of each leaf sheath in the growing season from 2020 to 2021.

| Leaf Sheath | Treatment | The End Time of Each Phase (d) | Duration of Each Phase (d) | Growth Rate of Each Phase (cm/d) |
|-------------|-----------|--------------------------------|---------------------------|-------------------------------|
|             |           | GIP   | RIP   | SIP  | GIP   | RIP   | SIP  | TIP  | GIP   | RIP   | SIP  |
| S3          | T₂        | 28.47a| 33.76a| 40.33a| 12.47a| 5.28b | 6.57b| 24.33a| 0.23b | 1.47a | 0.41a|
|             | T₃        | 27.48b| 33.65a| 41.32a| 11.48b| 6.16a | 7.67a| 25.32a| 0.24ab| 1.21b | 0.34b|
|             | T₄        | 27.37b| 33.59a| 41.34a| 11.37b| 6.22a | 7.74a| 25.34a| 0.24ab| 1.19b | 0.33b|
|             | T₅/T₆/W₀  | 27.32b| 33.70a| 41.63a| 11.48b| 6.16a | 7.67a| 25.36a| 0.24a | 1.17b | 0.32b|
| S4          | T₂        | 37.12a| 42.43a| 49.03a| 12.12a| 5.31a | 6.60a| 24.03a| 0.23ab| 1.47a | 0.41a|
|             | T₃        | 36.58b| 42.07ab| 48.91a| 11.58b| 5.49a | 6.84a| 23.91a| 0.25a | 1.43a | 0.40a|
|             | T₄        | 36.25b| 41.95ab| 49.04a| 11.25b| 5.70a | 7.09a| 24.04a| 0.25a | 1.33a | 0.37a|
|             | T₅        | 36.25b| 41.81ab| 48.72a| 11.25b| 5.55a | 6.91a| 23.72a| 0.24ab| 1.35a | 0.38a|
|             | T₆/T₆/W₀  | 36.17b| 41.31b| 47.70a| 11.17b| 5.14a | 6.40a| 22.70a| 0.23b | 1.36a | 0.38a|
| S5          | T₂        | 44.47a| 49.33ab| 55.38a| 10.47a| 4.86c | 6.05c| 21.38a| 0.31b | 1.79a | 0.50a|
|             | T₃        | 43.39a| 48.94bc| 54.60a| 10.39a| 4.55c | 5.66c| 20.60a| 0.31b | 1.96a | 0.55a|
|             | T₄        | 44.52a| 49.53a| 55.76a| 10.52a| 5.00bc| 6.23bc| 21.76a| 0.32ab| 1.86a | 0.52a|
|             | T₅        | 42.82b| 48.61cd| 55.82a| 8.82b | 5.79a | 7.21a| 21.82a| 0.34a | 1.41b | 0.39b|
|             | T₆        | 42.73b| 48.31d| 55.27a| 8.73b | 5.99ab| 6.95ab| 21.27a| 0.34a | 1.45b | 0.40b|
|             | W₀        | 42.80b| 48.42cd| 55.42a| 8.80b | 5.61ab| 6.99ab| 21.42a| 0.33a | 1.43b | 0.40b|
| S6          | T₂        | 49.64b| 56.29a| 64.57a| 9.65b | 6.65ab| 8.27ab| 24.57a| 0.39c | 1.54b | 0.43c|
|             | T₃        | 50.05a| 55.85a| 63.07ab| 10.05a| 5.80c | 7.22c| 23.07a| 0.37d | 1.73a | 0.49a|
|             | T₄        | 50.03a| 56.13a| 63.71ab| 10.03a| 6.09bc| 7.59bc| 23.71a| 0.38cd| 1.70a | 0.48ab|
|             | T₅        | 49.43b| 56.10a| 64.40ab| 9.43b | 6.67ab| 8.30ab| 24.40a| 0.41b | 1.60ab| 0.45bc|
|             | T₆        | 48.02c| 55.09b| 63.88ab| 8.02c | 7.06a | 8.79a| 23.88ab| 0.45a | 1.40c | 0.39d|
|             | W₀        | 47.60d| 54.41b| 62.89b| 7.60d | 6.81ab| 8.48ab| 22.98b| 0.44a | 1.35c | 0.38d|

GIP, the gradual incremental phase; RIP, the rapid incremental phase; SIP, the slow incremental phase; TIP, the total incremental phase. Different letters within a column show significantly different at \( p = 0.05 \) (LSD).

Figure 6. Internode length for different treatments in each wheat growing season. I1–I5 represent the first internode to the fifth internode in springtime. T₂ was not set in the growing seasons from 2018 to 2019 or 2019 to 2020, and W₀ was set only in the growing season from 2020 to 2021.
3.3.2. The Growth of the Internodes

As shown in Figure 7, the growth of the internodes also presented an “S”-shape. Simulations were performed with sigmoid curves, and all $R^2$ values were above 0.994. No significant difference was found among the treatments in the early stage of the internode growth, a result that differed from those of the leaves and leaf sheaths. The contrast emerged and gradually increased in the second half of the internode developmental process. The order of internode length among the treatments was stable during this stage.

Table 5 shows that the irrigation and N topdressing period had a more negligible effect on the termination of the GIP, the RIP, and the SIP of the internodes and the duration of the GIP, the RIP, and the SIP. However, the growth rate of $I_n$ ($n = 1, 2, 3, and 4$) during the GIP, the RIP, and the SIP were all higher under $T_{n+2}$ and $T_{n+3}$. The GIP, the RIP, and the SIP of
I5 were also higher under T3. This indicates that irrigation and N topdressing increased internode length, mainly by increasing the growth rate of the whole plant.

Table 5. Characteristic parameters of each internode growth process in the growing season from 2020 to 2021.

| Internode | Treatment | The End Time of Each Phase (d) | Duration of Each Phase (d) | Growth Rate of Each Phase (cm/d) |
|-----------|-----------|-------------------------------|---------------------------|---------------------------------|
|           |           | GIP  | RIP  | SIP  | GIP  | RIP  | SIP  | TIP  | GIP  | RIP  | SIP  |
| I1        | T2        | 36.76a | 41.96a | 48.44a | 8.76a | 5.20a | 6.48a | 20.44a | 0.18b | 0.84a | 0.24a |
|           | T3        | 37.12a | 42.34a | 48.84a | 9.12a | 5.22a | 6.50a | 20.84a | 0.20a | 0.95a | 0.27a |
|           | T4        | 36.76a | 41.74a | 47.95a | 8.76a | 4.98a | 6.20a | 19.95a | 0.19b | 0.90a | 0.25a |
|           | T5        | 36.88a | 41.98a | 48.34a | 8.88a | 5.16a | 6.42a | 20.34a | 0.18b | 0.86a | 0.24a |
|           | T6        | 36.76a | 41.92a | 48.34a | 8.76a | 5.16a | 6.42a | 20.34a | 0.18b | 0.85a | 0.24a |
|           | W0        | 36.92a | 41.93a | 48.16a | 8.92a | 5.01a | 6.23a | 20.16a | 0.18b | 0.89a | 0.25a |
| I2        | T2        | 43.83bc | 50.29a | 58.32a | 9.83bc | 6.45a | 8.03a | 24.32a | 0.19b | 0.80bc | 0.22bc |
|           | T3        | 43.74c | 50.22a | 58.27a | 9.74c | 6.47a | 8.05a | 24.27a | 0.19b | 0.80bc | 0.23b |
|           | T4        | 43.97bc | 50.50a | 58.63a | 9.97bc | 6.53a | 8.13a | 24.63a | 0.21a | 0.88b | 0.25b |
|           | T5        | 44.46a | 50.74a | 58.56a | 10.46a | 6.28a | 7.82a | 24.56a | 0.21a | 0.97a | 0.27a |
|           | T6        | 44.15ab | 50.46a | 58.31a | 10.15ab | 6.31a | 7.85a | 24.31a | 0.19b | 0.84bc | 0.24bc |
|           | W0        | 44.02bc | 50.51a | 58.59a | 10.02bc | 6.49a | 8.08a | 24.59a | 0.19b | 0.78c | 0.22c |
| I3        | T2        | 50.25ab | 55.98a | 63.11a | 10.25ab | 5.73a | 7.13a | 23.11a | 0.23b | 1.13b | 0.32b |
|           | T3        | 50.17ab | 55.92a | 63.07a | 10.17ab | 5.75a | 7.15a | 23.07a | 0.23b | 1.13b | 0.32b |
|           | T4        | 50.26ab | 56.01a | 63.17a | 10.26ab | 5.75a | 7.16a | 23.17a | 0.24b | 1.15ab | 0.32ab |
|           | T5        | 50.08ab | 55.86a | 63.05a | 10.08ab | 5.78a | 7.19a | 23.05a | 0.26a | 1.24ab | 0.35ab |
|           | T6        | 49.96b | 55.63a | 62.68a | 10.09bc | 5.66a | 7.05a | 22.68a | 0.26a | 1.28a | 0.36a |
|           | W0        | 50.40a | 55.80a | 62.51a | 10.02bc | 5.40a | 6.72a | 22.51a | 0.22b | 1.17ab | 0.33ab |
| I4        | T2        | 56.96a | 62.64a | 69.72a | 7.96a | 5.69a | 7.08a | 20.72a | 0.41bc | 1.56a | 0.44a |
|           | T3        | 56.91a | 62.62a | 69.74a | 7.91a | 5.71a | 7.11a | 20.74a | 0.42ab | 1.57a | 0.44a |
|           | T4        | 56.98a | 62.51a | 69.38a | 7.98a | 5.53a | 6.88a | 20.38a | 0.40bc | 1.60a | 0.45a |
|           | T5        | 56.80a | 62.66a | 69.95a | 7.80a | 5.86a | 7.29a | 20.95a | 0.43ab | 1.56a | 0.44a |
|           | T6        | 56.78a | 62.56a | 69.75a | 7.78a | 5.78a | 7.19a | 20.75a | 0.44a | 1.62a | 0.45a |
|           | W0        | 57.01a | 62.64a | 69.63a | 8.01a | 5.62a | 7.00a | 20.63a | 0.39c | 1.52a | 0.43a |
| I5        | T2        | 60.04bc | 66.58a | 74.72a | 8.04bc | 6.54a | 8.14a | 22.72a | 0.75ab | 2.52a | 0.70a |
|           | T3        | 60.01c | 66.55a | 74.70a | 8.01c | 6.55a | 8.15a | 22.70a | 0.76a | 2.54a | 0.71a |
|           | T4        | 60.24a | 66.79a | 74.95a | 8.24a | 6.55a | 8.16a | 22.95a | 0.73bc | 2.52a | 0.71a |
|           | T5        | 60.10abc | 66.53a | 74.52a | 8.10abc | 6.43a | 8.00a | 22.52a | 0.74ab | 2.55a | 0.71a |
|           | T6        | 60.09bc | 66.59a | 74.69a | 8.09bc | 6.51a | 8.10a | 22.69a | 0.72c | 2.43b | 0.68b |
|           | W0        | 60.17ab | 66.69a | 74.80a | 8.17ab | 6.52a | 8.11a | 22.80a | 0.65d | 2.22c | 0.62c |

GIP, the gradual incremental phase; RIP, the rapid incremental phase; SIP, the slow incremental phase; TIP, the total incremental phase. Different letters within a column show significantly different at $p = 0.05$ (LSD).

3.4. Effect of Timing of Irrigation and N Topdressing on Leaf Auricular Spacing

The ANOVA, as demonstrated in Table 2, showed that both years and treatments had significant effects on leaf auricular spacing, and there was a significant interaction effect between years and treatments on L3–L4 and L5–L6. Figure 8 shows that irrigation and N topdressing treatments could increase leaf auricular spacing, compared with W0. T5 had the largest leaf auricular spacing in L3–L4 and L4–L5 and the second-largest spacing in L5–L6. T6 had the largest leaf auricular spacing in L5–L6 and the second-largest spacing in L4–L5. This indicated that irrigation and N topdressing at the appearance of the top second (or flag) leaf could improve the vertical spacing of the upper three leaves.
Figure 8. Leaf auricular spacing for different treatments in each wheat growing season. L3–L4, L4–L5, and L5–L6 represent the spacing from the third leaf auricle to the fourth leaf auricle, from the fourth leaf auricle to the fifth leaf auricle, and from the fifth leaf auricle to the sixth leaf auricle, respectively. T₂ was not set in the growing seasons from 2018 to 2019 or 2019 to 2020, and W₀ was set only in the growing season from 2020 to 2021.

3.5. Effect of Irrigation and N Topdressing at Different Growth Stages of Each Organ

Combining the data from Tables 3–5, each treatment’s irrigation and N topdressing dates could be expressed by the number of days after an organ enters the GIP. Figure 9 and Table 6 present the amplitude in organ length increase relative to W₀, with irrigation at different growing stages of each organ. As shown in Figure 9, leaf enlargement diminished gradually after postponing the irrigation and N topdressing date. Irrigation and N topdressing from the eighth day before the leaves entered the GIP to the thirteenth day after the leaves entered the GIP had a greater effect on the leaves, with an increase of 20% to 40%. The thirteenth day after the leaves entered the GIP was close to the end date of the GIP of the leaves, which was 13 days to 15 days (Table 3).

Figure 9. Amplitude in organ length increase relative to W₀ with irrigation at different growth stages of each organ.

Table 6. The corresponding relationship between the treatment times and the times of organ entry into the GIP.

| Treatment | L4 | L5 | L6 | S3 | S4 | S5 | S6 | I1 | I2 | I3 | I4 |
|-----------|----|----|----|----|----|----|----|----|----|----|----|
| T₂        | 4  | −5 | −8 | 1  | −8 | −17| −23| −11| −17| −23| −32|
| T₃        | 11 | 2  | −1 | 8  | −1 | −10| −16| −4 | −10| −16| −25|
| T₄        | 22 | 13 | 10 | 19 | 10 | 1  | −5 | 7  | 1  | −5 | −14|
| T₅        | 29 | 20 | 17 | 26 | 17 | 8  | 2  | 14 | 8  | 2  | −7 |
| T₆        | 35 | 26 | 23 | 32 | 23 | 14 | 8  | 20 | 14 | 8  | −1 |

Irrigation and N topdressing from the seventeenth day before the leaf sheath entered the GIP to the second day after the leaf sheath entered the GIP had a more significant promotion effect on leaf sheaths with an amplification of 10% to 16%. Irrigation and N
topdressing from the fourth day before the internode entered the GIP to the eighth day after the internode entered GIP had a more significant promotion effect on internodes with an amplification of 10% to 17%. The promotion effect dropped rapidly to less than 5% when irrigation and N topdressing were carried out before or after this range. The eighth day after the internode entered the GIP was close to the end date of the internode GIP, which was eight to 10 days (Table 5).

In summary, although the largest increases in the lengths of the leaves, leaf sheaths, and internodes were observed when irrigation and N topdressing were applied before the organ entered the RIP, the specific growth stages were different among the three organs.

4. Discussion

4.1. Effect of Irrigation and N Topdressing at Different Leaf Ages on the Leaf, the Leaf Sheath, and the Internode

The report by Zhu et al. [32] on the effect on the length of leaves, internodes, and leaf sheaths of the irrigation and N topdressing stage at different leaf ages of winter wheat appeared in the 1970s. Their study showed that irrigation and N topdressing at spring n leaf age mainly lengthened leaves n + 1, n + 2, and n + 3, and when the length of the n + 2 leaf reached its maximum. In our study, leaves n + 1, n + 2, n + 3, and n + 4 lengthened significantly with irrigation and N topdressing at the n leaf age. The length of L4, L5, and L6 were all maximized by the earliest T2 treatment. This result was not consistent with those of previous studies. The study by Zhu et al. [32] showed that irrigation and N topdressing at the n leaf age mainly extended leaf sheaths n + 1, n + 2 and internodes n-2. Our study showed that leaf sheaths n + 1, n + 2, n + 3, and n + 4 and internodes n-2 and n-3 were extended by irrigation and N topdressing at the n leaf age. In summary, more leaves, leaf sheaths, and internodes were extended at the n leaf age irrigation in our study, compared with the investigation of Zhu et al. [32]. This may be due to the continuous straw return to the field and the high fertilizer input over the last 30 years. This has improved the supplying capacity of soil water and fertilizer and prolonged the validity period of irrigation and N topdressing [50,51].

Although there are few systematic studies about the effects of irrigation and N at different leaf ages on individual characters of winter wheat, some reports on the impacts of irrigation and N topdressing at different growth periods are available. Both Xu et al. [17] and Zhang et al. [16] found that the flag leaf was longer under irrigation at the upstanding stage than at the jointing stage. In our study, winter wheat reached the upstanding stage approximately after the emergence of the second leaf (T2) in spring and reached the jointing stage after the emergence of the fourth leaf (T4). In this study, the flag leaf of T2 was 10.93% longer than that of T4. Based on the above calculation, our result agrees with the findings of Xu et al. [17] and Zhang et al. [16]. Zhang et al. [26] showed that the basal first internode was longer under irrigation and N topdressing at the jointing stage than at the upstanding stage. This result is also consistent with the results of our study. However, both Zhou et al. [25] and Zhang et al. [28] concluded that the basal first internode was longer under irrigation and N topdressing at the regreening stage (equivalent to the time from the emergence of the first leaf to second leaf in spring) than at the jointing stage. This differs from our finding, as the first internode reached its maximum length with irrigation and N topdressing at the spring third or fourth leaf age. Our study did not arrange the irrigation treatment at the spring first leaf age. This needs further investigation.

Two other organ length results are worth exploring. Our results and that of Zhu et al. [32] showed that the effect of the irrigation period on L2 and L3 was smaller than the effect on the upper three leaves. This may be due to the lower temperature during the growth stages of L2 and L3, leading to a smaller difference in leaf growth rates among the treatments. Second, in our study, the T3 and T4 treatments had a longer I1, I2, and I5 but a shorter I3 and I4. In contrast, the T5 and T6 treatments had a shorter I1 and I5 but a longer I3 and I4. Therefore, we inferred that the adjacent internodes presented the wave-like growth process. When T3 and T4 promoted the elongation of internodes I1 and I2, more photosynthates were
consumed and inhibited the elongation of I3 and I4. The less photosynthetic consumption in I3 and I4 favored the extension of I5. Zhu et al. [32] shared a similar viewpoint.

4.2. Effect of Irrigation and N Topdressing at Different Leaf Ages on the Growth of the Leaf, Leaf Sheath, and Internode

Previous studies [44–46,52] showed that the growth of crop organs presented an “S” curve. In our research, the development of leaves, leaf sheaths, and internodes showed a slow–fast–slow “S” shape, similar to previous studies. Furthermore, we found that earlier irrigation and N topdressing treatments inhibited the growth of the early stage of leaf and leaf sheath. The inhibitory effect was more evident in the later-emerging leaves and leaf sheaths than in the earlier-emerged ones. However, they stimulated the growth rate during the mid-stage and late stage of organ growth. Earlier treatments did not significantly affect internodes (Figures 3, 5 and 7). There are no reports on the effect of irrigation and N topdressing periods on the development of winter wheat organs. We evaluated the possible causes of this phenomenon by combining the soil temperature changes under different irrigation and N topdressing periods.

The GIPs of L3, L4, L5, and L6 of W0 were between 4 to 19 days, 13 to 26 days, 22 to 35 days, and 25 to 41 days after regreening, respectively (Table 3). The GIPs of S3, S4, S5, and S6 leaf sheaths of W0 were between 16 to 28 days, 25 to 37 days, 34 to 43 days, and 40 to 48 days after regreening, respectively (Table 4). However, the length of I1 was approximately 4 cm on the fortieth day after regreening (Figure 7), when the plant’s growing point reached the ground surface. Thus, leaves and leaf sheaths mainly lay under the ground surface (L3–L6 and S3–S5) or reached the surface (S6) during their GIP. Their growth rate during the GIP was affected by the temperature of the surface soil layer. Zhou et al. [53] found that a soil temperature between 0 cm and 15 cm below the surface decreased after spring irrigation. Hou et al. and Chen et al. [54,55] intimated that low temperatures in spring could reduce the rate of wheat growth. In this study, the average temperature of the surface soil layer between 9:00 and 18:00 was 0.7 °C to 2.1°C lower in the earlier irrigation treatments (T2, T3, and T4) than in W0. It can be inferred that the reduced soil temperature caused by earlier irrigation inhibited the early growth of the leaf and the leaf sheath. However, the inhibition gradually weakened as the organs reached the ground surface with rising temperature. The positive role of irrigation and N topdressing emerged progressively, and the growth rate of the organ in the RIP and the SIP improved (Tables 3 and 4).

In this experiment, the irrigation dates of T5 and T6 were the forty-third and forty-eighth day after regreening, respectively, when all the leaves and most leaf sheaths were above the ground. Neither the leaves nor most of the leaf sheaths were significantly inhibited during their early growth stages by the T5 and T6 treatments. Compared with the late-emerging organs, the temperature was lower during the growth of early emerging leaves and leaf sheaths, which led to a smaller difference in ground temperature and organ growth rate among the treatments (Figure 10, Tables 3 and 4). Therefore, the early-emerging organs were less inhibited during the early growth stage. Hou et al. [54] also found that the difference in leaf growth rate between two wheat varieties at low temperature was significantly smaller than at an average temperature. This finding is similar to our result. Internode elongation was completed above the ground and was less influenced by the temperature of the surface soil layer. Early irrigation had no apparent inhibition during the early stage of internode growth.

4.3. The Effect of Irrigation and N Topdressing at Different Growth Stages of an Organ on Its Length

There are few reports on the effects of growth promoters or irrigation measures at different growth stages of organs. Dong et al. [56] concluded that applying chlorocholine chloride before the basal internode elongated had the most significant inhibition on the internodes. Mo et al. [57] suggested that irrigation before an organ reaches its maximum growth rate had a more substantial effect on an organ. Zhu et al. [13] suggested that
irrigation and N topdressing in the slow elongation stage of the leaf had the most significant impact on leaf length. The effect of irrigation and N topdressing before the leaf elongated was smaller than the former. All of these studies concluded that agronomic management measures taken in the early stages of organ growth had the greatest effect on this organ. But the above conjecture was not supported by any data. Our study obtained more detailed results combined with systematic monitoring data. A more significant growth in the leaf was achieved when irrigation and N topdressing were applied from the eighth day before the leaf entered the GIP to the thirteenth day after the GIP. Similarly, for the leaf sheath, it was obtained from the 17th day before the leaf sheath entered the GIP to the second day after entering the GIP. For the internode, it was from the 4th day before the internode entered the GIP to the eighth day after the GIP. The validity period of irrigation and N topdressing in our experiment was longer than previously reported. This may be related to the different soil textures and soil fertility in the other studies.

![Figure 10. Daily temperature difference from 9:00 to 18:00 between W0 and T2.](image)

**4.4. Interaction Effect between Irrigation and N Topdressing Period and Years**

In this study, temperature and precipitation varied across the five growing seasons (Figure 1), but the trends in organ length among the treatments were generally consistent. This result indicated that the regulatory effect of the treatments is found in most climatic year types. Although the trends among treatments were generally consistent, the differences in the treatments varied widely among years, resulting in a significant interaction effect between treatment and years. The temperature and precipitation differences may be the main reason for the more substantial differences over the years.

During the L5 building stage, the mean daily temperature was 11.35 °C and 15.24 °C in the growing seasons from 2012 to 2013 and 2013 and 2014, respectively. The variation of the L5 length among treatments was 20.85% and 63.24%, respectively, in these two years. This indicated that the temperature differences between the years should be an important reason for the differences in leaf length. A higher temperature enhances the effect of irrigation and N topdressing on leaf length. Li et al. [58] held the same view.

In the growing seasons from 2012 to 2013 and 2019 to 2020, the average daily temperature during the I4 building stages was 19.16 °C and 17.10 °C, respectively. The rainfall when I4 began elongating was 22.3 mm and 3.8 mm, respectively, and the variation of the length of I4 among the treatments was 3.26% and 15.02%, respectively. This suggested that a lower rainfall enhances the effect of irrigation and N topdressing on internode length.
5. Conclusions

The length of each leaf, leaf sheath, and internode in wheat could be directly regulated by irrigation and N topdressing at different leaf ages. Differences in temperature and precipitation over the years affected the differences in the range of organ length among the treatments. However, the orders of organ length among the treatments did not alter. The length of the upper three leaves gradually increased with the progression of irrigation and N topdressing. The most effective growth of the leaf sheath $n$ was achieved by irrigation and N topdressing at leaf stages $n-1$ or $n-2$. The most effective growth of the internode $n$ was achieved by irrigation and N topdressing at leaf stages $n + 2$ or $n + 3$. The vertical spacing among the upper three leaves was increased by irrigation and N topdressing at the appearance of the top second (or flag) leaf. The final was determined mainly by the growth rates during the RIP and the SIP. Although the largest increases in the lengths of the leaves, leaf sheaths, and internodes were observed when irrigation and N topdressing were applied before the organ entered the RIP, the specific growth stages were different among the three organs.

This experiment mainly analyzed the effects of irrigation and N topdressing on the growth of the leaves, leaf sheaths, and internodes at different leaf ages. The impact of irrigation and N fertilization on the development of wheat reproductive organs needs to be explored.

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Abbreviations

GIP the gradual incremental phase
RIP the rapid incremental phase
SIP the slow incremental phase
TIP the total incremental phase
L2, L3, L4, L5, L6, Ln the 2nd, 3rd, 4th, 5th, 6th, nth spring leaf
S2, S3, S4, S5, S6, Sn the 2nd, 3rd, 4th, 5th, 6th, nth spring leaf sheath
I1, I2, I3, I4, I5, In the 1st, 2nd, 3rd, 4th, 5th, nth internode
L3–L4, L4–L5, L5–L6 the spacing from the 3rd leaf auricle to the 4th leaf auricle, and from the 5th leaf auricle to the 6th leaf auricle
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