# The combined effect of sowing methods, and nitrogen application rates on photosynthetic characteristics, and soil water consumption of wheat

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**Research Article**

**Keywords:** Photosynthetic characteristics, soil water storage, furrow sowing, wide space sowing, nitrogen fertilizer

**Posted Date:** October 12th, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-883177/v1



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## Abstract

Sustainability of winter wheat yield under dryland conditions depends on Improvements in crop photosynthetic characteristics and, crop yield. Study the effects of sowing method and N-nitrogen rates on yield, selected sowing, and soil water storage, nitrogen translocation. Experiment comprised of three sowing methods: wide-space sowing (WSS), furrow sowing (FS), and drill sowing (DS) and seven nitrogen treatments: 0 kg ha$^{-1}$, 90 kg ha$^{-1}$, 180 kg ha$^{-1}$, 210 kg ha$^{-1}$, 240 kg ha$^{-1}$, 270 kg ha$^{-1}$ and 300 kg ha$^{-1}$.The results indicated that the sowing methods significantly affected the yield, and grain. The increase in grain yield was 25%, respectively. The photosynthetic traits, and leaf area index were highest under WS followed by FS. The plant height was highest under DS. I (WSS), and (II) (DS). Sowing method WSS with N level $N_{240}$ significantly enhanced the Photosynthesis Rate, intercellular $CO_2$, and transpiration rate .Our results indicated that implication of a proper sowing method coupled with enhanced nitrogen doses resulted in an increase in yield. WSS 240 kg ha$^{-1}$ enhances photosynthetic characteristics of flag leaves, and promotes to achieve high yield. The plants were improved, which ware beneficial to the improvement of sugar content.

## 1. Introduction

Winter wheat (*Triticum aestivum* L.) is one of the most important food crops in the world. It is an important crop in the southeast Loess Plateau of China, accounting for about one-fifth of food production. Nevertheless, the yields in this areaa are often unstable owing to limited and uneven precipitation distribution in the fallow and growing season (Kang et al., 2002). For dryland wheat production the major task is to use method which could effectively enhance the soil moisture consumption. Furrow sowing method has been used for dryland wheat production. Compared with drill sowing, furrow sowing can increase the growth of wheat at various growth stages, and improve the efficiency of water uptake and increase yield (Zhao et al., 2020). Nutrients management, and cultural practices greatly influence Photosynthesis in crops. Wise space sown is an adapted form of drill sowing in which the seeds are evenly distributed, and in the same level (Tao et al., 2018). Appropriate water management can improve the light transmittance and photosynthetic area of wheat in the later growth periods, promote the accumulation and translocation dry matter, in wheat before heading (Xu et al., 2010). Therefore, it is of great importance to investigate the high-yield cultivation of wheat while regulating the water content at the tillering stage. Photosynthesis is necessary to accumulate energy and dry matter for plant growth and development. Photosynthesis of wheat leaves accounts for 95% of yield. The influence of environmental factors on photosynthesis can be reflected by chlorophyll light (Tabassum e*t al*., 2007). Photosynthesis, transpiration, stomatal opening, and other physiological processes interact with each other (Wang *et al*., 2012). Previously, researchers believed that flag leaf photosynthesis provided most of the assimilates for grain filling (Evans et al., 1975);However, some studies have shown that wheat ear is an important source of photosynthetic carbon assimilation during grain filling, especially in the case of water deficit (Maydup et al., 2012; Jia et al., 2015).It is now generally accepted that ear photosynthesis in wheat is the main contributor to the final grain yield (Tambussi et al. 2007).Compared with flag leaves, the photosynthetic rate of wheat spike decreased less under water deficit condition (Martinez et al., 2003;Tambussi et al., 2005).Several traits may support better photosynthetic performance of wheat ear than flag leaf under drought conditions.First, wheat is closer to the grain, which is the main photosynthetic spike compared to flag leaves (Tambussi et al., 2007). Several traits may support better photosynthetic performance of wheat ear than flag leaf under drought conditions.First, wheat is closer to the grain, which is the main photosynthetic sink compared to flag leaves (Tambussi et al., 2007).The sowing methods used in wheat cultivation include DS, WSS and, FS, which affect the yield of wheat (Wang et al., 2016). Showed that drilling sown in dry land could increased stem height, lengthen the growth time of functional green leaves, improve spike quality and yield compared with that in flat land Yue et al. (2006). The wide space sowing is a three-dimensional uniform sowing in which seeds are evenly distributed despite sowing in rows. (Tao et al., 2018) reported that the tiller number and percentage of productive tillers, leaf area index, dry weight, and yield were increased by uniform sowing without a significant decline in grain protein. In China excessive applicaion of N fertilizers by farmers is widely practiced to sustain further increase grain yield, but grain yield does not keep synchronous increase with excessive N application (Meng et al., 2016). Nitrogen application during the wheat growing season generally exceeds 340 to 300 kg N ha$^{-1}$ however, some farmers use rates as high as 750 kg N ha$^{-1}$ (Cui et al., 2010; Lu et al. 2015; Zhang et al., 2015). This study were (i) to find the photosynthetic traits yield, and (ii). Compared with the Drill Sowing, Furrow Sowing's soil water storage of 0-200 cm soil at anthesis stage was significantly increased, and increased the soil water storage of 0–60 cm soil layer, 60–120 cm soil layer in Normal year (iii) to optimize N rates under the sowing methods which produced the highest yield of wheat crop.

## 2. Materials And Methods

# 2.1 | Descripton of experimental site

The field experiments were conducted during the winter season (2016–2017 and 2017-18 at the experimental station of Shanxi Agricultural University. The experimental area is geographically located in Wenxi county (34° 35 'N and 110°15' E.), Shanxi Province, China and characterised by, hilly, semi arid area. In these regions, precipitation is the sole source of moisture and the mean annual rainfall ranges from 450–630 mm, of which 60–70% precipitation is concentrated in July-September. Winter wheat is planted in early to mid- October and harvested in early June, while corn is planted in mid to late June and harvested in early October of the same year. The soil of the experimental site Table. 1

Table 1
Soil nutrient properties from experimental location in Shanxi. (Data source: Meteorological Station of Shanxi, Wenxi)

| Year | Organic matter (g kg$^{-1}$) | Total nitrogen (g kg$^{-1}$) | Alkali-hydrolysis nitrogen (mg kg$^{-1}$) | Available phosphorous (mg kg$^{-1}$) |
|---|---|---|---|---|
| 2012 | 8.63 | 0.71 | 32.89 | 15.73 |
| 2013 | 9.18 | 0.70 | 39.32 | 16.62 |
| 2014 | 9.55 | 0.68 | 37.65 | 17.64 |
| 2015 | 8.54 | 0.67 | 32.79 | 19.23 |
| 2016 | 10.62 | 0.69 | 38.22 | 15.28 |
| 2017 | 12.07 | 0.86 | 36.42 | 16.26 |
| 2018 | 12.61 | 0.88 | 44.07 | 12.71 |

We divided the studied years in to wet, normal, and dry years on the base of percentiles Because our goal was to characterize the wheat yield and other traits during the studied year according to precipitation, we selected the percentile range to ensure that there were adequate numbers of years to analyze. The 70th percentile (520.5 mm) and 30th percentile (425.8 mm) of the 37-year distribution of annual precipitation amounts were selected to distribute years. The years between 70th and 30th percentiles were taken as normal years (2013/14 and 2014/15). Whereas years 2011/12 (91.6 percentile) and 2010/11 (77.7 percentile) were characterized as the wet years which received 184 and 45.6 mm higher annual precipitation than the average respectively. The years 2009/10 (2.7 percentile), 2012/13 (5.5 percentile), 2015/16 (13.8 percentile), and 2016/17 (22.2 percentile) were considered as dry years with 154.1, 146.2, 102.3, and 82.8 mm less precipitation than the average precipitation.

### The precipitation distribution and relative deviation in precipitation

The precipitation distribution during the fallow and wheat growth stages, i.e. precipitation from sowing to jointing, jointing to anthesis, and anthesis to maturity of winter wheat are given in **Fig. 2.**The average of annual precipitation from 1981 to 2017 was 489.07 mm. During studied years, the relative deviation in precipitation from the mean average precipitation during the last 37 years were measured.

# 2.2 | Measurements and methods

### Site description

The study was conducted in the experimental wheat base of Shanxi agricultural university in Wenxi Shanxi Province, China (34°35'N, 110°15'E) from 2017–2019,which belongs to the temperate continental climate zone, with an average annual temperature of 10.4°C. The experimental area was located in the southeastern Loess Plateau. This site has a typical, semi-arid, warm temperate climate with 486.8 mm average annual precipitation (the sum of fallow season and growth period precipitation), 12.9 ∘C average daily temperature, and 2242 h of annual sunshine. The primary crop rotation system was rain-fed winter wheat-summer fallow. Winter wheat was sowed in late September or early October and harvested in early to late June of the following year. Rain-fed agriculture was popular owing to scarce rainfall, and unavailable irrigation condition from harvest in the previous growing season (early/mid-June every year) to sowing in the next growing season (late September/early October). Approximately 60% of the annual precipitation occurs between July and September during the summer fallow season and no irrigation system. Classified as aridic and loamy (Chinese soil taxonomy). The average of annual precipitation from 1981 to 2017 was 489.07 mm. During studied years, the relative deviation in precipitation from the mean average precipitation during the last 37 years were measured.

# 2.3 | Experimental design and treatments

The experiment had a single-factor randomized block design. The experiment comprised of three sowing methods: wide-space sowing WSS (row and sowing spacing were 25 and 8 cm,2BMF-12/6, tillage, auto-fertilization), furrow sowing, FS (furrows depth 6–7, ridge height 3-4cm, wide and narrow row spacing were 20–25, and 10–12 cm, 2BMFD-17/14 multipurpose), and drill sowing □DS (row and sowing spacing were 20 and 3 cm□2BXF-12Seed driller). The area of each plot was 2.5 m × 40 m = 100 m2 and repeated each treatment three times, Winter wheat (*Triticum aestivum* L.), cultivar ‘Yunhan 20410’ were obtained from the Wenxi Agriculture Bureau, Wenxi, China. The planting density was 225 × 104 plant ha$^{-1}$.

N in the form of 46% (wt/wt) urea was applied at the rates of 150 kg N ha$^{-1}$ before sowing. seven Nitrogen application rates (0 kg ha$^{-1}$, 90 kg ha$^{-1}$, 180 kg ha$^{-1}$, 210 kg ha$^{-1}$, 240 kg ha$^{-1}$, 270 kg ha$^{-1}$, and 300 kg ha$^{-1}$). Pure $P_2O_5$ and $K_2O$ were applied at the rate of 150 and 75 kg ha$^{-1}$ respectively. The seeds were sown on September 25, 2017, and September 25, 2018. Approximately 20–30 cm of the post-harvest stubble was left intact to increase soil organic carbon and reduce evaporation, and the remaining wheat stubble (20–30 cm) was plowed to a 25–30 cm depth using a rotator at the beginning to middle of July by deep plowing, as described by Sun et al. (2018). All plants were harvested in June 1, 2018 and June 2, 2019. The field was kept free from insects, pests, and diseases using pesticides as needed.

Table 2
Information on land preparation, and field management in the experiment.

| Items | Growing season | | |
|---|---|---|---|
| | 2016–2018 | 2016–2017 | 2017–2018 |
| Wheat cultivar | ‘Hanyun20410' | | |
| Wide-space sowing [WSS] | 22–25 cm depth | | |
| Furrow sowing [FS] | 10–12 cm depth | | |
| Drill sowing [DS] | 18–20 cm depth | | |
| Date of WSS, FS, and DS | 14 July | 14 July | 11 July |
| Date of Rotary tillage and land leveling | 21 Aug | 27 Aug | 24 Aug |

# 2.4 | Photosynthetic characteristics

The various photosynthesis attributes including net Photosynthesis Rate ($P_N$), transpiration rate ($E$), carbon dioxide concentration (Ci), and, stomatal conductance (Ci), ($g_S$) of upper most fully opened leaf was measured using a hand-held portable photosynthesis machine (CI-340 system USA). These measurements for wheat functional leaves were carried out in the morning from 9:00–11:00 a.m on a bright sunny day using in each growth period. Three samples were continuously measured for each treatment, and the test data were the average value measured throughout the day. In each treatment plants (20) dry biomass was recorded. At physiologicalmaturity, the ears were cut, save in the mesh bag, and were dried to investigate the number of spikes per unit area, average grain number per spike, and 1000-grain weight were recorded. Another 20 $m^2$ area was harvested to determine the grain yield (kg $ha^{-1}$).

# 2.5 | Grain to leaf area ratio

Grain to leaf ratio was calculated according to (Feng *et al.*,1999), using *Equations* 1 and 2:

$$\mathrm{Grainnumbertoleafarearatio} = \frac{\mathrm{totalnumberofgrainparunitarea}}{\mathrm{totalleafareonthesameplotatbootingstage}} \quad (\textit{Eq. 1})$$

$$\mathrm{Grainweighttoleafratio} = \frac{\mathrm{grainweight(mg)parunitarea}}{\mathrm{totalleafareonthesameplotatbootingstage}} \quad (\textit{Eq. 2})$$

# 2.6 | Statistical analysis

The data were subjected to analysis of variance (ANOVA) using DPS and SAS 7.5 and the significant difference between treatment means were compared using least significant difference (LSD) test at $P = 0.05$. All graphs were drawn using Microsoft Excel 2010.

## 3. Results

# 3.1 | Photosynthetic characteristics, and agronomic characteristics

With the development of winter wheat after anthesis, the photosynthetic rate of the flag leaf showed a continuous decreasing trend, with a large decrease in the early to middle stage of filling (Fig. $3_A$). The photosynthetic rate under wide space sowing in different periods after flowering was the highest, which was 63%, higher than drill sowing, and 42% ,in furrow sowing. WS, FS especially promoted the early and mid-filling stage, while drill sowing mainly promote the photosynthesis during the flowering and early filling stages. Among them, the wide space sowing showed the best effect. The transpiration rate of the flag leaf showed a continuous decreasing trend, and the decrease was greater in the middle to the end of filling (Fig. $3_B$). The transpiration rate under the wide-space sowing furrow sowing treatment at different periods after flowering was the highest, which was increased by 54%, and 126% respectively compared with the drill, and the furrow increased by,51% compared with the drill sowing. The different sowing methods can promote flag leaf transpiration after anthesis, especially at the end of filling stage. Among them, the wide space sowing has the best effect. The intercellular carbon dioxide concentration continues to increase, with a larger increase in the early to mid-stage filling (Fig. $3_C$). The intercellular carbon dioxide concentration under wide space sowing treatments at different periods flowering was the highest, which was increased by 21%, respectively compared with drill sowing. 6%, even sowing compared with drill sowing in the middle and end of grouting, increase by 4% and 5% respectively. The different sowing methods can promote the increase of intercellular carbon dioxide concentration in middle and late stage of filling, among which, wide space sowing can also promote the flowering and early stages of filling. As the growth process of winter wheat after anthesis progresses, the stomatal conductance of the flag leaf shows a continuous decreasing trend, and the decline is larger in the early to middle stage of filling (Fig. $3_D$). Stomatal conductance in different periods after flowering, wide space sowing increased by 40% compared with drill sowing, and furrow sowing increased by 32%, compared with drill sowing. Drill sowing increased by 25% respectively. Different sowing methods improved the stomatal conductance of flag leaves after anthesis, especially at the end of filling stage. Among them, except for the initial stage of grouting, the wide space sowing performs best.

Leaf area index LAI (Fig. $3_E$) in each growth period increased and then decreased, reaching the maximum at booting stage. The leaf area index of WSS was higher than that of direct seeding at different growth stages. especially WSS, significantly increased planting, and effect was more significant in the later growth period. That with the progress of fertility the plant height (Fig. $3_F$) Under different seeding methods, it rose first and then flattened out gradually.The plant height of WSS was higher than that of FS and DS.The showed that different planting methods had the most significant effect on increasing the plant height of WS, and FS LAI (Fig. $3_G$) It showed a trend of increasing first and then decreasing, and the difference between booting stage and maturity stage was obvious.At booting and maturity stages, the leaf area at WSS sowing date was significantly higher than that at other sowing dates, the leaf area at WSS was significantly higher than that at FS and DS, and the leaf area at FS sowing date was significantly higher than that at DS. Different sowing methods increased the leaf area of winter wheat at late growth stage, followed by wide sowing and even sowing.The effects of different sowing methods on plant height at different growth stages were observed. (Fig. $2_H$).There was no significant difference between the planting methods at winter and jointing stage, where, significant difference between DS and other planting methods were observed at anthesis and maturity period. The plant height of DS in different growth stages was the lowest. In wintering, jointing, and booting stage, the plant height was maximum at FS, and at the flowering and maturity stage, the plant height was higher in DS than FS.

## 3.2 | Effects of different sowing methods on soil water storage in 0-200 cm layer at flowering stage and grain yield and protein content

The soil moisture furrow sowing and wide sowing have different effects on the soil water storage in the 0-200 cm soil layer at the flowering stage of upland wheat (Table 3).Normal water year, compared with drill sowing, furrow sowing, and wide sowing increased soil water storage in 0–60 cm soil layer by 31%, and reached significant levels in 0–20 cm and 20–40 cm. Compared with other sowing methods, wide-space sowing significantly increased soil water storage in the 60–120 cm soil layer by 18.5–56.8%.In the 2018–2019 water-deficient years, compared with drill sowing, wide-space sowing significantly increased soil water storage in the 0–80 cm and 140–200 cm layers by 38%, while broad sowing reduced soil water storage in the 0-200 cm layer at the flowering stage. The furrow sowing is beneficial to increased soil water storage in 0–60 cm soil layer during flowering period, 60–120 cm soil storage in normal years, 140–200 cm soil storage in low water years, and wide-space sowing in normal years is beneficial to increase soil water storage in 0-120 cm soil layer.

Table 3
Effects of different sowing methods on soil water storage in 0-200 cm soil layer at flowering stage. Different lowercase letters indicated that different sowing methods had significant differences at the level of 0.05.

| **Sowing method** | **Normal year** | | | | | **Dry year** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Soil depth (cm)** | | | | | | | | | |
| | **0–20** | **20–40** | **40–60** | **0–60** | | **0–20** | **20–40** | **40–60** | **0–60** | |
| WSS | 28.74 b | 30.21 a | 24.92 b | 83.87 b | | 15.61 c | 17.29 c | 17.87 b | 50.77 b | |
| FS | 30.91 a | 31.07 a | 28.78 a | 90.76 a | | 19.74 a | 20.42 a | 21.84 a | 61.99 a | |
| DS | 23.58 c | 21.47 b | 26.72 ab | 71.76 c | | 17.25 b | 18.07 b | 16.82 b | 52.13 b | |
| | 60–80 | 80–100 | 100–120 | 60–120 | | 60–80 | 80–100 | 100–120 | 60–120 | |
| WSS | 22.43 b | 23.58 b | 25.10 b | 71.11 b | | 18.41 b | 20.43 b | 23.04 b | 61.88 b | |
| FS | 30.43 a | 31.73 a | 29.74 a | 91.89 a | | 24.62 a | 18.43 c | 16.36 c | 59.41 b | |
| DS | 19.43 c | 20.23 c | 20.80 c | 60.46 c | | 20.01 b | 26.00a | 25.34 a | 71.34 a | |
| | 120–140 | 140–160 | 160–180 | 180–200 | 120–200 | 120–140 | 140–160 | 160–180 | 180–200 | 120–200 |
| WSS | 24.99 a | 28.81 b | 27.81 b | 14.49 b | 96.10 c | 15.22 b | 18.02 c | 24.37 b | 13.84 b | 71.46 c |
| FS | 26.67 a | 25.53 c | 24.90 c | 23.48 a | 100.58 b | 18.76 a | 27.99 a | 28.55 a | 18.08 a | 93.38 a |
| DS | 22.28 b | 32.98 a | 35.42 a | 15.76 b | 106.45 a | 17.44 a | 20.17 b | 24.22 b | 13.24 b | 75.07 b |

Different sowing methods, Normal year, and Dry year extremely significant effects on grain protein content, protein yield and grain yield. The grain protein content of dry land wheat was higher in low water year than in normal water year, but the grain yield and protein yield were (Table 4), indicating that increasing soil water content was beneficial to increased grain yield and protein yield, while moderate drought was beneficial to increase grain protein content. Compared with the drill sowing, the grain yield was significantly increased by 39% and 43% by soil moisture, and the grain protein content and protein yield were significantly increased by 48% by soil moisture trenching compared with other sowing methods. Compared with other sowing methods, the contents of albumin, globulin and gluten and the ratio of gluten in grains were significantly increased by soil moisture seeding in the normal water year. The content of globulin in grains was significantly increased by wide sowing, but the ratio of gluten was decreased by wide-space sowing. In compared with other sowing methods, furrow sowing by soil monitoring significantly increased the albumin and globulin contents of grains, while wide-space sowing significantly decreased the Globulin, and gluten contents of grains .The furrow sowing under soil monitoring is beneficial to increase grain albumin and globulin content, protein content, protein yield and grain yield, and broad sowing in normal water year is beneficial to increase grain glutenin content.

Table 4
Effect of different sowing methods on yield and protein accumulation of grains in different precipitation years. Different lowercase letters indicated that different sowing methods had significant differences at the level of 0.05

| **Type** | **Sowing method** | **Albumin (%)** | **Globulin (%)** | **Gliadin (%)** | **Glutenin (%)** | **Glu/Gli** | **Protein content (%)** | **Yield (kg ha$^{-1}$)** | **Protein yield (kg ha$^{-1}$)** |
|---|---|---|---|---|---|---|---|---|---|
| Normal year | WSS | 3.44 b | 1.83 b | 4.87 a | 4.54 b | 0.93 c | 14.68 b | 4167.26 b | 611.74 b |
| | FS | 3.83 a | 1.95 a | 4.72 c | 4.64 a | 0.98 a | 15.14 a | 4592.45 a | 695.32 a |
| | DS | 3.41 c | 1.87 c | 4.79 b | 4.55 b | 0.95 b | 14.62 b | 3814.76 c | 557.57 c |
| Dry year | WSS | 3.46 b | 1.97 b | 4.72 c | 4.61 b | 0.98 a | 14.75 c | 3202.50 b | 472.33 b |
| | FS | 3.88 a | 2.06 a | 4.87 b | 4.79 a | 0.98 a | 15.60 a | 3925.00 a | 612.32 a |
| | DS | 3.47 b | 1.96 b | 4.90 a | 4.81 a | 0.98 a | 15.14 b | 2711.64 c | 410.50 c |
| F Values | | | | | | | | | |
| Year(Y) | | 52.45$^{**}$ | 251.31$^{**}$ | 47.35$^{**}$ | 139.24$^{**}$ | 176.33$^{**}$ | 373.03$^{**}$ | 2259.98$^{**}$ | 2435.12$^{**}$ |
| Sowing(S) | | 2088.41$^{**}$ | 89.31$^{**}$ | 40.48$^{**}$ | 37.70$^{**}$ | 57.00$^{**}$ | 472.70$^{**}$ | 905.07$^{**}$ | 1594.25$^{**}$ |
| Y×S | | 5.38$^{*}$ | 4.38$^{*}$ | 313.17$^{**}$ | 16.87$^{**}$ | 60.33$^{**}$ | 60.60$^{**}$ | 44.91$^{**}$ | 65.52$^{**}$ |

## 3.3| Correlation analysis between soil water storage. grain protein accumulation in different soil layers at anthesis stage Soil consumption of 0-200 cm at each growth stage.

There was a negative correlation between the soil water storage and the contents of albumin, globulin and protein and the yield of protein in the 60–120 cm soil layer at the flowering stage of different precipitation years (Table 5). Normal Year, the soil water storage in the 0–60 cm soil layer at flowering stage was positively correlated with the content and yield of albumin and protein, while the soil water storage in the 60–120 cm soil layer was negatively correlated with albumin and protein. water-deficient years, the soil water storage in the 0–60 cm and 120–200 cm layers was significantly or extremely significantly positively correlated with the contents of albumin, globulin, protein and protein as well as protein yield, while the soil water storage in the 60–120 cm layer was negatively correlated with the content of protein and protein yield. The soil water storage in the 0–60 cm layer was significantly positively correlated with the content and yield of albumin and protein in different years, while the soil water storage in the 60–120 cm layer was negatively correlated with the content and yield of protein. Soil water storage in the 120–200 cm depth was positively correlated with albumin, globulin, protein content and protein yield in the water-deficient years.

Table 5
Correlation coefficients between soil water storage at different depths at anthesis and protein accumulation in grain

| Year | Soil depth (cm) | Albumin (%) | Globulin (%) | Gliadin (%) | Glutenin (%) | Glu/Gli | Protein content (%) | Protein yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Normal year | 0–60 | 0.8148** | 0.4902 | -0.3639 | 0.5607 | 0.5499 | 0.8121** | 0.9441** |
| | 60–120 | -0.7908** | -0.4449 | 0.3660 | -0.5807 | -0.5409 | -0.7866** | -0.9424** |
| | 120–200 | -0.1629 | 0.2310 | -0.3662 | 0.1200 | 0.1887 | -0.1508 | -0.4532 |
| Dry year | 0–60 | 0.9735** | 0.9789** | 0.4564 | 0.4854 | 0.6444 | 0.9125** | 0.9083** |
| | 60–120 | -0.6249 | -0.7061* | 0.4406 | 0.3671 | -0.0047 | -0.2463 | -0.8320** |
| | 120–200 | 0.9894** | 0.9645** | 0.5059 | 0.5435 | 0.6492 | 0.9465** | 0.8959** |

## 3.4| Effects of different nitrogen application rates on soil water storage of 0-200 cm at each growth stage and yield,

Soil water storage of 0-200 cm at different growth stages with different sowing methods combined to different nitrogen application rates had different changes (Table 6). Under wide-space sowing, the soil water storage at the wintering stage was significantly highest at N270, and lowest at N90; the soil water storage at the jointing stage, flowering stage and maturity stage was significantly lowest at N240. The soil water at the jointing stage mainly consumed 20–80 cm soil layer, and the soil water at the flowering, and maturity stage mainly consumed 100–200 cm soil layer (Fig. 4A).In furrow sowing, N240 and N210 were the highest and lowest values for soil water storage at wintering and jointing stages, and N210 were also the lowest values at flowering and mature stages. The soil water storage at jointing stage was mainly stored below the soil layer of 100 cm, and the soil water in the soil layer of 40–80 cm was mainly consumed at jointing and flowering stages. In the flowering stage, 100–200 cm depth mainly consumed (Fig. 4B). In drill sowing, the wintering, and jointing stages was the lowest at N0, while at the flowering and mature stages the lowest at N210 (Fig. 4C). The soil water in the 40–80 cm depth was mainly consumed at the jointing stage, and that in the 100–160 cm depth was mainly consumed at the flowering and mature stages.

Table 6 Effects of sowing method, and N input on soil water storage of 0-200 cm depth at different growing stage for winter wheat

| Sowing method | N rate | Wintering | | Jointing | | Flowering | | Maturity | |
|---|---|---|---|---|---|---|---|---|---|
| WSS | N0 | 444 | b | 369 | a | 428 | a | 364 | a |
| | N90 | 386 | e | 359 | b | 409 | b | 316 | b |
| | N180 | 404 | d | 363 | ab | 392 | c | 316 | b |
| | N210 | 430 | c | 339 | c | 376 | d | 295 | c |
| | N240 | 428 | c | 303 | d | 331 | e | 234 | d |
| | N270 | 457 | a | 355 | b | 383 | cd | 293 | c |
| | N300 | 445 | b | 373 | a | 403 | b | 358 | a |
| FS | N0 | 453 | c | 367 | b | 396 | b | 340 | a |
| | N90 | 445 | c | 369 | b | 383 | c | 318 | c |
| | N180 | 463 | b | 372 | b | 367 | d | 319 | c |
| | N210 | 428 | d | 365 | b | 384 | c | 307 | d |
| | N240 | 489 | a | 389 | a | 382 | c | 299 | d |
| | N270 | 428 | d | 371 | b | 405 | a | 323 | c |
| | N300 | 427 | d | 368 | b | 411 | a | 332 | b |
| DS | N0 | 393 | c | 366 | d | 404 | d | 377 | a |
| | N90 | 451 | ab | 382 | b | 457 | a | 368 | ab |
| | N180 | 441 | b | 409 | a | 431 | b | 336 | c |
| | N210 | 458 | a | 383 | b | 378 | e | 268 | e |
| | N240 | 453 | ab | 401 | a | 433 | b | 344 | d |
| | N270 | 446 | b | 374 | c | 432 | b | 348 | b |
| | N300 | 463 | a | 395 | ab | 417 | c | 336 | c |

The yield and panicle number increased firstly and then decreased with the increase of nitrogen application rate. (Table 7) The yield increased by 35%, and the panicle number increased by 1.2%-16.0% with the increase of N240, furrow sowing and N210, respectively. Grain number per panicle and 1000-grain weight were also higher in wides drill with N240, and drill with N210, and 1000-grain weight was higher in furrow with N210.

Table 7
Effects of sowing method, and N input on grain yield components Different letters indicate significant differences (p < 0:05) among treatments within a growth stage by Fisher's least significant difference.

| Sowing method | N rates | Ear numbers ($10^6$ $ha^{-1}$) | | Grain number per ear | | 1000-grain weight(g) | | Yield (Kg $ha^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|
| WSS | N0 | 7.99 | d | 29.6 | b | 36.9 | b | 7361 | d |
| | N90 | 8.39 | c | 31.9 | ab | 40.3 | ab | 8744 | c |
| | N180 | 8.69 | b | 31.3 | ab | 40.2 | ab | 9443 | b |
| | N210 | 8.70 | b | 31.5 | ab | 40.4 | ab | 9630 | b |
| | N240 | 9.00 | a | 32.6 | a | 43.8 | a | 10829 | a |
| | N270 | 8.70 | b | 32.2 | a | 42.8 | a | 9891 | b |
| | N300 | 8.10 | d | 29.7 | b | 38.0 | b | 7445 | d |
| FS | N0 | 7.66 | cd | 29.7 | ab | 37.8 | c | 7280 | d |
| | N90 | 8.04 | b | 30.3 | ab | 41.8 | b | 8572 | c |
| | N180 | 8.27 | ab | 30.6 | a | 43.2 | ab | 8925 | b |
| | N210 | 8.54 | a | 30.7 | a | 45.0 | a | 9569 | a |
| | N240 | 8.37 | a | 31.2 | a | 44.9 | a | 9401 | a |
| | N270 | 7.99 | bc | 29.6 | ab | 42.6 | ab | 8729 | bc |
| | N300 | 7.56 | d | 28.2 | b | 38.5 | c | 7072 | d |
| DS | N0 | 6.45 | e | 29.7 | b | 37.6 | b | 6299 | e |
| | N90 | 6.64 | d | 31.7 | ab | 40.1 | a | 7002 | c |
| | N180 | 6.94 | c | 32.4 | a | 39.5 | ab | 7565 | b |
| | N210 | 7.48 | a | 32.8 | a | 40.8 | a | 8492 | a |
| | N240 | 7.39 | ab | 31.4 | ab | 41.5 | a | 8342 | a |
| | N270 | 7.25 | b | 29.1 | b | 36.1 | b | 6596 | d |
| | N300 | 6.52 | de | 30.1 | b | 38.8 | ab | 6570 | d |

## 3.5 | Effect of nitrogen rate on photosynthetic characteristics, and agronomic attributes and soluble sugar content, sucrose and cereal starch.

The of $CO_2$ concentration of the flag leaves in different treatments showed a gradually declining trend with the grouting process and the 0-7D. With increase in the amount of N-nitrogen fertilizer,the net photosynthetic rate ($P_N$) increased showing a single peak curve at the 7–14 days after flowering (**Fig. 5**$_{A}$), After flowering the $P_N$ value was still higher at

N300 but wasnot significantly different from 270 kg ha$^{-1}$ and 240 kg ha$^{-1}$ .After flowering 21D and 28D $P_N$ was increased with N application and the flower 21D was higher with 240 kg ha$^{-1}$ as compared to other treatments. After 28D of flowering, the Pn was still the highest with N240, but the difference was not significant compared to 180 kg ha$^{-1}$, 210 kg ha$^{-1}$, 270 kg ha$^{-1}$ and 300 kg ha$^{-1}$. Overall, the application of N fertilizer enhanced the Pn after flowering, but the effect of high nitrogen treatments 270 kg ha$^{-1}$, 300 kg ha$^{-1}$ was weakened in the later grouting and the WSS coupled with 240 kg ha$^{-1}$ sustained higher values at the whole grouting period. The intercellular $CO_2$ ($C_i$) of the flag leaves of DS and WSS, was gradually decreased with the growing process, however, with the increase in the amount of N application, Pn showed a first decreasing and then increaseing trend after flowering. From the **Fig. 5$_B$**, it is obvious trhat the 240 kg ha$^{-1}$ treatment was significantly lower than other treatments on 7-14D and 21D after flowering and 0 kg·ha$^{-1}$ was the highest 240 kg ha$^{-1}$ and was lowest on 28D after flowering, but the difference was not significant compared with 270 kg ha$^{-1}$. The increase of nitrogen fertilizer can significantly reduce the intercellular $CO_2$ concentration in the leaves of the flags after flowering and the whole grouting period can be continued. The $G_S$ of the flag leaves in WSS and DS treatment was gradually decreased with advancement of growth stages\ while first increased and then decreased with increasing nitrogen application rate. From the **Fig. 5$_C$** it was evident that the 240 kg ha$^{-1}$ treatment resulted in higher $G_S$ values than other treatments on the 14D after flowering and, was the lowest in 0 kg·ha$^{-1}$ and was highest in 240 kg·ha$^{-1}$ at 21-28D, but the difference was not significant. That increased N fertilizer can significantly increase the $G_S$ of flower flag leaves but the effect lasts until the middle stage of growth and the effect was weakened in the later stage. Moreover, the $T_R$ of flag leaves gradually decreased with the grouting process and the *T*r of flag leaves was first increased and then decreased with the increase in N application after flowering. The **Fig. 5$_D$** indicated that after flowering the Tr values in 240 kg ha$^{-1}$ and 270 kg ha$^{-1}$ treatments were significantly higher as compared to the other treatments from 7–14 days and 21D, and 0kg ha$^{-1}$ was the lowest. After 28D, the values was greater in 240 kg ha$^{-1}$ than other treatments and 0kg ha$^{-1}$ was the lowest. These results indicated thatthe increase in N fertilizer can significantly enhance the Tr of flag leaves after flowering and last for the whole growth period and the best effect was observed in 240 kg ha$^{-1}$ coupled with large WSS, DS

The plant height of wheat in WSS treatment showed a steady increase and then decline with the increase in N rates (**Fig. 5$_E$**). At jointing stage, plant height of $N_{240}$ treatment was significantly higher than other treatments and there was no significant difference between $N_{210}$ and $N_{270}$, $N_{180}$ and $N_{300}$, $N_0$ and $N_{90}$. After entering the jointing stage, the treatment with $N_{210}$ and $N_{240}$ showed the highest plant heigh, and the values in $N_{90}$ and $N_0$ was the lowest. The $N_{240}$ increased the plant height and promoted the growth of wheat in the middle stage of wheat growth. Similar to plant height, he leaf area index LAI of WSS showed an increasind and then a declining trendat jointing and booting stages with an increase in nitrogen rates (**Fig. 5$_F$**). Joint, booting, 240 kg ha$^{-1}$ was significant It was significantly higher than other treatments, and N0 was the lowest. WSS was beneficial to wheat growth and WSS combined with $N_{240}$ had the largest leaf area index and the best growth condition in each growth stage.

The soluble sugar wide sowing decreased gradually with grain filling, but increased continuously with the increased of N rate at each stage after flowering (Fig. 6$_A$). From 5d to 30d after an thesis, N300 treatment had the highest soluble sugar content, but other treatments (except N0) had no significant difference, and N0 treatment had the lowest soluble sugar content. At 35d after anthesis, there was no significant N0. In conclusion, increasing nitrogen fertilizer was beneficial in enhancing levels of soluble sugar at the middle and late stage, which could last until 25D after anthesis, and provided conditions for starch synthesis. However, there was no difference between N240, N270 and N300, and the effect of nitrogen fertilizer was weakened in the late stage. During grain filling, the sucrose content of wide sowing wheat decreased gradually, but showed an increasing trend with the increase of nitrogen application rate, and maintained the highest level on the 5th day after anthesis (Fig. $6_B$).The content of sucrose in different periods after anthesis could be increased by increasing nitrogen application rate. On the 5th day after anthesis, sucrose contents of N300 was higher as compared to restof the treatments. On the 15th day after anthesis, the highest sucrose content was found in N270, followed by N210, N240, N300. At 25D after anthesis, N300 had the highest value, but it was statistically similar to that in N240, N270 treatments.At 35D after anastomosis, N300 treatment still had the highest value, but there was no significant difference among different treatments. In conclusion, increasing nitrogen fertilizer can promote sucrose synthesis, and lay the foundation for starch accumulation, especially in the early stage of grain filling, and in the middle stage of high nitrogen treatment N240, N270, and N300, there is no significant difference, and the effect of nitrogen fertilizer is weakened in the late stage. The soluble sugar of wide sowing wheat increased gradually with grain filling, and the starch content at different stages increased continuously with increase in N rate (Fig. $6_C$). The starch of N300 treatment was highest, and the starch content of N0 treatment was the lowest. Compared with other treatments, starch content of N300, N270 and N240 increased significantly from 15d to 35d after flowering. Therefore, increasing nitrogen fertilizer can promote starch accumulation and increase grain weight, and the effect is significant in the middle and late stage, but there is no significant difference among high nitrogen treatments N240, N270 and N300.

## 3.6 | Effects on dynamic changes of protein content and components in grains from 0 to 35, and grain yield.

The protein content of wide space swing wheat showed a trend of decreasing first and then increasing with the filling process and the protein content was the lowest 15D after the flowering (Figure. 7A).The protein content at different stages after flowering N rate increased. The grain protein content of increased nitrogen fertilizer had a greater impact, but there was no significant difference in the regulatory effect between high nitrogen treatment after 5D, 15D, 25D, 35D and N240 respectively. Therefore, choosing appropriate nitrogen application amount is more beneficial to efficient production. The content of albumin was the highest at 5D after flower and decreased with the development and maturity of grains. Compared with other components, the globulin content was the lowest and began to rise 15days after flowering. The content of gliadin and glutenin increased continuously. With the highest value of N300 and the lowest value of N at different time after flowering. The albumin was significant than other treatments on 5D after flowering N300, 15D after flowering N300 and N270, and 25D-35D after flowering N300, N270 and N240 (Figure. 7B).The globulin protein content was significantly higher than that of N300, N270, N240, N210, N180 treatment on 5D after flowering than that of N90, and N0 treatment and was significant higher than that of other treatments on 15D-35D after flowering (Figure. 7C).The content of gliadin increased with the increase of N rate. At 5D after flowering, difference between nitrogen application amounts was not significant, and at 15D-35D after flowering, (Figure. 7D). Glutenin was significant N300, N270, N240, N210 and N180 treatments than in N90 and N0 treatments on 5D after flowering, but was significantly higher in N300 and N270 treatments than in other treatments on 15D after flowering, in N300 and N270 treatments than in other treatments on 25D after flowering, and in N300, N270 and N240 than in other treatments on 35D after flowering (Figure .7E). The adding N rate can improve increased of grain protein. Albumin was regulated N fertilizer in the early stage of filling, globulin is more regulated throughout the filling stage, while gliadin and glutenin are more sensitive to N rate in the late stage of filling.

The N fertilizers rates significantly effected the final grain yield and compositional factors of yield evident by an Increased ear number, yield and increased ear number (Table 8). The spikes number of, ear shots, and the thousands grains weight, and grain yield showed an afirst increase and then decreasing trend with application of nitrogen fertilizer amount. The yield and yield components were significantly higher in $N_{240}$ followed by $N_{210}$ under DS planting methods when compared to the other nitrogen treatment.Wide and drill sowing methods optimized the output of the three elements at the same time of WSS coupled with with 240 kg $ha^{-1}$ and DS casting 210 kg $ha^{-1}$ to achieve the increase of the output. Both DS and WS significantly increased spike number and yield.With the increased of nitrogen application rate, the three factors of yield increased first and then decreased.The yield and three elements of WSS and DS were the highest at 240 kg ha$^{-1}$and 210 kg ha$^{-1}$, respectively.

Table 8
Effect of different sowing methods and grain yield of winter wheat. Different letters indicate significant differences (p < 0:05) among treatments within a growth stage by Fisher's least significant difference.

| Sowing method | N rate ( kg ha$^{-1}$) | Spike number (10$^4$ ha$^{-1}$) | Grain number Per spike | 1000-grain weight (g) | Yield ( kg ha$^{-1}$) |
|---|---|---|---|---|---|
| WSS | $N_0$ | $678.25_{c}$ | $29.92_{b}$ | $36.41_{cd}$ | $6433.31_{e}$ |
| | $N_{90}$ | $704.75b_{c}$ | $30.69_{a}$ | $37.33_{c}$ | $6938.22_{d}$ |
| | $N_{180}$ | $715.50_{c}$ | $29.73_{b}$ | $40.66_{b}$ | $7447.64^{c}$ |
| | $N_{210}$ | $726.25_{c}$ | $30.56_{a}$ | $41.35_{ab}$ | $7841.61_{b}$ |
| | $N_{240}$ | $824.25_{a}$ | $31.52_{a}$ | $42.58_{a}$ | $9234.26_{a}$ |
| | $N_{270}$ | $757.75_{b}$ | $30.95^{a}$ | $39.07_{b}$ | $8003.31_{b}$ |
| | $N_{300}$ | $694.50_{c}$ | $28.08b_{c}$ | $38.90_{c}$ | $6684.08_{de}$ |
| DS | $N_0$ | 512.25e | $27.96_{c}$ | $35.56_{d}$ | $4231.12_{h}$ |
| | $N_{90}$ | 548.75e | $28.56_{bc}$ | $39.70_{b}$ | $5139.00_{g}$ |
| | $N_{180}$ | 569.25e | $29.87_{b}$ | $40.73_{b}$ | $5857.49_{f}$ |
| | $N_{210}$ | 626.50d | $30.39_{a}$ | $42.10_{a}$ | $6921.53_{d}$ |
| | $N_{240}$ | 586.50d | $29.11_{b}$ | $41.28_{ab}$ | $6092.60_{f}$ |
| | $N_{270}$ | 541.00e | $28.03_{bc}$ | $38.91_{b}$ | $5087.64_{g}$ |
| | $N_{300}$ | 514.75f | $27.19_{c}$ | $35.84_{cd}$ | $4256.07_{h}$ |

# 4. Discussion

## 4.1 | The photosynthesis characteristics of nitrogen rate, growth and yield characteristics.

The wide space sowing is a newly introduced sowing method. Furrow sowing is gaining popularity for wheat because seeds are sown in furrows that facilitate fertilization and effectively improve nutrient utilization (Cui et al. 2010). Sowing method affects canopy structure by altering the arrangement and spacings of plants. The better plant distribution effectively intercepts radiation and improves photosynthesis efficiency and growth (Tao et al. 2018). The results of our present study showed that the wide space sowing and furrow sowing can improve radiation interception as shown by the higher leaf area index under these sowing methods. Photosynthetic active radiation was found positively related to the leaf area index and the number of spikes (Tao et al. 2018). The results from this study showed that the grain yield and other yield traits under WSS, FS, and stereoscopic sowing were higher than the drill sowing. The highest yield was attained by WSS, followed by FS. The that sowing methods mainly effected yield by influencing the number of spikes (Das *et al*. 2011). The furrow sowing was proved beneficial in maintaining a higher photosynthesis rate. A previous study indicated that furrow planting increased chlorophyll content and photosynthesis as a result of which dry matter accumulation increased in each growth period (Yue et al., 2006; Wang et al. 2004). The furrow sowing produces stronger seedlings before winter, increases tiller numbers from booting to maturity stage, increases earning rate by 3.5%, and significantly increases yield (Li et al. 2013; Wang et al. 2003). believed that $C_i$ and $P_N$ values could be used as indicators to determine whether photosynthesis is limited by stomatal closure or metabolic damage. Our results showed that the decrease in stomatal conductance caused by the partial closure of stomata in the DS treatments was the main reason for the decrease in photosynthetic rate, which was mainly manifested by the decrease of Pn and the increase of Ci. The gs value and Pn value of each treatment had good synchronization, which showed that they decreased with the decrease in water content, and both the Pn and gs values recovered after rewatering, with the WS and FS treatments having a high recovery level (Jones *et al.* 2010). Stomatal conductance is an important biological process reflecting carbon accumulation and transpiration in plants, and $CO_2$ flows into photosynthetic sites through stomata (Sikder et al. 2015).Inconsistent results were found in the analysis of stomatal distribution in ear buds of spring wheat.It should be noted that under moderate water deficit conditions, stomata were distributed in the front and back of the wheat ear buds, and in the lower part of the front of the wheat ear buds.The characteristics of the paraxial stomata may contribute to the absorption of $CO_2$ released by grain respiration, and the recycling of respiratory $CO_2$ is considered to be a key process for complete assimilation in wheat ears (Bort et al., 1996, Gebbing *et al.* 2001). Previously, it was reported that that the wide-precision planting significantly increased the leaf area index and interception of photosynthetic active radiation of winter wheat (Tao et al. 2018) reported that the uniform sowing was more conducive for light interception for the production of more grain. The plant height was highest indirect sowing whereas the leaf area index was lowest, which might indicate the effect of shading under direct sowing methods as compared to uniform sowing, furrow sowing, and wide space sowing. The photosynthetic rate Tr, and gs of the flag leaves were higher under WSS, FS sowing especially at the end of flowering (Fan et al. 2019). Showed a lower reduction in both flag leaves and spikes under water deficit compared to during the middle and late grain-filling stages. In contrast, gs in flag leaves were more sensitive to drought than that of spikes (Saeidi *et al.* 2015). Showed that the decline in $P_N$ may occur due to decreased $T_R$ in wheat, and a similar result was observed in mulberry (Lakshmi et al. 1996). However, variations of gs would produce differences in E for wheat leaves (Martin et al. 1994). Our study indicated that under the WSS, and FS, wheat crop produced a more favorable canopy structure with higher photosynthesis and grain yield. Higher yield depends on the higher photosynthesis rate and thus increasing photosynthetic rate is the main objective to increase production. Furthermore, the photosynthesis rate is positively related to leaf mass per unit area. However, the excessive growth at the early stages is not much favorable under dryland conditions. It is also manifested by the highest plat height while low leaf area index by drill sowing as compared to other sowing method (Wang et al. 2005).

## 4.2 | Effects of nitrogen rate and sowing methods on yield formation of winter wheat

Th results indicated that the optimum nitrogen application rates vary with the sowing method in terms of increasing production. Compared with other treatments, the N amount of 210 kg $h^{-1}$ and 240 kg $h^{-1}$ combined with wide-space sowing and furrow sowing resulted in higher tiller numbers, optimized the yield components and improve the grain yield. This might be because row spacings are larger in the wide-space sowing than the furrows, whereas, space for the growth of single plant reduced and competition between plants for natural resources has been increased. Therefore, the effect of higher nitrogen application rate proved better because fertility has improved plant growth by promoting the absorption and transportation of water and fertilizer by the root system (Noor et al. 2020). In addition it also facilitated the deep fertilizers application ,improved radiation interception and water utilization (Li et al. 2013; Lv et al. 2020). Leaf area is an important canopy structural feature closely associated with the ability of leaves to collect light and photosynthesize (Yang et al. 2018). As compared with drill sowing, the leaf area index of winter wheat increased under wide space sowing, especially in the middle and late growth period. The differences in leaf area under the different planting methods could be attributed to the differences in the canopy distribution. Canopy with wider spacing intercepts light more properly with a higher photosynthesis rate and leaf area index (Fan et al. 2019). In this study, wide space sowing proved better than drill sowing in photosynthesis. This may be due to the reason that wide seed spacings not only expand the growth space of a single plant and reduce the competition of plants for natural resources (Das *et al*. 2011). Our study indicated that under WSS and, FS the wheat crop produced a more favorable canopy structure with higher photosynthesis and grain yield. Higher yield depends on the higher photosynthesis rate and thus increasing photosynthetic rate is the main objective to increase production. Furthermore, the photosynthesis rate is positively related to radiation use efficiency and leaf mass per unit area. However, the excessive growth at the early stages is not much favorable under dryland conditions. It is also manifested by the highest plat height while low leaf area index by drill sowing as compared to other sowing methods.

# Conclusion

The use of wide drill and furrow sowing techniques for winter wheat in southern Shanxi is conducive to promoting growth and development, improving flag leaf photosynthesis capacity, promoting dry matter production, obtaining higher yield and grain protein content. (WSS) and, (FS) increased. After (WSS) and, (FS), the plant height decreased and the leaf area index (LAI) increased. Under (WSS) and, (FS), the post-anthesis flag leaf photosynthetic rate ,the transpiration rate ,the intercellular carbon dioxide concentration , and flag leaf stomatal conductance were significantly increased. Drill Sowing, Furrow Sowing's soil water storage of 0-200 cm soil at anthesis stage was significantly increased by 8.2-18.7%, and increased the soil water storage of 0-60 cm soil layer, 60-120 cm soil layer in Normal year, and 120-200 cm soil layer in Dry year; Wide Space Sowing's soil water storage of 0-200 cm soil at anthesis stage was significantly increased by 5.2% in Normal year. The N rate at rate of N210 and N240 significantly increased the grain yield under the WSS and, FS. The WSS with nitrogen level $N_{240}$ improved the photosynthetic characteristics of flag leaves, significantly increased the net photosynthetic rate, stomatal conductance, and transpiration rate of flag leaves after flowering, and significantly reduced the intercellular carbon dioxide concentration.

# Declarations

### COMPETING INTERESTS

The authors declare that they have no competing interests.

### AUTHOR CONTRIBUTIONS

H.N. conceived and designed the research; H.N. performed the experiments; S.M., M.K, L.W., and Z.G. contributed to the field experiment; and H.N. wrote the manuscript

### FUNDING

The authors are thankful to 'Modern Agriculture Industry Technology System Construction' (No. CARS-3124). The National Key Research and Development Program of China (No. 2018YFD020040105), The Sanjin Scholar Support Special Funds Projects, National Natural Science Foundation of China (No. 31771727), The '1331' Engineering Key Innovation Cultivation Team- Organic Dry Cultivation and Cultivation Physiology Innovation Team (No. SXYBKY201733) for financial support of this study.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

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# Figures

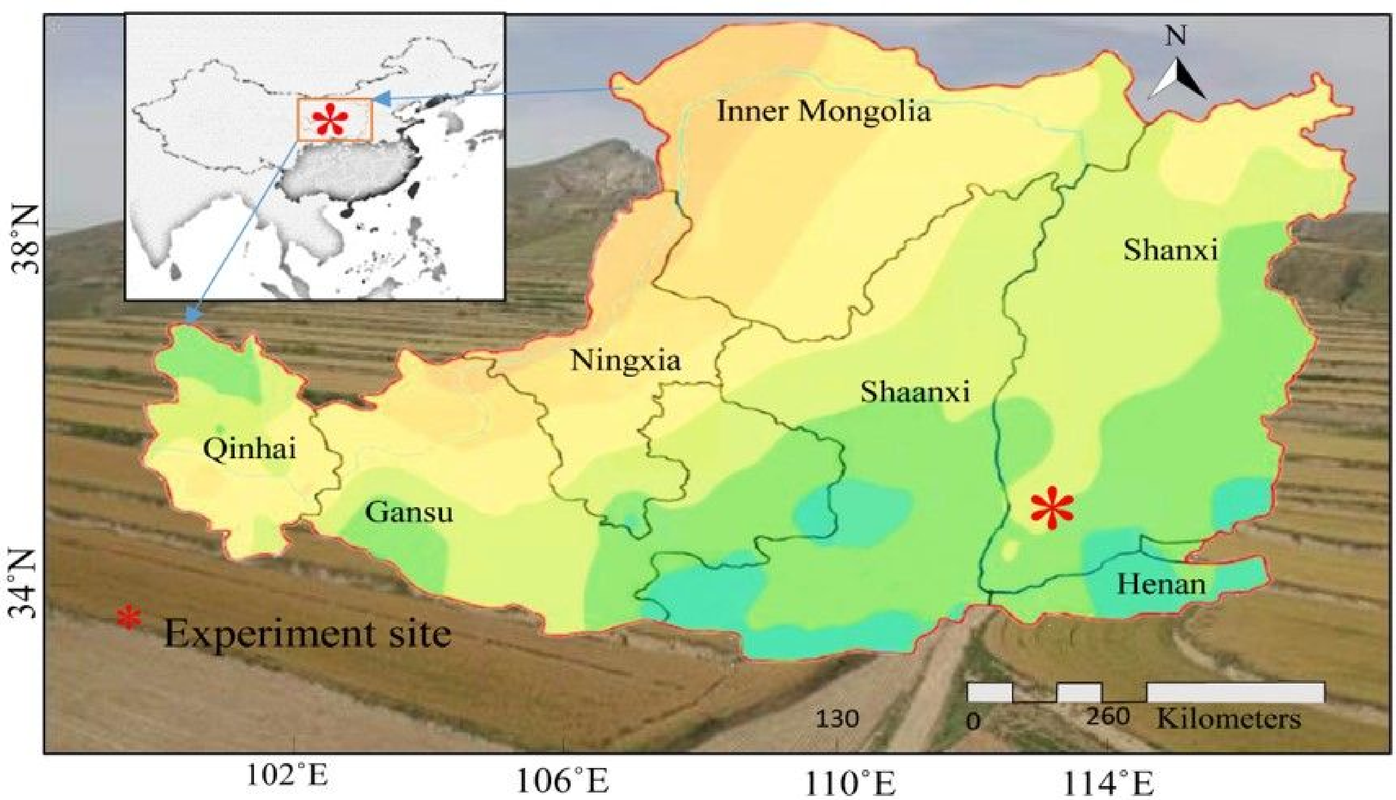



**Figure 1**

Location preparation at experimental site was located wenxi Shanxi

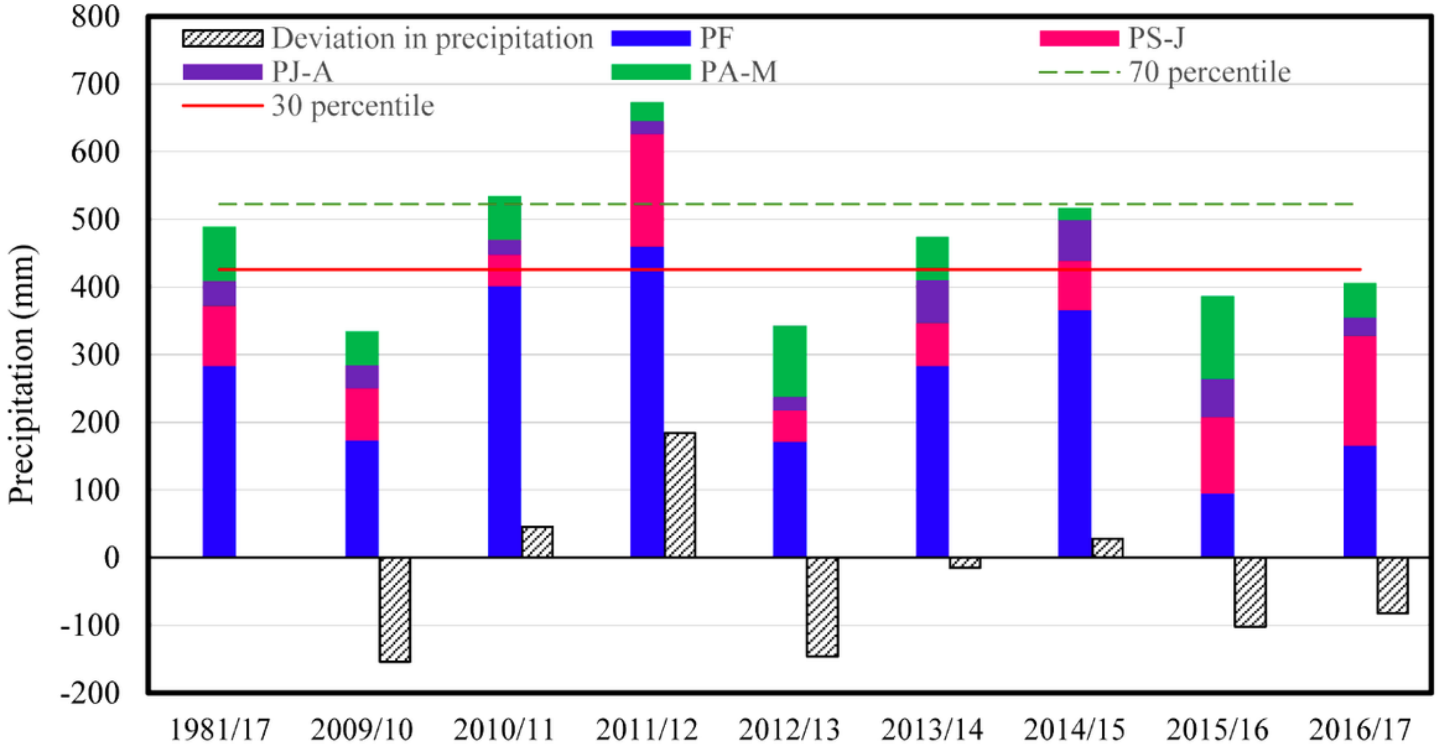
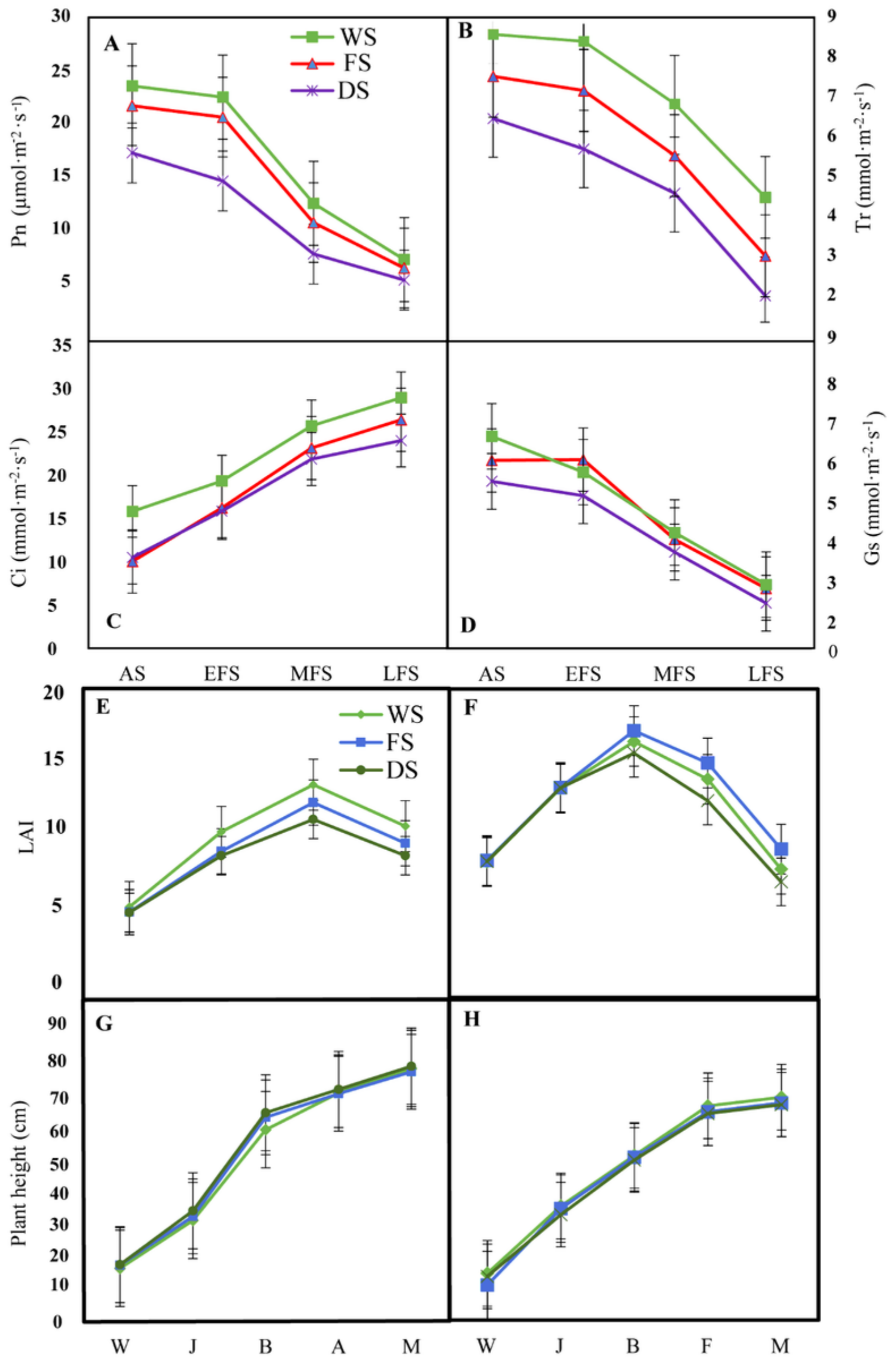



**Figure 2**

The precipitation distribution during the fallow, anthesis to maturity, sowing to jointing, and jointing to maturity stage of winter wheat and the deviation of precipitation from the long-term average data.




## Figure 3

Effect of sowing method on a) net photosynthesis (Pn), b) transpiration rate (Tr), c) substomatal CO2 concentration (Ci), and d) stomatal conductance (Gs) of flag leaves of winter wheat after anthesis at different growth stage. AS, EFS, MFS, and LFS indicate anthesis, early grain filling, mid grain filling, and late grain filling stages, and leaf area index (LAI)e,f) plant height g,h) W indicate wintering, J, jointing B, booting F, Flowering A, anthesis and M maturity. All data represent means ± standard errors of three replicates. Values with different letters on the same sampling day indicate significant differences at P<0.05

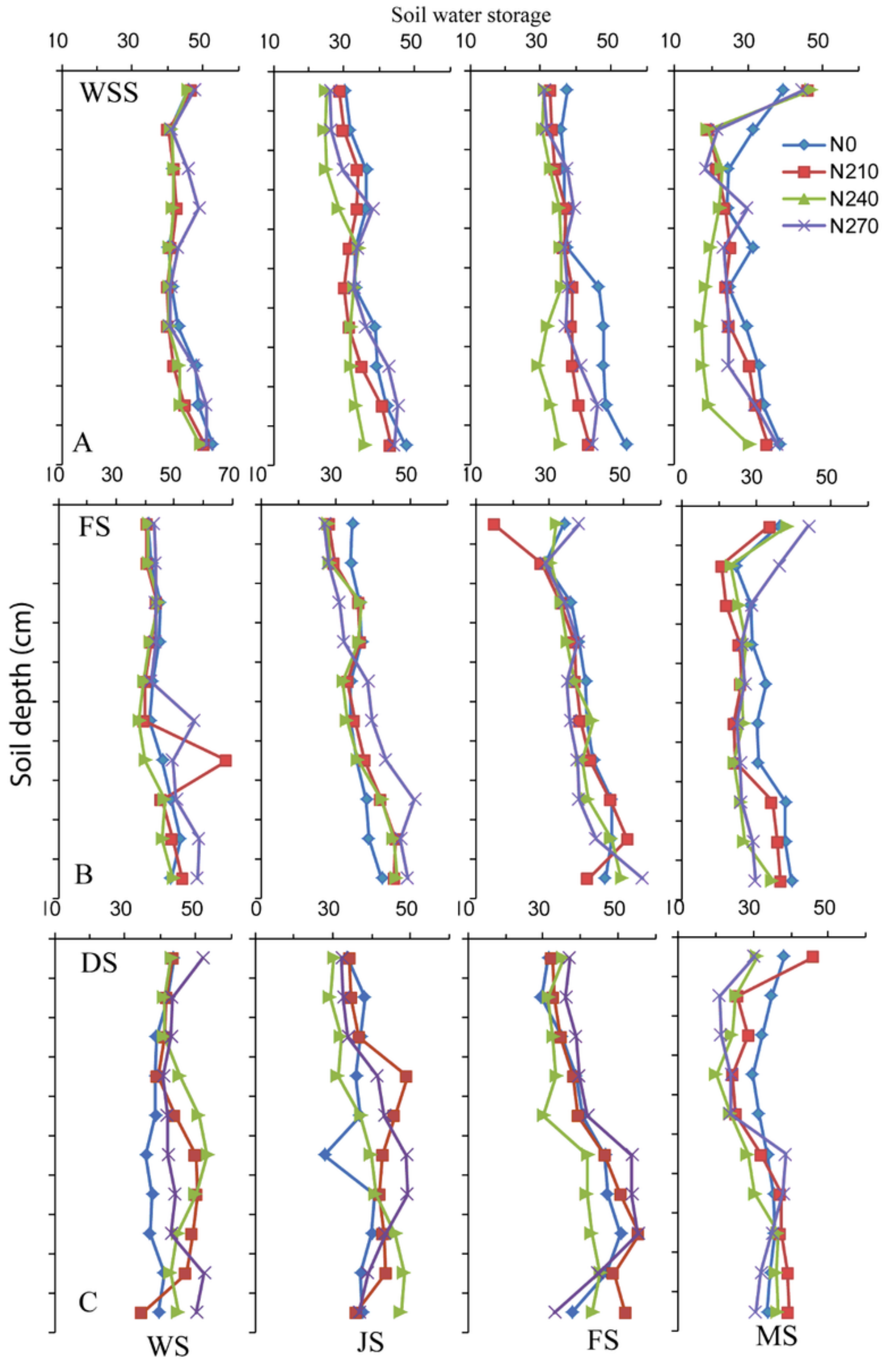
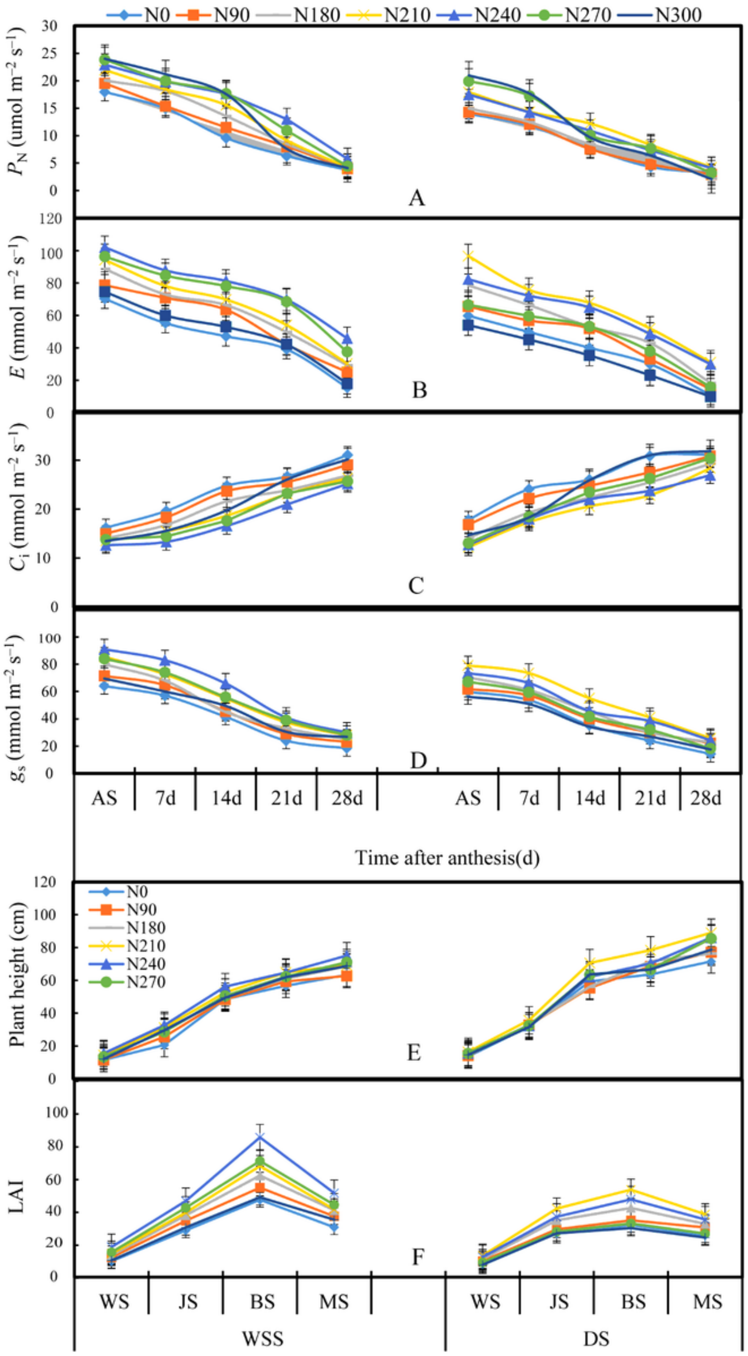


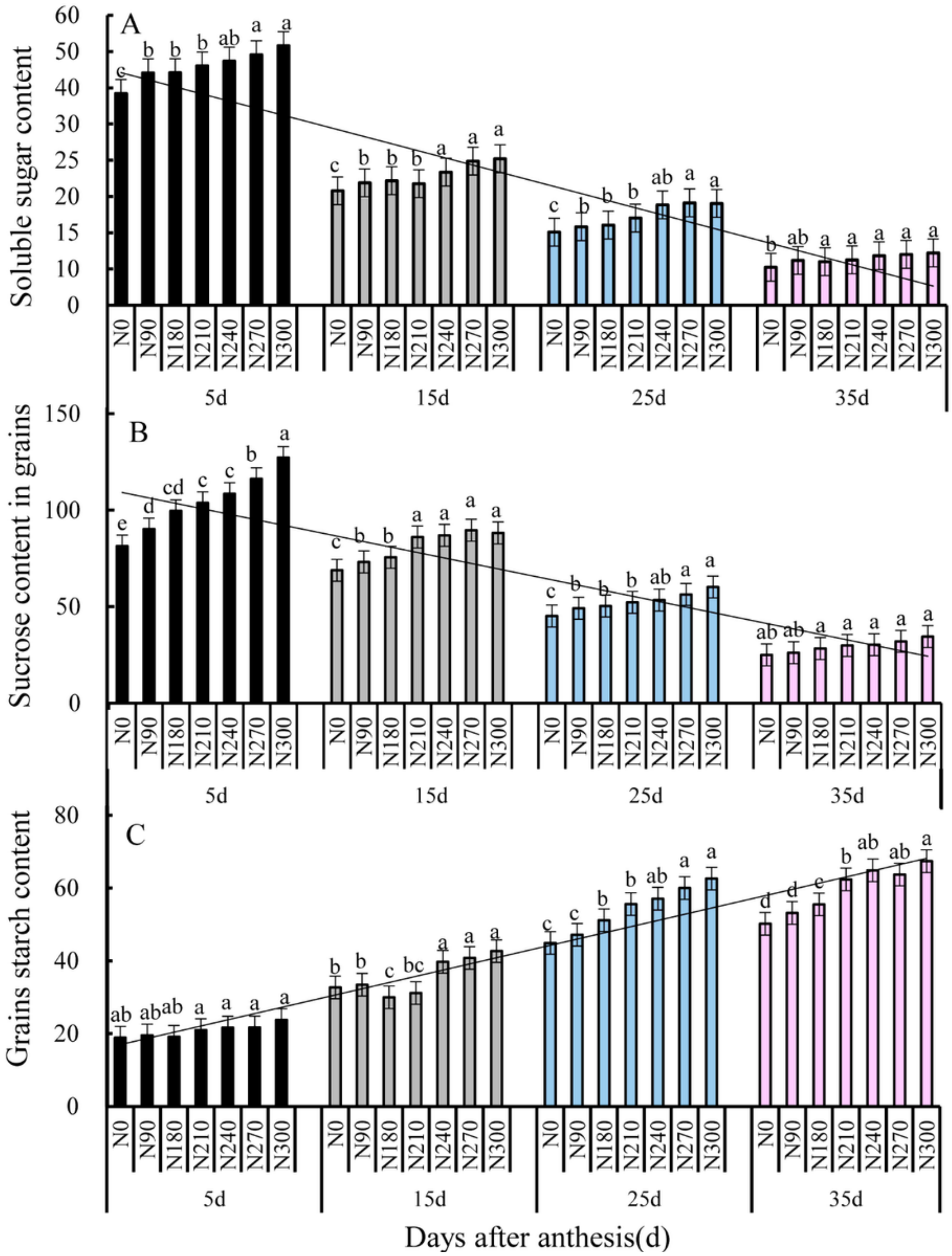

**Figure 4**

Effects of WSS, FS, and DS N input on soil water storage of 0-200 cm depth at different growing stage for winter wheat All data represent means ± standard errors of three replicates. Values with different letters on the same sampling day indicate significant differences at P<0.05



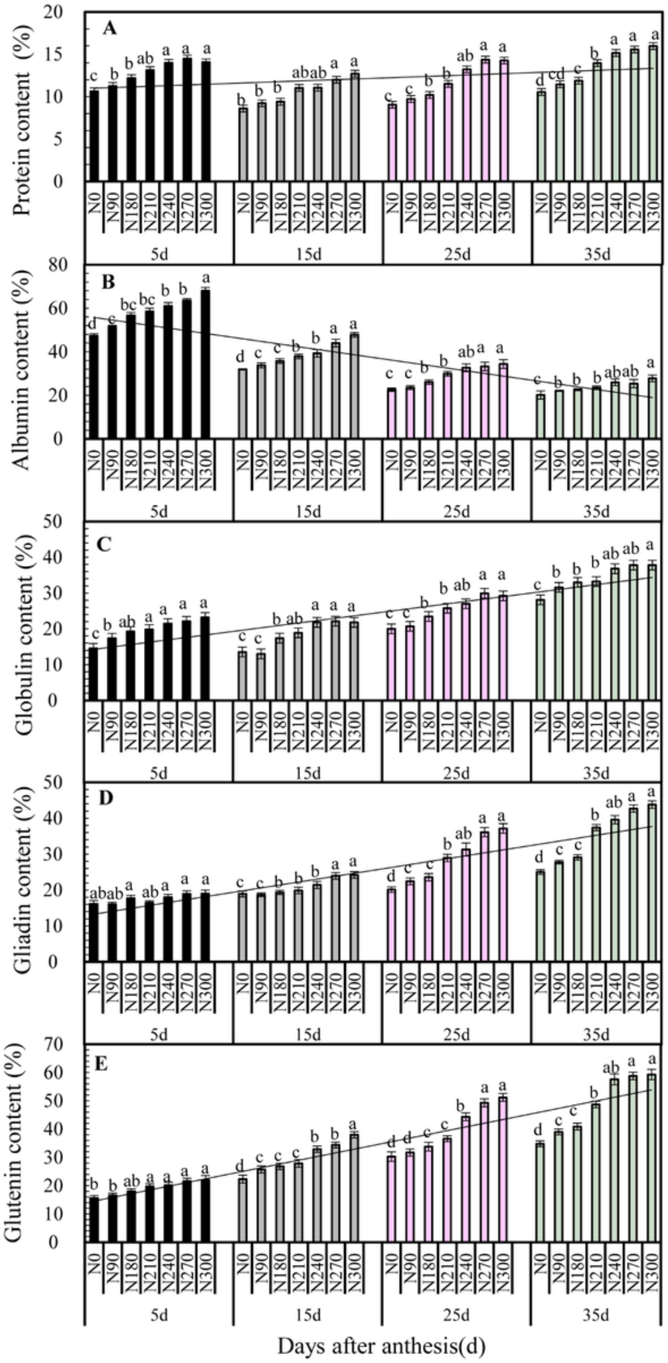

## Figure 5

Effect of Nitrogen rates and different sowing methods (A) 0-7 Days, 14D, 21D, 28D on Net Photosynthesis Rate (A), (PN), carbon dioxide concentration (B), (Ci), stomatal conductance (C), (GS) and transpiration rate (D), (E) of flag leaves (E), plant height (F), leaf area index (LAI) WS indicate wintering stage, JS, jointing stage BS, booting stage FS, Flowering stage AS, anthesis stage and, MS maturity stage All data represent means ± standard errors of three replicates. Values with different letters on the same sampling day indicate significant differences at P<0.05




## Figure 6

Effect of nitrogen rate on soluble sugar, sucrose and, starch content. All data represent means ± standard errors of three replicates. Values with different letters on the same sampling day indicate significant differences at P<0.05




## Figure 7

Effect of nitrogen rate on changes of grain protein content, Albumin content, Globulin content, Gliadin content, Glutenin content