

The combined effect of sowing methods and nitrogen rates on wheat yield and regulation of soil water consumption in Loess Plateau

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Abstract

Field experiments were conducted to assess the effect of four sowing methods on the growth, photosynthetic, and yield traits of dryland winter wheat. Furthermore, the impact of N input rates was also evaluated on water consumption by the wheat plants from the soil. The seeds of winter wheat were sown using wide space sowing (WS), furrow sowing (FS), stereoscopic sowing (SS), and drill sowing (DS). The results indicated that different sowing methods significantly affected the yield and grain quality. The increase in grain yield was 25%, 17%, and 11%, respectively, under WS, FS, and SS compared to that in DS. From sowing to jointing, the water consumption was highest under WS, mainly in deep soil layers. The photosynthetic traits and leaf area index were highest under WS, followed by those under FS. The plant height was highest under DS. The water consumption index and grain yield were higher at the N rate 210-240 kg ha⁻¹ than those at the other N rates applied. In conclusion, the WS and 210 kg N ha⁻¹ improved the canopy structure, water consumption, and winter wheat yield.

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Introduction

China is one of the largest producers of wheat (*Triticum aestivum* L.), although the yield of winter wheat in the southeast of the Loess Plateau region is often unstable due to the uneven distribution of precipitation (Xue et al., 2019). The quality traits and yield of wheat depend on many factors such as varieties, environment, and cultivation practices (Liang et al., 2019; Zhao et al., 2020).

The wheat crop is mostly planted using sowing methods of broadcasting, seed drilling, and wide belt and furrows sowing, although different sowing methods could affect yield by influencing water consumption (Wang et al., 2016). For dryland wheat production, the major task is to use the method which could effectively enhance the soil moisture consumption. The furrow sowing method has been used for dryland wheat production for a long time. Some studies have shown that compared with conventional sowing, the furrow sowing can increase the growth of wheat by improving the efficiency of water uptake (Kumar et al., 2011; Dong et al., 2018). The use of furrow sowing in dryland wheat could increase stem height, extend the duration of functional green leaves, increase spike quality, and increase yield by 53% compared to those by the flat field sowing (Liu et al., 2018). The soil moisture is not easily lost, and water retention in the soil is higher under furrow sowing. With furrows, the surface

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temperature of 0-5 cm cultivated soil layer increases by 1-2 °C (Yue et al., 2006). Stereoscopic sowing is a three-dimensional uniform sowing in which seeds are evenly distributed despite sowing in rows. Tao et al. (2019) reported that the uniform sowing increased the number of tillers and productive tillers, and biomass and wheat yield without declining the grain protein. Furthermore, it also enhanced the N use efficiency in wheat (Raun et al., 2002).

Fertilizers constitute an integral part of improved crop production technology. Nitrogen (N) is an essential nutrient, and the proper amount of N fertilizer application is considered a key to high crop production (Liang et al., 2019). An increase in grain yield is often associated with low protein content (Triboi and Triboi-Blondel, 2002). Application of N fertilizer promotes wheat root elongation, increases soil water consumption, promotes wheat plant growth, and significantly improves wheat yield. The grain protein content is also affected by soil moisture content and precipitation (Sun et al., 2014). The farmers in China are excessively applying N fertilizers exceeding the rate up to 300 to 500 kg ha⁻¹, but an increase in N rate is not always accompanied by a synchronous increase in yield (Khan et al., 2017; Khan et al., 2020).

Furthermore, excessive N supply also reduces nitrogen-use efficiency (NUE) while causing environmental pollution by leaching (Ahmed et al., 2020). The proper and efficient application of fertilizer is necessary to attain sustainable wheat yield under water-limiting conditions of the Loess Plateau. Sowing methods should be optimized for ideal coordination between soil moisture and temperature (Li et al., 2007, 2013). Thus, we designed this experiment to (i) find the effect of different sowing methods on water consumption, photosynthetic traits, and yield of winter wheat, and (ii) optimize N rates under the sowing methods, which produced the highest yield of the wheat crop.

Materials and Methods

Experimental field and conditions

The experiment was conducted during the winter wheat growing season from 2016 to 2017 in a field area of Shanxi Agricultural University. The experimental site is located in Wenxi county (34° 35 'N and 110°15' E.), Shanxi Province, China. It is dryland, a semi-arid region with an average precipitation of 440 to 630 mm per year, and precipitation is a sole source of moisture from which 60-70% of precipitation is concentrated from July-September of the year (Figure 1).

The cropping season of winter wheat is from early to mid-October to early June. The soil in the test site belongs to calcareous cinnamon soil according to the Chinese Soil Classification Standards. The basic nutrient properties of soil from 0-20 cm depth determined were as follow: 7.93 pH, 12.07 g kg⁻¹ organic content, 0.06 g kg⁻¹ total N, 36.42 mg kg⁻¹ available N, 16.26 mg kg⁻¹ available phosphorus, and 218.7 mg kg⁻¹ available potassium.

Experimental Design and Treatments

Two separate field experiments were carried out at Wenxi, Shanxi Agricultural University, China, in 2016-2017. The first experiment comprised four sowing methods: furrow sowing (FS), wide sowing (WS), drill sowing (DS), and stereoscopic sowing (SS) (Figure 2).

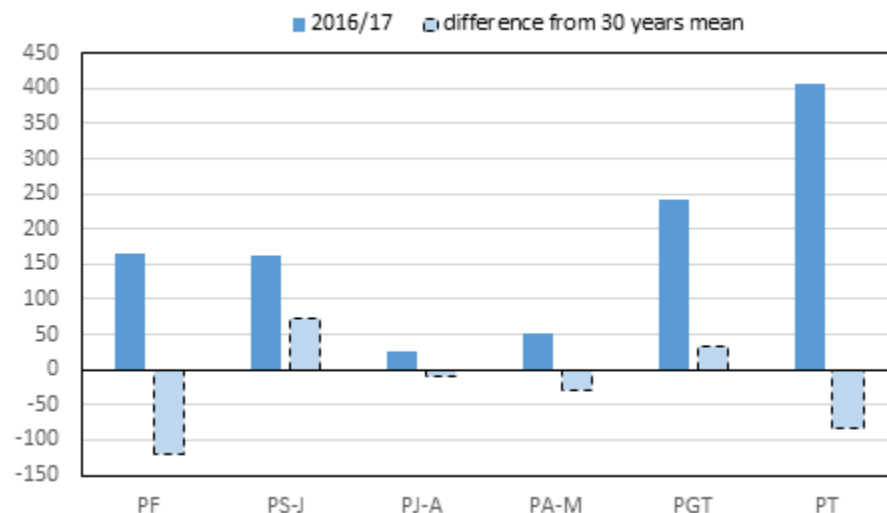


Figure 1. Precipitation during the study period (2016-2017) and difference in precipitation from average precipitation in last 36 years (1981-2017) at different growth stages of wheat at the experimental site in Wenxi, China. PF, PS-J, PJ-A, PA-M, PGT, PT indicate the fallow precipitation, precipitation from sowing to jointing, jointing to anthesis, anthesis to maturity, total growth period, and total precipitation, respectively.



Figure 2. a) furrow sowing (FS), b) wide space sowing (WS), c) drilling sowing (DS), d) and stereoscopic sowing (SS)

Table 1. The details of sowing methods adopted during the experiment

Sowing method	Sowing technique	Line spacing	Tillage
Furrow sowing (FS)	2BMFD-17/14 multipurpose, no-till, auto-fertilization	Wide line space: 20-25 cm, narrow line space: 10-12 cm	No-tillage
Wide space sowing (WS)	2BMF-12/6, tillage, auto-fertilization	Line space: 22-25 cm	Subsoiling, rotary tillage
Drilling sowing (DS)	2BXF-12Seed driller, Nonghaha company, no-till, auto-fertilization	Line space: 20 cm	No-tillage
Stereoscopic sowing (SS)	Litiyunboji, no-till, auto-fertilization	No line, evenly distributed seeds	No-tillage

The experiment was set up using a single-factor completely randomized design. The area of each plot was 2.5 m x 40 m, and each treatment repeated three times. After the harvest of the previous maize crop, wheat seeds were sown on October 9, 2016, at the seeding rate of 225 kg ha⁻¹. The details of the sowing methods are described in Table 1. At sowing, 750 kg ha⁻¹ of compound NPK fertilizer (N-P-K ratio is 20-20-5) was applied, and 225 kg ha⁻¹ of urea (46% N) was applied at tillering.

The second experiment was conducted using a two-factor split-plot design, taking the wide space (WS) and furrow sowing (FS) practices as the main factor and nitrogen (N) rates as a subplot. After the harvest of the former corn, wheat seeds were sown on October 9, 2016, and seven nitrogen levels: 0 (N0), 90 (N90), 180 (N180), 210 (N210), 240 (N240), 270 (N270), and 300 (N300) kg ha⁻¹ were applied using pure nitrogen. All treatments were repeated three times. The area of each plot was 5 m x 10 m. At sowing, 150 kg ha⁻¹ phosphate fertilizer (16%) and 90 kg ha⁻¹ potash (51%) were applied. The seeding rate was 225 kg ha⁻¹.

Measurement of soil water storage and water consumption

The soil was collected from 300 cm depth at sowing and the wheat stages of wintering, jointing, anthesis, and maturity. The soil water storage (mm) was determined by the oven-drying method (Liang et al., 2019) as follows:

Soil water storage

$$= \left(\frac{\text{weight of wet soil} - \text{weight of dry soil}}{\text{weight of dry soil}} \times 100 \right) \times \text{thickness of soil layer} \times \text{bulk density of soil}$$

Other soil-water traits such as the difference in soil water storage, water consumption from the soil, percentage of water consumption to total water consumption, and daily water consumption were calculated as follows:

$$\begin{aligned}\Delta SWS &= SWS1 - SWS2 \\ CA &= P + I - \Delta SWS \\ CP &= CAG / CA \\ CD &= \text{the } CAG/d\end{aligned}$$

Where ΔSWS is the difference in soil water storage; $SWS1$ and $SWS2$ are the soil water storage at the beginning and end of the stage, respectively; CA is water consumption from soil (mm); CAG is water consumption at a certain stage; CP is the percentage of water consumption to total water consumption; P is the precipitation (mm); I is the irrigation amount, and d is the number of days.

The water use efficiency ($\text{kg ha}^{-1} \text{mm}^{-1}$) for yield was calculated as:

$$WUE = \text{wheat yield} / ET$$

Where wheat yield was in kg ha^{-1} and ET was total water consumption.

Determination of plant agronomic traits

Twenty randomly selected plants with uniform growth were uprooted from the field, and the plant height was measured by taking the vertical distance from the roots to the top of the main stem. At the same time, the length, width, and the number of green leaves were measured, and the leaf area index (LAI) was calculated from the formula:

$$LAI = \frac{\text{length} \times \text{width} \times \text{number of green leaves}}{\text{Land area}}$$

The photosynthesis measurement apparatus (CI-340, USA) was used to determine the photosynthetic parameters of the flag leaf of wheat at 0, 10, 20, and 30 d after flowering. All the measurements were recorded from 9 to 12 am. The plants were dried to constant weight, and dry biomass was recorded. At maturity, the ears were cut, saved in mesh bags, and dried to investigate the number of spikes ha^{-1} , average grain number spike $^{-1}$, and 1000-grain weight. Another 20 m^2 area was harvested to determine the grain yield (kg ha^{-1}).

Data analysis

The data were subjected to analysis of variance (ANOVA) using SAS 7.5, and graphs were drawn using Microsoft Excel 2010. LSD (least significant difference) was used to test the significant differences between treatment means.

Results

Water consumption characteristics of wheat in response to sowing methods

The model coefficients of water consumption showed that the water consumption was highest from anthesis to maturity of wheat, followed by wintering to the jointing stage (**Table 2**). The water consumption intensity at the jointing to the flowering stage was the lowest. The water consumption, water consumption percentage, and daily water consumption during the wintering to the jointing stage and the jointing to the flowering stages were significantly increased under FS, and during the anthesis to maturity stage were increased under the SS. It can be observed that, in terms of promotion of water consumption, WS performed better in the early stage of wheat growth, whereas the effect of FS and SS was more prominent during the middle and late growth stages of wheat, respectively.

Soil water consumption in different soil layers in response to sowing methods

During the sowing to wintering stage, soil water consumption was mainly concentrated in the 120-180 cm soil layers, and the water consumption at this depth under WS was higher than that in the other sowing methods (**Figure 3**). During the wintering to the jointing stage, soil water consumption decreased with the soil depth. In the 0-100 cm soil depth, the water consumptions of soil under

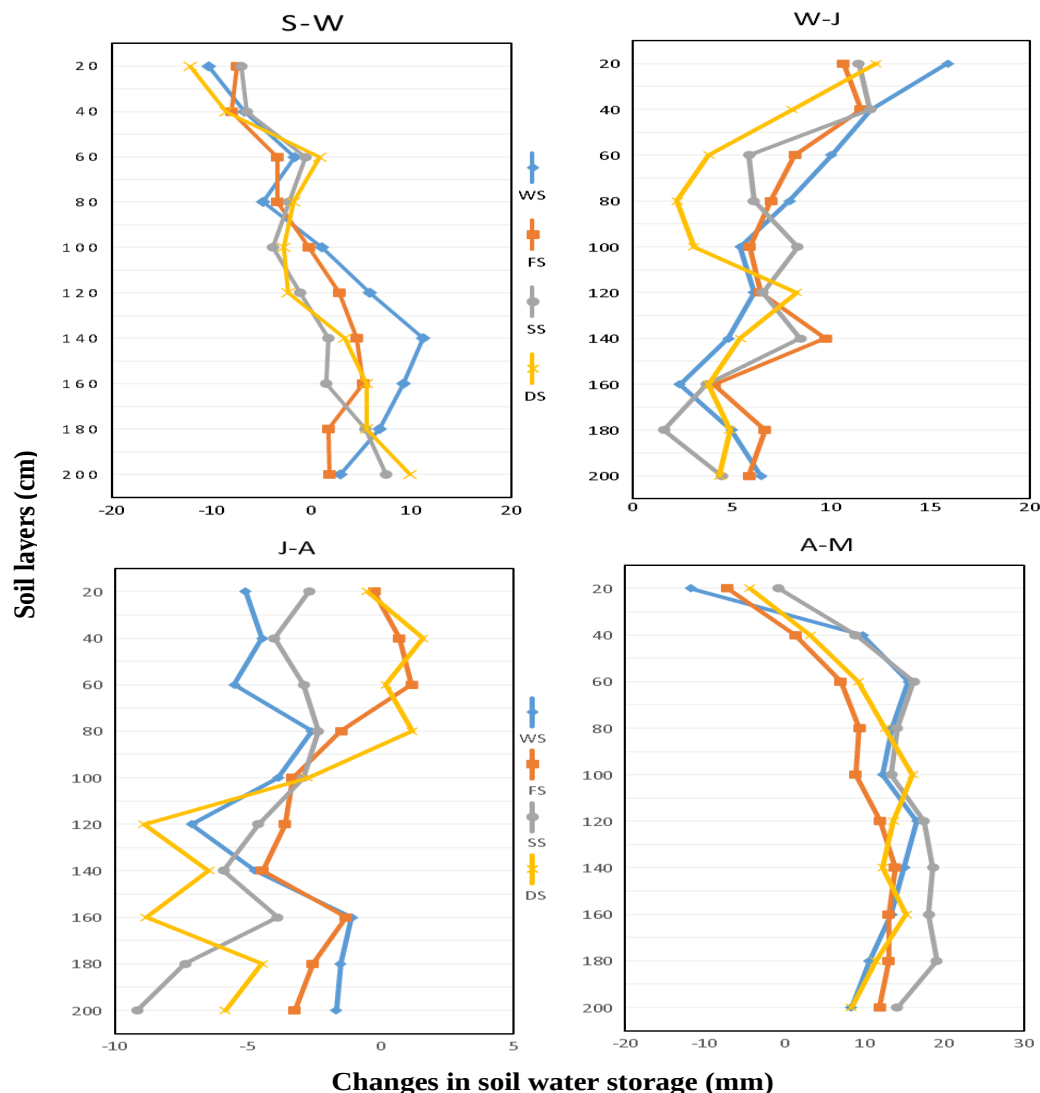
Table 2. Effects of sowing methods on water consumption amount, percentage of total water consumption, and water consumption per day at different growth stages of winter wheat

Sowing methods	S-W			W-J			J-A			A-M		
	CA (mm)	CP (%)	CD (mm)	CA (mm)	CP (%)	CD (mm)	CA (mm)	CP (%)	CD (mm)	CA (mm)	CP (%)	CD (mm)
WS	97.8 ^a	23.3 ^a	1.24 ^a	130.7 ^a	30.9 ^{ab}	0.82 ^{ab}	49.8 ^b	11.9 ^c	1.72 ^b	142.6 ^b	34.0 ^b	3.48 ^b
FS	77.8 ^b	19.6 ^b	0.98 ^b	130.7 ^a	32.7 ^a	0.82 ^a	69.0 ^a	17.1 ^a	2.38 ^a	122.9 ^d	30.7 ^d	3.00 ^d
SS	79.1 ^b	18.9 ^b	1.00 ^b	123.1 ^a	29.1 ^b	0.77 ^b	41.6 ^c	9.87 ^d	1.43 ^c	178.7 ^a	42.2 ^a	4.36 ^a
DS	81.9 ^b	21.6 ^{ab}	1.04 ^b	111.0 ^b	29.0 ^b	0.70 ^c	52.6 ^b	13.62 ^b	1.81 ^b	137.2 ^c	35.8 ^c	3.35 ^c

Different letters indicate significant differences on the level of $P < 0.05$. WS: wide space sowing; FS: furrow sowing; DS: drilling sowing; SS: stereoscopic sowing; S-W: sowing to wintering; W-J: wintering to jointing; J-A: jointing to anthesis; A-M: anthesis to maturity; CA: the amount of water consumption; CP: percentage of CA to total water consumption; CD: daily water consumption

WS, FS and SS were all higher than that under DS, and the water consumption of soil under WS was highest in the 0-80 cm depth and lowest in the 100-160 cm. FS was higher than DS in the 120-160 cm soil layer. At jointing to anthesis, soil water consumption was in a negative state.

In the anthesis to maturity stage, the soil water consumption in the 20-60 cm soil layer under different sowing methods showed an increasing trend, while in 60-200 cm, it was relatively stable. In the 20-80 cm soil layer, the water consumption under WS and SS was higher than that under DS. It can be observed that WS mainly promoted water consumption from deep soil during the sowing and jointing stage, while wintering, anthesis, and maturity mainly promoted water use in shallow soil layers, and FS mainly promoted water consumption during wintering to jointing stage.

**Figure 3. Effects of sowing methods on changes in soil water storage amount in different soil layers at different growth stages of winter wheat**

Plant height and leaf area index at different growth stages in response to sowing methods

Effects of sowing methods on plant height were observed at different growth periods (**Figure 4a**). There were no significant differences between sowing methods at the wintering and jointing stages. In contrast, a wide difference between SS and other sowing methods was observed at the anthesis and maturity period. The plant height of SS was the lowest in different growth periods. 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 that in FS and SS. Leaf area index (LAI) in each growth period increased and then decreased, reaching the maximum at the booting stage (**Figure 4b**). At different growth stages, the leaf area index of WS was higher than in the other sowing methods and increased as compared with DS. It can be noticed that different sowing methods, especially WS, improved LAI, and the effect was more significant at the later growth stages.

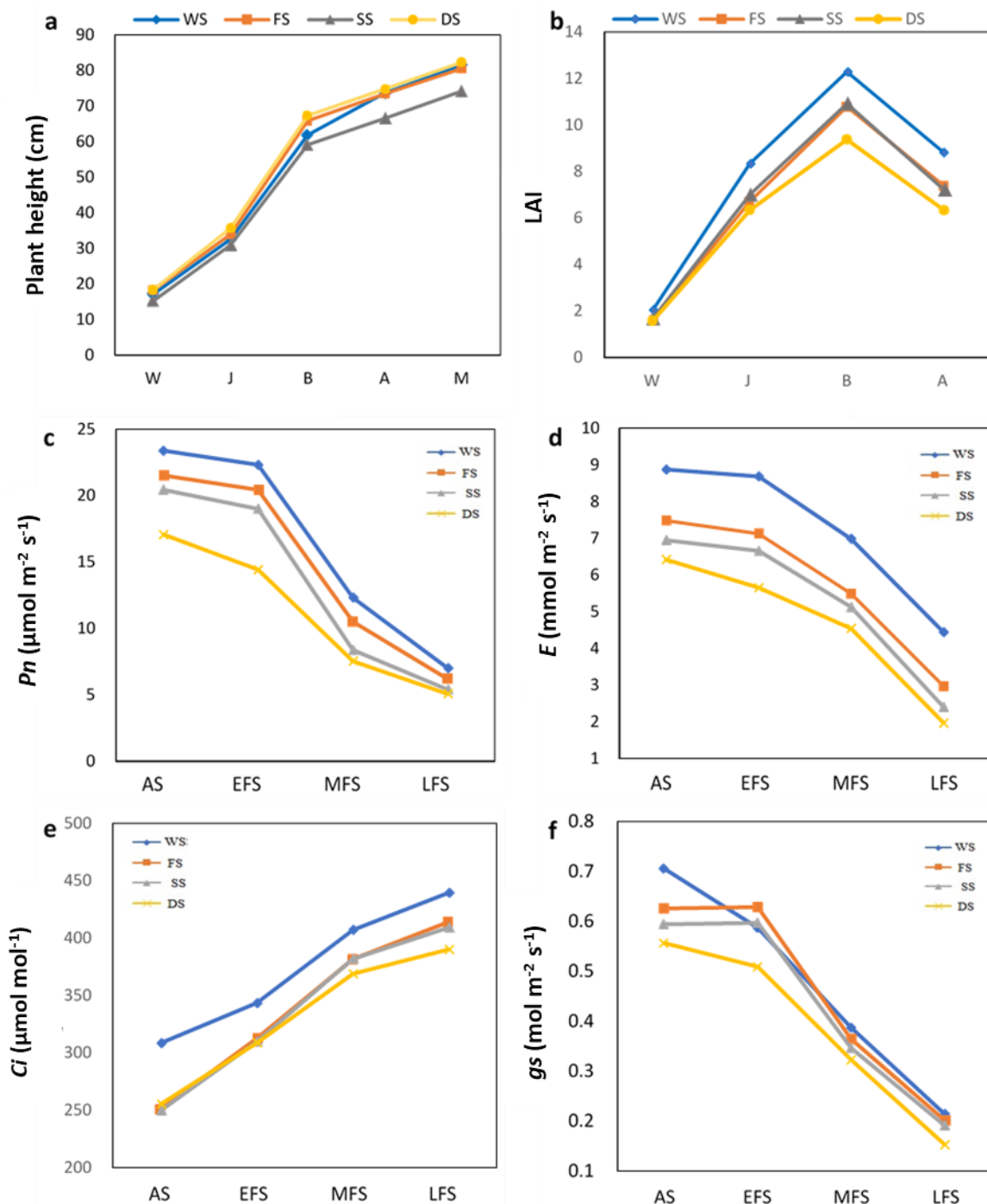


Figure 4. Effect of sowing methods on a) plant height, b) leaf area index (LAI), c) net photosynthesis (P_n), d) transpiration rate (E), e) substomatal CO_2 concentration (C_i), and f) stomatal conductance (g_s) of flag leaves of winter wheat after anthesis at the different growth stage. AS, EFS, MFS, and LFS indicate anthesis, early grain filling, mid grain filling, and late grain filling stages, 60, 61, 65, and 69 according to the Zadoks scale

Photosynthesis characteristics of the flag leaves in response to sowing methods

With the progress of the reproductive stage after anthesis, the photosynthesis rate (P_n), transpiration rate (E), and stomatal conductance (g_s) of the flag leaves decreased consistently, whereas substomatal CO_2 concentration (C_i) increased (Figure 4c-f). The decrease in P_n from the initial to medium flowering was abrupt. It can be seen that different seeding methods promoted post-anthesis P_n , E , and C_i of the flag leaves, and the highest rates of P_n , E , and C_i were recorded under WS in different periods after flowering, followed by FS and minimum under DS. The P_n at WS increased by 37%, 55%, 63%, 38%, compared with that under DS, 26%, 42%, 39%, 22% than under FS, and 20%, 32%, 11%, and 6% than under SS at anthesis, early, mid and late grain filling, respectively (Figure 4c). The E under WS was 38%, 54%, 54%, and 126% higher than that under DS and 16%, 26%, 21%, 51% higher than under SS and 8%, 18%, 13%, and 22% higher than under FS at anthesis, early, mid and late grain filling, respectively (Figure 4d). The increase in C_i under WS was 21, 11%, 10%, and 13% as compared to that under DS (Figure 4e). The g_s at WS was 27%, 15%, 20%, and 40% higher than that under DS (Figure 4f).

Effects of sowing method on protein and protein components in grain at maturity stage

Effects of the sowing methods on protein and component content in grain at the maturity stage (Table 3) showed that the mature grain protein, albumin, gliadin, glutenin, and protein yield were improved by WS, FS, and SS, as compared with the conventional drilling. The protein content increased significantly by 13%, 15%, and 4%, and protein yield by 42%, 35%, and 16% under WS compared to those under FS, SS, and DS, respectively. The grain protein, globulin, gliadin, and glutenin were highest under FS, and albumin and grain protein yield were highest under WS.

Effects of sowing methods on yield components at maturity stage

The yield at WS, FS, and AS was higher than at the DS (Table 4). The increase in the number of spikes was 22%, 16%, and 7%, the increase in thousand-grain weight was 3%, 7%, and 4%, and the increase in grain yield was 25%, 17%, and 11%, respectively under WS, FS, and AS as compared to that under DS. The difference between the seeding method was not significant for thousand-grain weight. The number of spikes and grain yield were highest under WS, followed by that under FS; the number of grains per spike was highest under AS and significantly similar to that under WS. It can be observed that different seeding methods mainly increased the yield by increasing the number of spikes.

Influence of nitrogen rates under two sowing methods on water consumption at different growth stages of winter wheat

The influence of N fertilizer rates under WS and FS was observed on water consumption at the growth stages of winter wheat (Table 5). It can be noticed that under different N application rates, WS promoted water consumption in winter wheat more than that by FS, especially under high N application rates. Under the condition of WS, the highest water consumption indices during sowing to anthesis were observed at N_{90} and N_{180} , and the water consumption and percentage to water consumption were significantly different from other N application rates. From wintering to jointing and jointing to anthesis, the highest water consumption indices were observed at N_{240} and N_{270} . Under FS, the water consumption index from sowing to jointing and anthesis to maturity was higher at N_{210} than at N_0 , N_{180} , and N_{240} . From wintering to jointing, the water consumption index of N_{240} was higher, and the difference with those of N_{90} , N_{210} , N_{270} , and N_{300} was significant. The water consumption index of N_{210} was higher, and the difference with N_0 , N_{180} , and N_{240} was significant.

Impact on yield production and its composition

With increasing N application, the number of spikes and grain yield under WS and FS were recorded to be increased and then decreased (Table 6). Under WS, the number of spikes, grain numbers per spike, 1000-grain weight, and yield were higher under N_{240} , and there was 13%, 10%, 19%, and 47% increase in

Table 3 Protein components and protein yield of wheat under different sowing methods

Sowing methods	Albumin (%)	Globulin (%)	Gliadin (%)	Glutenin (%)	Protein content (%)	Protein yield (kg ha ⁻¹)
WS	2.27 ^a	1.87 ^{ab}	4.18 ^a	4.83 ^a	14.18 ^b	1298.0 ^a
FS	2.25 ^a	2.00 ^a	4.25 ^a	4.84 ^a	14.43 ^a	1235.0 ^b
SS	2.18 ^a	1.80 ^{ab}	3.74 ^b	4.29 ^b	13.03 ^c	1060.3 ^c
DS	1.93 ^a	1.82 ^{ab}	3.52 ^b	4.11 ^b	12.54 ^d	917.2 ^d

WS: wide space sowing; FS: furrow sowing; DS: drilling sowing; SS: stereoscopic sowing. The different letters indicate the significant differences at the level of $P < 0.05$.

Table 4. Yield of wheat under different sowing methods

Sowing methods	Spike number ($\times 10^4 \text{ ha}^{-1}$)	Grain number per spike	1000-grain weight (g)	Yield (kg ha^{-1})
WS	850.9 ^a	31.26 ^a	40.35 ^{ab}	9049.1 ^a
FS	806.0 ^b	30.05 ^b	41.98 ^a	8506.6 ^b
AS	742.5 ^c	32.02 ^a	40.87 ^{ab}	8058.2 ^c
DS	695.0 ^d	31.01 ^{ab}	39.19 ^b	7266.5 ^d

WS: wide space sowing; FS: furrow sowing; DS: drilling sowing; SS: stereoscopic sowing

Table 5. Effects of sowing methods and N input on water consumption amount, percentage of total water consumption, and water consumption per day of winter wheat at different growth stages

Sowing methods	N rate (kg ha^{-1})	S-W			W-J		
		CA (mm)	CP (%)	CD (mm)	CA (mm)	CP (%)	CD (mm)
WS	N0	81.3 ^{bc}	20.6 ^b	1.03 ^d	129.8 ^c	32.9 ^{cd}	0.82 ^c
	N90	139.5 ^a	33.4 ^a	1.77 ^a	81.5 ^e	19.5 ^f	0.51 ^e
	N180	121.1 ^a	29.2 ^a	1.53 ^b	96.0 ^d	23.1 ^e	0.60 ^d
	N210	95.8 ^b	22.6 ^b	1.21 ^c	145.7 ^b	34.4 ^{bc}	0.92 ^b
	N240	97.7 ^b	20.7 ^b	1.24 ^c	179.0 ^a	37.9 ^a	1.13 ^a
	N270	68.3 ^c	16.1 ^c	0.86 ^e	156.9 ^b	36.9 ^{ab}	0.99 ^b
	N300	80.6 ^{bc}	20.2 ^b	1.02 ^{de}	126.4 ^c	31.7 ^d	0.79 ^c
FS	N0	72.6 ^{bc}	19.2 ^d	0.92 ^{bc}	140.7 ^{ab}	37.2 ^a	0.88 ^{ab}
	N90	80.2 ^b	19.3 ^{cd}	1.01 ^b	130.7 ^{bc}	31.5 ^{bc}	0.82 ^{bc}
	N180	62.2 ^c	14.8 ^e	0.79 ^c	145.9 ^{ab}	34.6 ^{ab}	0.92 ^{ab}
	N210	97.5 ^a	22.8 ^{bc}	1.23 ^a	117.0 ^c	27.4 ^c	0.74 ^c
	N240	36.7 ^d	9.00 ^f	0.46 ^d	154.2 ^a	37.8 ^a	0.97 ^a
	N270	97.3 ^a	25.7 ^{ab}	1.23 ^a	112.1 ^c	29.6 ^c	0.70 ^c
	N300	98.1 ^a	26.2 ^a	1.24 ^a	114.0 ^c	30.5 ^{bc}	0.72 ^c
		J-A			A-M		
		CA (mm)	CP (%)	CD (mm)	CA (mm)	CP (%)	CD (mm)
WS	N0	27.9 ^c	7.07 ^c	0.96 ^c	155.8 ^{ab}	39.5 ^a	3.80 ^{ab}
	N90	36.9 ^{bc}	8.84 ^{bc}	1.27 ^{bc}	159.5 ^a	38.2 ^a	3.89 ^a
	N180	57.7 ^a	13.9 ^a	1.99 ^a	140.2 ^c	33.8 ^b	3.42 ^c
	N210	50.2 ^{ab}	11.8 ^{ab}	1.73 ^{ab}	131.9 ^c	31.1 ^{bc}	3.22 ^c
	N240	59.3 ^a	12.6 ^{ab}	2.05 ^a	136.0 ^c	28.8 ^c	3.32 ^c
	N270	59.1 ^a	13.9 ^a	2.04 ^a	141.1 ^{bc}	33.2 ^b	3.44 ^{bc}
	N300	57.1 ^a	14.4 ^a	1.97 ^a	133.9 ^c	33.6 ^b	3.27 ^c
FS	N0	57.7 ^{cd}	15.2 ^{cd}	1.99 ^{cd}	107.6 ^d	28.43 ^b	2.63 ^d
	N90	73.0 ^b	17.6 ^{bc}	2.52 ^b	131.0 ^b	31.6 ^{ab}	3.19 ^{ab}
	N180	92.2 ^a	21.8 ^{ab}	3.18 ^a	121.5 ^{cd}	28.8 ^b	2.96 ^{bc}
	N210	69.0 ^{bc}	16.2 ^{cd}	2.38 ^{bc}	143.3 ^a	33.6 ^a	3.49 ^a
	N240	94.2 ^a	23.1 ^a	3.25 ^a	122.6 ^c	30.1 ^b	2.99 ^{bc}
	N270	53.2 ^{cd}	14.1 ^{de}	1.84 ^{de}	115.7 ^{cd}	30.6 ^{ab}	2.82 ^{cd}
	N300	44.0 ^d	11.7 ^e	1.52 ^e	118.4 ^{cd}	31.6 ^{ab}	2.89 ^{bcd}

WS: wide space sowing; FS: furrow sowing; CA: water consumption from soil; CP: percentage of water consumption to total water consumption; CD: daily water consumption

Table 6. Effects of seeding methods and N input on yield and its components of winter wheat

Seeding methods	N rate (kg ha^{-1})	Spike number ($\times 10^4 \text{ ha}^{-1}$)	Grain number per spike	1000-grain weight (g)	Yield (kg ha^{-1})
WS	N0	798.5 ^d	29.60 ^b	36.88 ^b	7361.4 ^d
	N90	839.2 ^c	31.86 ^{ab}	40.34 ^{ab}	8744.4 ^c
	N180	868.5 ^b	31.34 ^{ab}	40.19 ^{ab}	9442.9 ^b
	N210	870.0 ^b	31.50 ^{ab}	40.42 ^{ab}	9629.5 ^b
	N240	900.2 ^a	32.58 ^a	43.85 ^a	10829.1 ^a
	N270	870.2 ^b	32.22 ^a	42.76 ^a	9891.3 ^b
	N300	809.5 ^d	29.69 ^b	38.00 ^b	7445.0 ^d
FS	N0	765.7 ^{cd}	29.69 ^{ab}	37.76 ^c	7279.8 ^d
	N90	804.0 ^b	30.26 ^{ab}	41.82 ^b	8571.5 ^c
	N180	826.7 ^{ab}	30.62 ^a	43.20 ^{ab}	8924.9 ^b
	N210	853.5 ^a	30.70 ^a	45.04 ^a	9568.5 ^a
	N240	837.2 ^a	31.23 ^a	44.89 ^a	9400.7 ^a
	N270	798.5 ^{bc}	29.60 ^{ab}	42.61 ^{ab}	8728.7 ^{bc}
	N300	756.2 ^d	28.23 ^b	38.51 ^c	7072.0 ^d

WS: wide space sowing; FS: furrow sowing

these traits, respectively, as compared to that under no addition of N. The number of spikes and grain yield were significantly higher at N_{240} than those at other N levels. Under FS, the yield and yield traits were higher under N_{210} and N_{240} than at other N levels. Grain yield was highest at N_{210} and was non-significantly different from that at N_{240} , whereas 31%, 12%, 7%, 10%, and 35% higher than those at 0, 90, 180, 270, and 300 kg N ha⁻¹. It can be noted that the optimum level of N applied under WS was 240 kg ha⁻¹, and under FS was 210 kg ha⁻¹ to improve the grain yield.

Discussion

Effects of sowing methods on water consumption, growth, and yield characteristics of wheat

Different sowing methods affect the distribution of plants and growth and developmental characteristics. Therefore, it is important to explore suitable sowing methods to ensure a high yield of crops (Tao et al., 2018). Undoubtedly, compared with manual sowing, machine sowing has a higher sowing efficiency and saves a lot of manpower and resources. At the same time, machine sowing also performs shallow rotation to break the surface layer of soil, which can effectively improve the germination of seeds (Zhang et al., 2016).

The wide space seeding is a newly introduced sowing method, but furrow sowing is gaining popularity for wheat because seeds are sown in furrows that facilitate irrigation and fertilization and effectively improve water and nutrient utilization (Cui et al., 2010). The results from this study showed that the grain yield and other yield traits under the wide space sowing, furrow sowing, and stereoscopic sowing were higher than those from the drill sowing. The highest yield was attained by the wide space sowing, followed that by the furrow sowing. The increase in grain yield was 25%, 17%, and 11%, respectively, under the wide space sowing, furrow sowing, and stereoscopic sowing as compared to that under the drill sowing. It can be noted that different seeding methods affect mainly the yield by influencing the number of spikes as earlier reported elsewhere (Das and Yaduraju, 2011). Tao et al. (2018) also found a positive correlation between spike number with wheat yield. With the wide space sowing and furrow sowing, the soil fertility of the cultivated soil layer is improved, and the coordination of water and fertilizer is high, thereby promoting root growth, which improves the uptake of water and basic nutrients.

Sowing methods could affect canopy structure by altering the arrangement and spacings of plants. The better plant distribution effectively intercepts radiation and improves photosynthetic efficiency and growth (Tao et al., 2018). This study showed that the wide space sowing and furrow sowing could improve radiation interception, as demonstrated by a higher leaf area index under these sowing methods. Furthermore, photosynthetically active radiation was found to be positively related to the leaf area index and the number of spikes as already reported by Tao et al. (2018). Changing the planting methods of wheat affects soil temperature and moisture and can effectively improve the environmental conditions for wheat growth and increase wheat yield. The previous results showed that the temperature of topsoil with almost 5 cm furrows is 1-2 °C higher than that the under flat planting. In the wide space sowing, the soil is compressed during sowing, due to which water evaporation slows down after infiltration, so the wide space and furrow planting improve water holding ability, whereas for the direct seeding, the soil is loose, and water evaporates from the soil surface layer (Yue et al., 2006).

Increasing soil water consumption can effectively increase the proportion of dry matter accumulation and post-anthesis matter accumulation, thereby increasing yield (Xue et al., 2019). Our study indicated that the wheat crop produced a more favorable canopy structure with higher photosynthesis and grain yield under the wide space sowing and furrow sowing. High yield depends on the higher photosynthesis rate, and thus increasing the photosynthetic rate is the main objective of increasing production. Furthermore, the photosynthetic 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 plant height while low leaf area index by the drill sowing as compared to those under the other sowing methods.

Different sowing methods have different regulatory effects on soil water content and water consumption in the winter wheat growth period. The results of this study showed that compared with the conventional drill sowing, the wide space sowing increased water consumption at the initial growth stages and the furrow sowing promoted water consumption in the wintering to jointing, and the jointing to anthesis stage of winter wheat, especially in the deep soil layers. The wide space sowing increased the total water consumption by 10%, and the furrow sowing increased the total water consumption by 5% as compared to that by the conventional drill sowing. A previous study indicated that the furrow seeding increased the soil moisture content in the 0-10 cm soil layer by 6.3% compared with the traditional flat sowing (Wang et al., 2005). Wang et al. (1999) showed that irrigation water could be reduced by 30% by

the furrow sowing without affecting the growth and development of wheat, and water use efficiency could still be improved. Furthermore, less soil water in upper soil layers stimulates the growth of roots in deeper layers (Wang et al., 2018).

In this study, the wide space seeding proved better than the furrow sowing in promoting the growth and development of winter wheat, water consumption, photosynthesis, and water utilization. This may have been due to the reason that the wide seed spacing not only expand the growth space of a single plant and reduce the competition of plants for natural resources (Das and Yaduraju, 2011), but also facilitate the deep application of fertilizers, and improve 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). The results of this study showed that the leaf area index was increased until the bolting stage and then decreased. The reduction in leaf area index at the later growth stage could be due to leaf senescence (Tao et al., 2018). As compared with the conventional sowing, the leaf area index of winter wheat increased under the wide space sowing, especially in the middle and late growth periods. The leaf area under the stereoscopic sowing and the furrow sowing methods was also higher than that under the conventional drill sowing. 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) reported that the wide-precision planting significantly increased the leaf area index and interception of photosynthetically active radiation of winter wheat. Tao et al. (2018) reported that the uniform seeding was more conducive to light interception for the production of more grain. The plant height was highest in direct seeding, whereas the leaf area index was lowest, which might indicate the effect of shading under the direct sowing methods as compared to that under the uniform seed sowing, furrow sowing, and wide space sowing.

The furrow sowing proved beneficial in maintaining a higher photosynthetic rate. A previous study indicated that the furrow planting increased chlorophyll content and photosynthesis, as a result of which dry matter accumulation increased in each growth period (Wang et al., 2004; Yue et al., 2006). The furrow sowing produces more vigorous seedlings before winter, increases tiller numbers from booting to maturity stage, increases earing rate by 3.5%, and significantly increases yield (Wang et al., 2003; Li et al., 2013). The photosynthetic rate, transpiration rate, and stomatal conductance of the flag leaves were higher under the wide space sowing and furrow sowing, especially at the end of flowering. Fan et al. (2019) reported that the photosynthesis rate was higher under wide planting, and photochemical efficiency and chlorophyll contents at the heading and anthesis stages were higher under the wide planting than those under the conventional sowing.

Nitrogen fertilizer effect on water consumption characteristics, growth, and yield formation of wheat

The results of this study showed that the appropriate nitrogen application rates of wide seeding and furrow seeding were different in promoting water consumption at different growth stages of winter wheat. Under the wide-width sowing, water consumption at the sowing-wintering and anthesis-maturity was higher at N application rate of 90 kg ha⁻¹ and at the wintering-jointing and jointing-anthesis was stronger at 240 kg N ha⁻¹. Under the furrow sowing, water consumption at the sowing-wintering and anthesis-maturity was higher at the N application amount of 210 kg ha⁻¹. However, water consumption at the wintering-jointing and jointing-anthesis was higher with the N application rate of 240 kg ha⁻¹. Therefore, only the reasonable coordination of water and nitrogen can promote the effective absorption of water from the soil and promote the growth and development of plants (Das and Yaduraju, 2011).

It can be observed that the optimum nitrogen application rates vary with the sowing method in terms of increasing production. Compared with other treatments, the N amount of 240 kg ha⁻¹ and 210 kg ha⁻¹ combined with the wide space sowing and furrow sowing obtained higher tiller numbers, nitrogen accumulation, and translocation, and finally optimized the grain yield components and improved the yield. This may have been because the row spacings are larger in the wide-row seeding than those in the furrows, whereas the space for the growth of a single plant was reduced, and competition between plants for natural resources increased. Therefore, the effect of a higher nitrogen application rate proved better, because fertility improved plant growth by promoting the absorption and transportation of water and fertilizer by the root system (Khan et al., 2020).

Conclusion

From the present study, it is concluded that the wide space sowing and furrow sowing significantly increased the grain and protein yield of winter wheat compared to the conventional seed drilling

method. The wide space sowing produced the best suitable canopy structure, thereby increasing water consumption from deep soil layers. The higher water consumption increased the photosynthetic traits, leaf area index, number of spikes, and wheat grain yield. Furthermore, the N rates 210 kg ha⁻¹ and 210-240 kg ha⁻¹ significantly increased the water consumption and grain yield under the wide space sowing and furrow sowing.

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References

- Ahmed, M., Rauf, M., Akhtar, M., Mukhtar, Z., Saeed, N.A. (2020). Hazards of nitrogen fertilizers and ways to reduce nitrate accumulation in crop plants. *Environmental Science and Pollution Research* 27:17661-17670.
- Cui, Z.L, Chen, X.P., Zhang, F.S. (2010). Current nitrogen management status and measures to improve the intensive wheat-maize system in China. *AMBIO* 39:376-384.
- Das, T.K., Yaduraju, N.T. (2011). Effects of missing-row sowing supplemented with row spacing and nitrogen on weed competition and growth and yield of wheat. *Crop and Pasture Science* 62:48-57.
- Dong, S., Sun, M., Gao, Z., Xue, L., Lei, M., Hou, C. (2018). Effects of sowing methods on nitrogen utilization and yield of dryland wheat. *Journal of Shanxi Agricultural Sciences* 46:207-210.
- Fan, Y., Liu, J., Zhao, J., Ma, Y., Li, Q. (2019). Effects of delayed irrigation during the jointing stage on the photosynthetic characteristics and yield of winter wheat under different planting patterns. *Agricultural Water Management* 221:371-376.
- Khan, S., Anwar, S., Kuai, J., Ullah, S., Fahad, S., Zhou, G. (2017). Optimization of nitrogen rate and planting density for improving yield, nitrogen use efficiency, and lodging resistance in oilseed rape. *Frontiers in Plant Science* 8:532.
- Khan, S., Anwar, S., Gao, Z., Sun, M., Ashraf, M.Y., Ren, A., Yang, Z. (2020). Soil water consumption, water use efficiency and winter wheat production in response to nitrogen fertilizer and tillage. *PeerJ* 30:e8892.
- Kumar, M., Yadav, A., Sheoran, P., Singh, S. (2011). Effect of sowing methods and nitrogen management strategies on yield and nutrients uptake of wheat (*Triticum aestivum* L.). *Ecology, Environment and Conservation* 17:665-668.
- Li, Q.Q., Chen, Y.H., Liu, M.Y., Zhou, X.B., Dong, B.D. (2007). Effect of irrigation to winter wheat on the soil moisture, evapotranspiration, and water use efficiency of summer maize in North China. *Trans Asabe* 50:2073-2080.
- Li, R., Hou, X., Jia, Z., Han, Q., Ren, X. (2013). Effects on soil temperature, moisture, and maize yield of cultivation with ridge and furrow mulching in the rainfed area of the Loess Plateau, China. *Agricultural Water Management* 116:101-109.
- Liang, Y.F., Khan, S., Ren, A.X., Lin, W., Anwar, S., Sun, M., Gao, Z.Q. (2019). Subsoiling and sowing time influence soil water content, nitrogen translocation and yield of dryland winter wheat. *Agronomy* 9:p.37.
- Liu, X., Wang, K., Yang, Z., Xue, J., Du, T., Zong, Y., Hao, X., Sun, M., Gao, Z. (2018). Effects of different matching sowing dates and sowing methods on agronomic characters and yield of winter wheat in dryland in two cropping years. *North China Agricultural Journal* 33:232-238.
- Lu, D.J., Lu, F.F., Pan, J.X., Cui, Z.L., Zou, C.Q., Chen, X.P., He, M.R., Wang, Z.L. (2015). The effects of cultivar and nitrogen management on wheat yield and nitrogen use efficiency in the North China Plain. *Field Crops Research* 171:157-164.
- Lv, X., Zhang, Y., Li, H., Fan, S., Feng, B., Kong, L. (2020). Wheat belt-planting in China: an innovative strategy to improve production. *Plant Production Science* 23:12-18.
- Mon, J., Bronson, K.F., Hunsaker, D.J., Thorp, K.R., White, J.W., French, A.N. (2016). Interactive effects of nitrogen fertilization and irrigation on grain yield, canopy temperature, and nitrogen use efficiency in overhead sprinkler-irrigated durum wheat. *Field Crops Research* 191:54-65.
- Raun, W.R., Solie, J.B., Johnson, G.V., Stone, M.L., Mullen, R.W., Freeman, K.W., Thomason, W.E., Lukina, E.V. (2002). Improving nitrogen-use efficiency in cereal grain production with optical sensing and variable rate application. *Agronomy Journal* 94:351-815.
- Sun, M., Ge, X.M., Gao, Z.Q., Ren, A.X., Deng, Y., Zhao, W.F., Zhao, H.M. (2014). Relationship between water storage conservation in fallow period and grains protein formation in dryland wheat in different precipitation years. *Scientia Agriculture Sinica* 47:1692-1704 (in Chinese).
- Tao, Z., Wang, D., Ma, S., Yang, Y., Zhao, G., Chang, X. (2018). Light interception and radiation use efficiency response to tridimensional uniform sowing in winter wheat. *Journal of Integrative Agriculture* 17:566-578.

- Triboi, E., Triboi-Blondel, A.M. (2002). Productivity and grain or seed composition: a new approach to an old problem: invited paper. *European Journal of Agronomy* 16:163–186.
- Wang, F.H., Liu, S.J., Wang, X.Q. (1999). Ecological and physiological effects of ridge cropping on wheat. *Shandong Agricultural Sciences* 1999:4-7.
- Wang, H.Z., Chen, J.P., Meng, Z.J. (2004). Experimental study on cultivation and cultivation of wheat and cotton sheath by furrow planting in the eastern Henan plain. *Journal of Irrigation and Drainage* 23:10-13.
- Wang, S., Qi, H., Wang, Y., Zhang, Q., Feng, G., Lin, Y., Liang, Q. (2016). Effects of seeding rate and seeding mode on wheat growth and development and yield under wheat-cotton intercropping mode. *Journal of Shandong Agricultural University* 48:39-43.
- Wang, X., Yuan, H., Chen, D., Sun, J., Zhao, G., Kang, L., Zhang, W. (2005). Research on the water-saving planting technology of spring wheat by ridge planting in Ningxia irrigated area with Yellow River basin. *Ningxia Journal of Agriculture and Forestry Science and Technology* 3:15-17.
- Wang, X., Wang, F., Li, S., Yu, Z., Li, Z. (2003). Effect of bed-planting on grain yield and quality of wheat. *Shandong Agricultural Sciences* 6:15-17.
- Wang, Y., Zhang, Y., Zhang, R., Li, J., Zhang, M., Zhou, S., Wang, Z. (2018). Reduced irrigation increases the water use efficiency and productivity of winter wheat-summer maize rotation on the North China Plain. *Science of the Total Environment* 618:112-120.
- Xue, L., Khan, S., Sun, M., Anwar, S., Ren, A., Gao, Z., Lin, W., Xue, J., Yang, Z., Deng, Y. (2019). Effects of tillage practices on water consumption and grain yield of dryland winter wheat under different precipitation distribution in the Loess Plateau of China. *Soil and Tillage Research* 191:66-74.
- Yang, F., Feng, L., Liu, Q., Wu, X., Fan, Y., Raza, M. A., Cheng, Y., Chen, J., Wang, X., Yong, T., Liu, W. (2018). Effect of interactions between light intensity and red-to-far-red ratio on the photosynthesis of soybean leaves under shade condition. *Environmental and Experimental Botany* 150:79-87.
- Yue, J., Shao, Y., Chen, Y., Qin, F., Li, W., Jin, X. (2006). Effects of different sowing ways on the topsoil water and physiological characteristics of winter wheat. *Acta Agriculturae Boreali-Sinica* 21:17-19.
- Zhang, M., Sun, M., Gao, Z., Zhao, H., Li, G., Ren, A., Hao, X., Yang, Z. (2016). Relationship between water conservation and plant nitrogen operation and yield in dryland wheat field during fallow period. *Chinese Journal of Applied Ecology* 27:117-124.
- Zhao, J., Khan, S., Anwar, S., Mo, F., Min, S., Yu, S., Dong, S., Ren, A., Lin, W., Yang, Z., Hou, F. (2020). Plastic film-mulching with appropriate seeding rate enhances yield and water use efficiency of dryland winter wheat in Loess Plateau, China. *Applied Ecology and Environmental Research* 18:1107-1127.