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Impact of subsoiling and sowing time on soil water content and contribution of nitrogen translocation to grain and yield of dryland winter wheat

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Abstract: Dryland winter wheat in Loess Plateau is facing yield reduction due to shortage of soil moisture and delayed sowing time. Field experiment was conducted at Loess Plateau in Shanxi Province, China from 2012 to 2014, to study the effect of subsoiling and conventional tillage and different sowing dates on the soil water storage and contribution of N accumulation and remobilization to yield of winter wheat. The results showed that subsoiling significantly improved the soil water storage at 0-300 cm depth, improved the number of tillers and pre-anthesis N translocation in various organs of wheat and post-anthesis N accumulation, eventually increased the yield up to 17-36%. Delaying sowing time had reduced the soil water storage at sowing and winter accumulated temperature by about 180˚C. The contribution of N translocation to grain yield was maximum in glume+spike followed by in leaves and minimum by stem+sheath. In addition a close relationship was found between the N accumulation and translocation and the soil moisture in the 20-300 cm. Subsoiling during the fallow period and the medium sowing date was beneficial for improving the soil water storage and increased the N translocation to grain, thereby increasing the yield of wheat, especially in dry year.

Keywords: dryland wheat; subsoiling; sowing date; nitrogen accumulation; nitrogen translocation; yield

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1. Introduction

Wheat is a dominant crop in Loess Plateau accounting for 35% of total planting area [1–2]. Dryland wheat production in Loess Plateau is highly dependent on the timing and extent of rainfall whereas most of the precipitation is mainly concentrated during summer fallow period. Significant climatic changes have been observed in this area such as average precipitation is decreasing by 3 mm and average temperature is increasing by 0.6°C per decade with sudden incidence of drought [3–4]. These climatic changes are causing the unstable wheat production in dryland area of Shanxi province due to extreme variation in precipitation and low water retention capacity of soil [5]. In the Loess Plateau, a short summer fallow of about 3 month is practiced after the harvest of the previous winter wheat in late June and planting of the succeeding crop in late September to conserve soil water. Available soil moisture at sowing time depends on the tillage method used during fallow period [6-8]. Thus, improving soil water conservation is crucial to increase the yield of dryland wheat.

The sowing date also has a significant effect on the yield response of wheat [9, 10]. Sowing time influences the accumulating temperature before winter, and affects the nutrient uptake and transportation of plants, and ultimately affects the yield [11]. Sowing date strongly influence the use of environmental resources and optimal sowing can make full use of resources such as pre-winter light, heat, nutrient and water to develop strong seedlings and promote yield formation [12]. Under irrigation system the sowing time can be adjusted whereas in rain-fed dryland farming the sowing

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time might be delayed due to scarcity of residual soil moisture under erratic rain condition [13]. Furthermore, conventional tillage method also results in excessive soil disturbance and drying of surface soil. Therefore, saving the residual soil moisture from precipitation during fallow season and adjustment of sowing date become key determining factors for yield determination of dryland winter wheat [6].

Yield formation of rainfed winter wheat is effected to different extent under early and late sowing [13]. Sun et al. [14] studied the impact of different sowing dates on yield in the North China Plain and found that the yield of wheat sown after October 10 was significantly reduced with the delay in sowing date. Zhou et al. [5] showed that late planting could increase the pre-anthesis accumulation of nitrogen in the vegetative organs and the contribution rate of nitrogen to the grain. In contrast, Qu et al. [15] showed that the pre-anthesis transport and translocation of nitrogen in the vegetative organs, and contribution rate of nitrogen to grain were decreased with the delay of sowing date and the grain yield was increased significantly under delayed sowing time and increasing density.

Subsoiling has previously proved a promising technique for increasing water storage, reducing water loss, enhancing water availability, and saving energy, as well as increasing wheat yield. Liu et al. [16] showed that subsoiling improved soil moisture content in the 0-160 cm soil layer before sowing, which was increased by 1% than traditional tillage. Wang et al. [17] showed that during the fallow period, the subsoiling improved the soil water storage capacity of 0-180 cm by 9-24 mm before sowing. Wang et al. [18] showed that subsoiling can effectively accumulate precipitation during fallow period, significantly increased soil water storage capacity from 0 to 200 cm before sowing, improve water use efficiency by 39% and finally increase yield.

In addition, different tillage methods could also affect the uptake and accumulation of nitrogen in plants by affecting soil moisture. Zheng et al. [19] have shown that subsoiling can increase the nitrogen accumulation of wheat after jointing and the distribution of nitrogen to grain during mature period, and obtain high grain yield. Wang et al. [20] also reported that subsoiling improve the efficiency of nitrogen utilization, and increased wheat yield by enhancing the distribution and translocation of nitrogen from vegetative organs to grain after flowering. The amount of nitrogen in the vegetative organs before flowering and its contribution to grain were found highest in leaves, followed by glume+cobs and lowest was in stem+leaf sheaths. Furthermore, tillage practice has increased the amount of nitrogen by 20 kg ha^{-1}, 9 kg ha^{-1}, and 2 kg ha^{-1}, than no-tillage which in turn increased the final yield increased by 26% [21].

It can be seen that tillage and sowing time can affect the translocation of plant nutrient thus affecting the yield, and need is to further explore how to adjust the sowing time to realize the increase of production under the premise of realizing the water storage. Therefore, the aim of the present research was to explore the effects of different sowing time on the changed source-sink ratio, accumulation and translocation of nitrogen and its contribution to yield of dryland wheat and condition of water storage in soil under subsoiling, in order to provide a theoretical basis for the realization of yield increase in dryland. .

2. Materials and Methods

2.1 Site characteristics and description

The experiment was carried out from 2012 to 2014 at the dryland wheat experimental station of Shanxi Agricultural University located at Wenxi (35°20′N,111°17′E), Shanxi Province, China. Rain-fed agriculture is popular in this area due to unavailable irrigation condition. Winter wheat is usually planted in the early October and no irrigation was supplied. After the harvesting of wheat, field was left fallow until next sowing.

2.2 Meteorological conditions

The experimental area is hilly arid land with semiarid climate typical of Northeast Loess Plateau where 60-70% precipitation fell in the summer months during fallow season

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(July-September). Precipitation data were provided by Agricultural Bureau of Wenxi and monthly precipitation during the experimental years for 2012-2014 is shown in Figure 1.

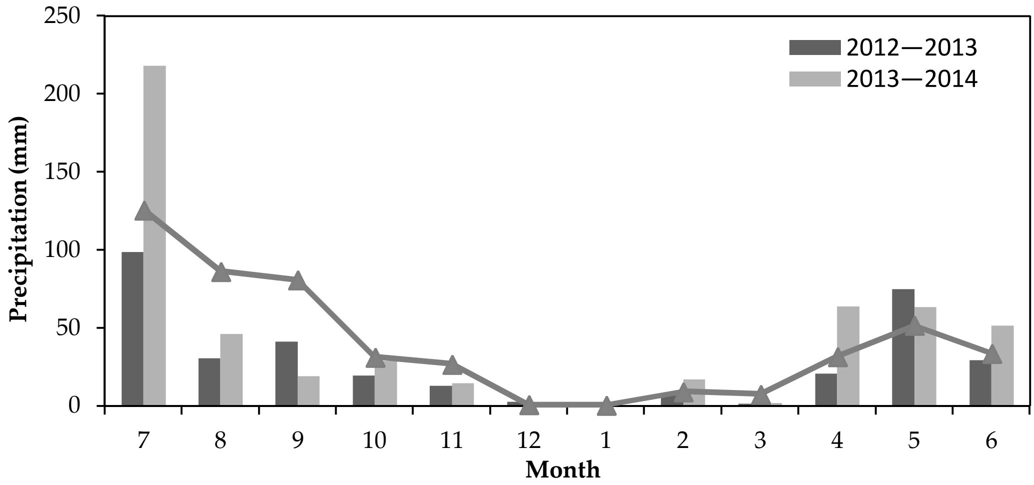

Figure 1. Precipitation at the experimental site in Wenxi (Source: Meteorological Observation of Wenxi County, Shanxi Province, China

Average rainfall of site was 487.6 mm from 2009 to 2014. The annual precipitation in 2012-2013 growth seasons was lower than usual and 171.1 mm rainfall was during fellow period and 171.8 mm in growth period. The total precipitation during 2013-2014 growth seasons was close to the average annual precipitation, from which 283.7 mm rain was fell during fallow period and 242 mm during growth period.

2.3 Field trial management and experimental design

Former wheat stubble (20-30 cm) which was left in field was shredded, followed by tillage in mid-July. Tillage practices were performed during the fallow season. Subsoiling (SS) was conducted with a subsoiling chisel plow at the depth of 30-40 cm on 15th July in 2012 and 2013. Local conventional tillage (CT) was taken as a control. Rotary tillage was used to crumble large lump and level the fields on 25th August 2012 and 23rd August 2013. The area of each plot was 150 m^2 (50 m × 3 m).

The wheat variety 'Yunhan 20410' provided by the Agriculture Bureau Wenxi, was sown on three different dates: 20th September (T_1, early sowing), 1st October (T_2, conventional normal sowing), and 10th October (T_3, late sowing) in 2012 and 2013. Seeds were sown at density of 90 kg ha^{-1} with row spacing of 30 cm and after emergence seedling density was maintained at 225×10^4 ha^{-1}.

The two-factor split plot design was adopted, taking the tillage method as the main factor and sowing dates as the sub-plot factor. Each treatment was repeated 3 times. Before sowing, nitrogen, phosphorus and potash fertilizers were applied using 150 kg ha^{-1} of urea, P_2O_5, and K_2O respectively. No top fertilizer was applied during growth period. Basic soil properties were determined from 0-20 cm soil layer and soil was classified as silty clay loam. Soil properties recorded on 10th June 2012 were: organic matter 11.9 g kg^{-1}, available nitrogen 38.6 mg kg^{-1}, and available phosphorus 14.6 mg kg^{-1}, whereas soil properties recorded on 10th June 2013 were: organic matter 10.2 g kg^{-1}, available nitrogen 39.3 mg kg^{-1}, and available phosphorus 16.6 mg kg^{-1}.

2.4 Sampling and measurements

2.4.1 Soil moisture content

Soil samples were collected from different soil depths at different durations. Soil samples were taken with soil drilling after every 20 cm soil layer from 0-300 cm total depth. The samples were weighed and dried at 105°C until constant weight and soil moisture was measured at 30 (after

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harvest), 112 (pre-sowing), 185 (overwintering period), 301 (joining stage), 312 (booting stage), 327 (flowering period) and 365 (maturation period) days after the harvest of the former wheat. Soil water storage was calculated from the following formula:

$$\text{Soil water storage capacity (mm)} = [(\text{wet soil weight} - \text{dry soil weight}) / \text{dry soil weight} \times 100\%] \times \text{soil thickness} \times \text{soil bulk density}, \quad (1)$$

2.4.2 Total nitrogen content and nitrogen accumulation

Dry matter and total nitrogen content of plant were measured at overwintering, jointing, booting, flowering and maturity stages. Twenty whole plants were sampled and at jointing and booting stages divided into two parts (stems and leaves sheath), at the flowering stage plants were divided into three parts (leaves, stems, and ears), and at the maturity stage were divided into four parts (leaves, stems+sheath, glumes+spikes, and grains). Samples were kept at 105 °C for 30 min and at 75 °C until constant weight, after which they were weighed, grinded, and the total nitrogen content were determined by using Kjeldahl method. The parameters, related to translocation, accumulation and remobilization of nitrogen within the wheat plant were calculated by using following equations:

$$\text{Pre-anthesis N translocation} = \text{N content in vegetative organ at anthesis} - \text{N content in vegetative organ at maturity}, \quad (2)$$

$$\text{Contribution of pre-anthesis N to grain N (\%)} = (\text{pre–anthesis N translocation}) / (\text{grain N content at maturity}) \times 100, \quad (3)$$

$$\text{Post-anthesis N accumulation} = \text{N content of whole plant at maturity} - \text{N content of the whole plant at anthesis}, \quad (4)$$

$$\text{Contribution of post-anthesis remobilized N to grain N (\%)} = (\text{post–anthesis remobilized N}) / (\text{grain N content at maturity}) \times 100, \quad (5)$$

2.4.3 Yield and yield component

At the maturity stage, fifty plants per plot were harvested and number of panicles, the number of grains per panicle, and the 1000-grain weight were measured. Plants from 20 m^2 were harvested from each plot and the grains were air-dried to determine plot yield and to calculate the economic output.

2.5 Statistical analysis

Data was analyzed using SAS 9.0 (SAS Corp., Cary, NC, USA) software to determine the statistical significance and the difference between the treatments were analyzed by LSD (least significant difference) test at $p < 0.05$, and graphs were constructed using Microsoft Excel 2003 and SigmaPlot 12.5 software.

3. Results

3.1 Effects of tillage practices and sowing timing on soil water storage

Soil water storage in 0-300 cm layer storage was more under the subsoiling practices as compared to conventional tillage (Figure 2). Under subsoiling, soil water storage in 0-300 cm soil layer was increased by 35, 55 and 68 mm in 2012-13 and 40, 35 and 52 mm in 2013-14 at T_1, T_2 and T_3 sowing dates respectively, as compared to conventional tillage.

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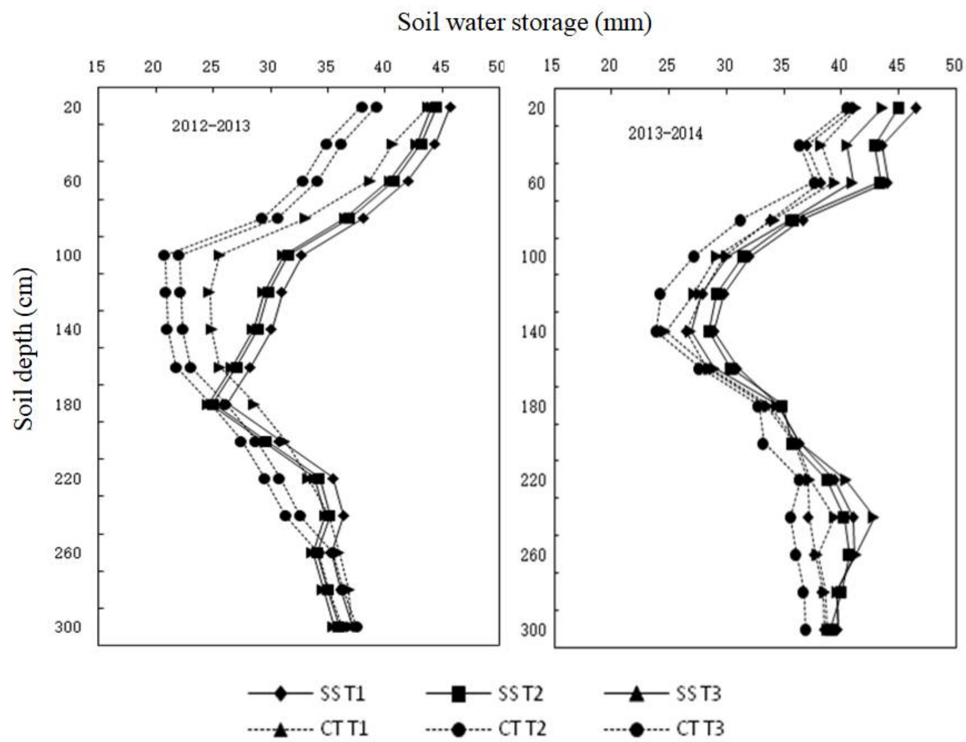

Figure 2. Effect of subsoiling and sowing date on soil water storage during 2012-2014. SS: Subsoiling during fallow period; CT: Conventional tillage; T1: Early sowing date; T2: Timely sowing; T3: Late sowing. Values followed by different small letters indicate significant difference at 0.05 level.

Furthermore, soil water storage was highest under early sowing as compared to medium and late sowing (Figure 2). In 2012-2013, subsoiling especially increased the soil moisture in 0-180 cm and 200-240 cm soil layers, and in 2013-2014 subsoiling increased soil moisture in 0-220 cm and 260-300 cm soil layers. With the delay of the sowing date, soil water storage at the sowing stage decreased, but the difference was not significant from 2012 to 2013. It was significantly lower than early and medium sowing in the late planting period from 2013 to 2014, especially 0-180 cm soil layer. With the delay of sowing time, the soil water storage was decreased and difference was more significant during 2013-2014. The soil water storage at late sowing in 2013-2014 was obviously lower than early and middle sowing, especially in 0-180 cm soil layer.

3.2 Effects of subsoiling and sowing time on number of tillers at different stages of winter wheat and effect of sowing time on accumulated temperature

Winter accumulated temperature was decreased with the delay of sowing time. The accumulated temperature of late sowing was reduced by 379 ℃ and 172℃ than in early and conventional sowing time of winter wheat respectively (Figure 3). The number of tiller under subsoiling was significantly higher than that in conventional tillage. The highest number of tillers was recorded in conventional sowing time (T_2), but during wintering stage, the difference was not significant with early sowing time (T_1), whereas in joining, booting and maturity stages, the number of tillers were significantly higher in T_2 than T_1 and T_3. Under medium sowing time (T_2), subsoiling resulted in averagely 13% increase in tillage number as compared to conventional tillage. Late sowing resulted in 17% and 15% reduction in number of tillers as compared to medium sowing time under subsoiling and conventional tillage respectively. Early sowing (T_1) and the conventional medium sowing (T_2) times were favorable to the formation of more tiller in winter, but the medium sowing is more favorable to the formation of effective spike number, thus increasing the yield.

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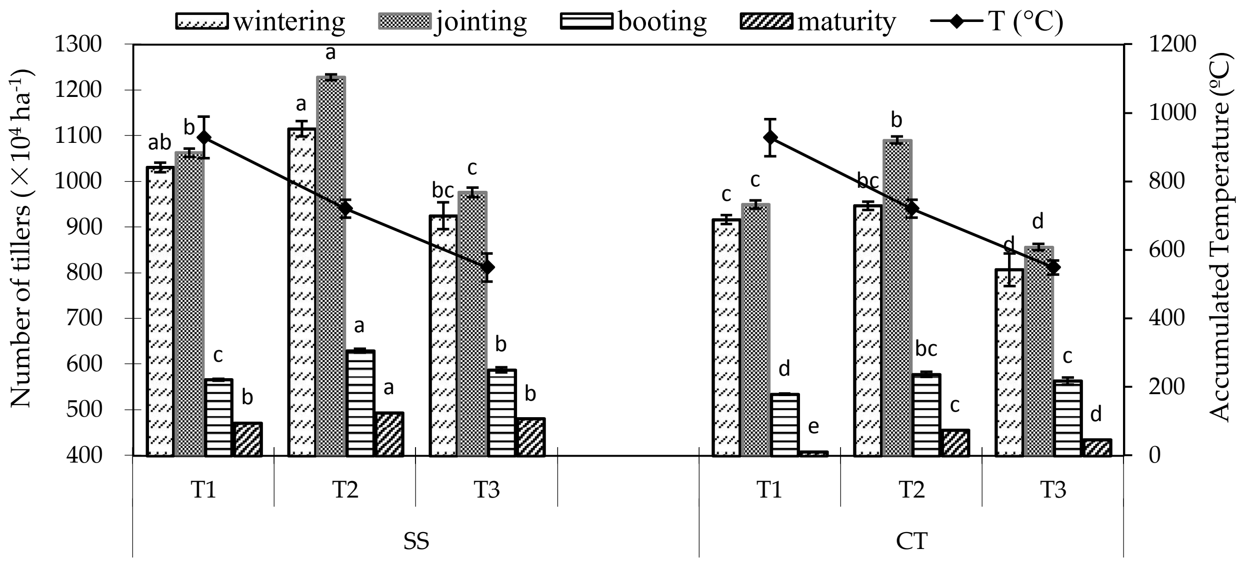

Figure 3. Effect of subsoiling and different sowing times on number of tillers (×10^4 ha^{-1}) and winter accumulated temperature at different stages of winter wheat during 2013-2014. SS: Subsoiling during fallow period; CT: Conventional tillage; T1: Early sowing date; T2: Timely sowing; T3: Late sowing.

3.3 Effect of subsoiling and sowing time on N accumulation and translocation

3.3.1 Pre-anthesis N translocation and post-anthesis N accumulation

The contribution rate of N translocation in the plant before anthesis (about 75%) was greater than the contribution rate of N accumulation after anthesis (about 25%) to the grain N (Table 1).

Table 1 Effect of subsoiling and sowing dates on pre-anthesis nitrogen translation and post-anthesis nitrogen accumulation to grain nitrogen

Tillage	Sowing date	Pre-anthesis		Post-anthesis	
		NT (kg ha^{-1})	Contribution of NT to grain N (%)	NA (kg ha^{-1})	Contribution of NA to grain N (%)
SS	T_1	96.74 b	76.67 ab	29.43 b	23.33 cd
	T_2	111.94 a	78.16 a	31.27 a	21.84 d
	T_3	86.25 d	75.93 bc	27.34 d	24.07 bc
CT	T_1	73.98 e	74.45 c	25.39 e	25.55 b
	T_2	91.01 c	75.92 bc	28.86 c	24.08 c
	T_3	61.61 f	69.30 d	27.29 d	30.70 a

Different letters in the same column indicate significant difference at 0.05. NT, N translation; NA, N accumulation

Under subsoiling, the N translocation and the contribution rate to the grain of the pre-anthesis were significantly increased. Pre-anthesis nitrogen translocation was increased by 21-25 kg ha^{-1}, whereas the contribution rate to grain N was increased by 2-7% by subsoiling as compared to conventional tillage. It can be seen that under the conditions of subsoiling in fellow period, the translocation of N before anthesis, N contribution to grain, and the amount of N accumulation after anthesis was higher in medium sowing time as compared to early and late sowing time. In late sowing time the N translocation, contribution of N translocation and post-anthesis N accumulation was decreased as compared to medium sowing times, whereas the post-anthesis contribution of N accumulation to grain N was increased.

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3.3.2 Pre-anthesis N accumulation and translocation in various plants parts

The accumulation and translocation of N before flowering and contribution to grain were highest in the stem+leaf sheath, and the lowest in the glume+spike (Table 2). In leaf, N accumulation and N translocation and contribution to grain was less than the stem+sheath and higher than in glume+spike. Compared with the control, subsoiling during the fellow time significantly increased the accumulation and translocation of N in plants parts and its contribution to grains before flowering. Nitrogen accumulation was increased by 4–7 kg ha^{-1}, 13–18 kg ha^{-1}, and 3–4 kg ha^{-1}, and the amount of nitrogen translocation was increased by 6–7 kg ha^{-1} and 12–14 kg ha^{-1}, and 3–4 kg ha^{-1} in leaves, stems+sheaths, glume+spike respectively.

Accumulation and translocation of N in all plant parts was highest under medium sowing time, while the late and early sowing significantly decreased the N accumulation and translocation in leaf, stems+sheaths, glume+spike (Table 2). Contribution rate to the grain was highest in medium sowing time for leaf and stem+sheath. Under subsoiling conditions, the early and late sowing time has decreased the contribution of leaf and stem+sheath to grain as compared to medium sowing time, whereas there was no significant difference between sowing times in glume+spike. It can be seen that the medium sowing time is beneficial to the translocation of N in the leaves and stems and sheath under subsoiling practice during fallow period.

Table 2 Effect of subsoiling in fallow period and different sowing date on nitrogen accumulation, translocation and contribution ratio to grain of wheat before anthesis

Tillage	Sowing date	Leaf			Stem+sheath			Glume+spike		
		NA (kg h^{-1})	NT (kg ha^{-1})	Contribution of NT to grain N (%)	NA (kg h^{-1})	NT (kg ha^{-1})	Contribution of NT to grain N (%)	NA (kg h^{-1})	NT (kg ha^{-1})	Contribution of NT to grain N (%)
SS	T_1	27.48 c	24.12 b	19.11 b	80.98 b	60.42 b	47.88 b	19.85 b	12.21 b	9.68 a
	T_2	32.35 a	28.88 a	20.17 a	86.69 a	69.08 a	48.24 a	23.44 a	13.98 a	9.40 a
	T_3	28.48 b	21.86 d	19.25 b	76.38 c	53.49 c	47.09 b	18.06 c	10.89 c	9.59 a
CT	T_1	22.71 d	17.77 e	17.88 c	63.03 d	47.30 d	47.60 b	16.20 d	9.90 d	8.96 c
	T_2	28.27 b	22.60 c	18.86 b	72.77 c	57.28 b	47.79 b	20.08 b	11.13 c	9.28 b
	T_3	21.12 e	14.54 f	16.36 d	57.93 e	39.14 e	44.02 c	14.90 e	6.93 e	7.79 d

Different letters in the same column indicate significant difference at 0.05. NT, N translation; NA, N accumulation

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3.4 Correlation coefficients between soil moisture and nitrogen accumulation and translocation in plant parts before anthesis

Under subsoiling and different sowing periods, the soil water storage in the 0-300 cm soil layers during the fallow period was positively correlated with the nitrogen accumulation and translocation of plant parts before flowering (Table 3). Significant and positive correlation was found for nitrogen accumulation in leaves and soil moisture in 80-140 cm, 160-180 cm, and 260-280 cm soil layers; nitrogen accumulation in stems and sheaths and soil water storage in 0-180 cm and 240-300 cm soil layers; and nitrogen accumulation in glume + spike and soil water storage in the 80-140 cm soil layer. It was shown that the accumulation of N in leaf, and glume+spike was closely related to soil moisture in 80-140 cm, and the stem+sheath were closely related to 0-180 cm soil layer. The N translocation in glume+spike and soil water storage in the 60-140 cm, 160-180 cm, and 240-300 cm soil layers was significantly related. It was shown that the N translocation of leaves, and stem+sheaths is closely related to the soil moisture of 20-180 cm, and the N translocation of glume+spike was closely related to 60-200 cm and 240-300 cm soil layer.

Table 3 Correlation coefficients between soil water storage at different soil depth and nitrogen accumulation and translocation in different organs before anthesis

Soil depth (cm)	Leaf		Stem+sheath		Glume+spike	
	NA	NT	NA	NT	NA	NT
0-20	0.6486	0.7505	0.8496*	0.7444	0.6455	0.6302
20-40	0.6817	0.7853*	0.8654*	0.7752*	0.6785	0.6884
40-60	0.6717	0.7863*	0.8602*	0.7807*	0.6853	0.6823
60-80	0.7489	0.8102*	0.8778**	0.8121*	0.6871	0.8269*
80-100	0.8030*	0.8937**	0.9302**	0.9080**	0.8197*	0.8369*
100-120	0.7961*	0.8812*	0.8981**	0.9036**	0.8128*	0.8631*
120-140	0.8622*	0.9212**	0.9697**	0.9216**	0.8595*	0.8279*
140-160	0.6584	0.7944	0.8553*	0.8031*	0.6424	0.6650
160-180	0.8152*	0.8568*	0.9104**	0.8355*	0.7403	0.8631*
180-200	0.5797	0.6072	0.6309	0.6294	0.7068	0.7554*
200-220	0.6255	0.5904	0.7311	0.5486	0.4217	0.6401
220-240	0.5514	0.5453	0.6593	0.5171	0.3656	0.6565
240-260	0.7502	0.7631	0.8675*	0.7364	0.6183	0.7778*
260-280	0.8258*	0.8624*	0.9029**	0.8527*	0.7477	0.9079**
280-300	0.6628	0.6874	0.7643*	0.6882	0.5436	0.7809*

* Significant at $P<0.05$; ** Significant at $P<0.01$

3.5 The relationship between nitrogen translocation and grain yield before flowering

3.5.1 Relationship between N translocation and grain production

Significant linear positive correlation was found between grain yield and pre-anthesis nitrogen translocation (Figure 4). For N translocation in the leaves and glume+spike, the fitting equations were $y = 89.933x + 2834.6$ ($r = 0.887^{**}$) and $y = 179.15x + 2867.5$ ($r = 0.876^{**}$). There was a significant relationship between the N translocation in stem+sheath and grain yield, and the fitting equation was $y = 40.92x + 2551.6$ ($r = 0.842^{*}$).

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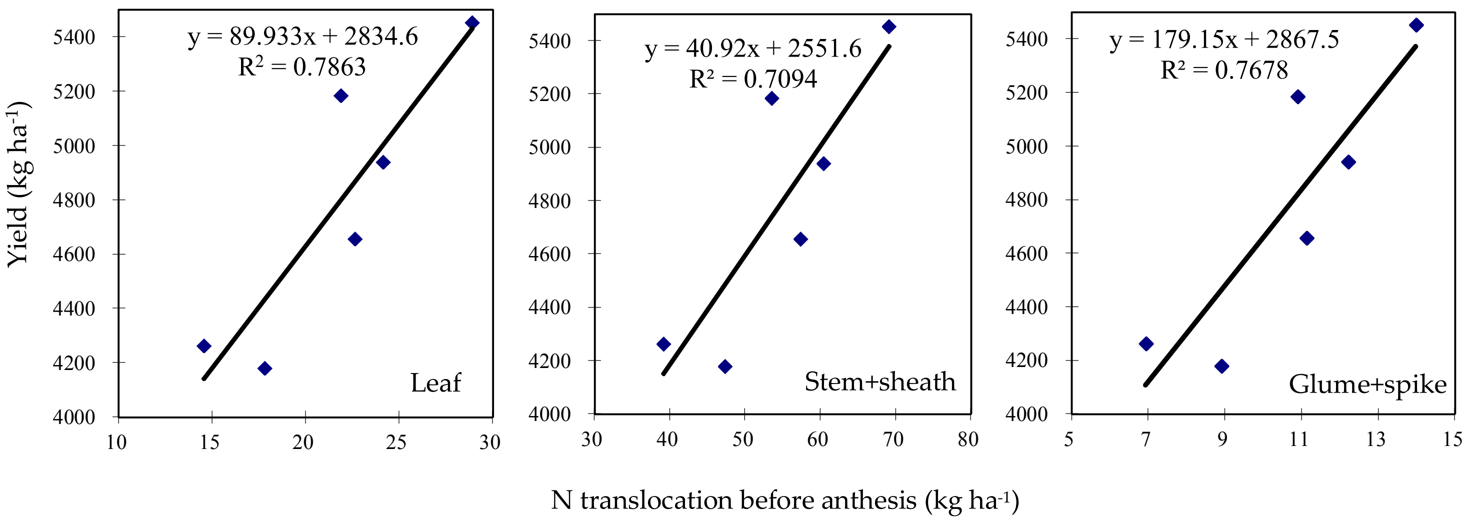

Figure 4. Relationship of yield with nitrogen translocation before anthesis (2013-2014), Solid lines are linear regressions, dashed lines are the 95% confidence intervals

3.5.2 The contribution of subsoiling to increase nitrogen translocation

Subsoiling during the fallow period significantly increased the yield by 19%-36% (2012-2013) and 17-22% (2013-2014) compared with the conventional tillage (Table 4). Under subsoiling, the medium sowing timing significantly increased the yield by 13%-16% and 5%-10%, in 2012-2013 and 2013-2014 respectively. Under the conventional tillage, in 2012-2013 the highest yield was attained in early sowing treatment but the difference between early and medium sowing treatments were not significant, however, in 2013-2014, maximum yield was attained at medium sowing time which was 11% and 9% higher than the early and late sowing.

Table 4 Effect of subsoiling at different sowing dates on the contribution of N translocation before anthesis on yield

Year	Tillage	Sowing date	Yield (kg ha-1)	ΔNT (kg ha-1)			ΔY (kg ha-1)	ΔY/ΔNT		
				Leaf	Stem + sheath	Glume + spike		Leaf	Stem + sheath	Glume + spike
2012-2013	SS	T_1	3353.4 b	4.91 c	7.05 a	2.31 c	537.2	109.4 b	76.20 b	232.9 b
		T_2	3796.7 a	5.14 a	5.66 c	3.35 a	1015.0	198.0 a	179.4 a	302.7 a
		T_3	3283.2 b	5.01 b	6.41 b	2.96 b	827.7	165.5 b	129.1 b	279.2 b
	CT	T_1	2816.3 c	—	—	—	—	—	—	—
		T_2	2781.7 c	—	—	—	—	—	—	—
		T_3	2455.5 d	—	—	—	—	—	—	—
2013-2014	SS	T_1	4940.6 c	6.34 b	13.11 b	3.31 b	760.63	119.9 b	58.03 b	235.2 b
		T_2	5453.0 a	6.28 c	11.80 c	2.85 c	796.20	127.4 a	67.57 a	282.6 a
		T_3	5184.3 b	7.32 a	14.35 a	3.96 a	920.60	125.9 b	64.35 b	246.1 b
	CT	T_1	4180.0 e	—	—	—	—	—	—	—
		T_2	4656.8 d	—	—	—	—	—	—	—
		T_3	4263.7 e	—	—	—	—	—	—	—

The contribution of N translocation to grain yield was maximum in glume+spike, followed by leaf and minimum was in stem+leaf sheath. Medium sowing time significantly increased the contribution of the amount of N in each organ to the yield as compared to early and late sowing. It can be seen that the practice of subsoiling during the fallow period and medium sowing time (1st

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October) was beneficial to the pre-anthesis N translocation in plant organs and contribution of N to the yield and the effect was more prominent during the drier year (2012-13).

4. Discussion

The results from experiment showed that the subsoiling during fallow period significantly increased the soil water storage from 0 to 300 cm soil before sowing, especially in 2012-2013 (Figure 2). Previous reports also showed that subsoiling during fallow period promotes the water storage capacity in the deeper horizons of the soil profile in dryland areas [8, 22, 23]. Hou et al. [24] showed that subsoiling during the fallow period improved the water storage capacity of 0-200 cm soil before the sowing in dryland wheat field. Fu et al. [25] reported that subsoiling accumulated 50% of the summer rainfall in dryland wheat fields, and increased the soil water storage capacity by 76.2 mm in 0-200 cm soil before sowing. Mao et al. [26] showed that subsoiling during the fallow period in the dryland wheat field increased the soil water storage capacity of 0-300 cm by 21 mm and increased the yield by 5.5%. Ren et al. [27] found that subsoiling during the fallow period increased the water storage capacity of 0-300 cm soil in dryland wheat (especially in 80-160 cm soil layer). These indicating that subsoiling can accumulate precipitation during the fallow period and increases the soil moisture reserve in fallow period, favoring timely sowing and subsequent germination of dryland winter wheat [8, 28].

Adequate soil moisture is conducive for the growth and development of wheat, which directly affects the accumulation and translocation of N, thus affecting the yield. The results of this experiment showed that subsoiling during fallow period can significantly increase the amount of N of various organs before flowering, especially in leaves and stems+sheaths (Table 2). The contribution rate of N translocation to grain before flowering and nitrogen accumulation after flowering were significantly improved. This may be due to the improvement of effective soil water storage capacity to promote water and N absorption. Previous studies have showed that subsoiling treatment increased the uptake of N after anthesis and further improve the N accumulation of grain by enhancing the absorption of water and nutrients by roots and increasing the supply of N metabolism substrates in the aboveground parts [15, 20]. Zheng et al. [19] showed that subsoiling + rotary tillage and subsoiling + strip rotary tillage significantly increased N accumulation at flowering and N translocation from vegetative organs to grain after flowering, compared with the rotary tillage and strip rotary tillage and thereby increasing yield. Wang et al. [29] showed that subsoiling had increased N accumulation after flowering and its contribution to grain by 50% and 38%, respectively.

On the basis of suitable sowing date, the growth of root system was promoted further improving the absorption capacity of soil nitrogen and fertilizer in dryland wheat and promoting the vegetative and reproductive growth promoted the transport of N stored in the leaves, stems and sheaths to the grain, which increased the amount of N before the flowering and the contribution rate to the grain, thereby increasing the yield [8]. Ren et al. [30] showed that the soil storage capacity of 0-300 cm was positively correlated with the accumulation of N in the vegetative organs and the amount of the biomass before anthesis.

Subsoiling during the fallow period significantly increased the yield (17%-36%) compared with the conventional tillage (Table 4). Wang and Shangguan [7] reported that wheat yield in Loess Plateau region is sensitive to soil water content at plantation and grain yield increased linearly with the soil water at planting, under subsoiling and other tillage methods. SS increased yield by improving N accumulation and translocation to grain. The amount of N mobilization in stem + sheath had a significant effect on grain yield [31]. The activities of key nitrogen metabolism enzymes and intermediate products of nitrogen assimilation were significantly higher by subsoiling than the rotary tillage and conventional tillage methods [20, 32]. Subsoiling tillage had higher translocation of N from vegetative organs to grain, higher absorption of N after flowering and higher contribution from absorbed N after flowering to grain than the other two tillage methods. As compared to subsoiling, the amount of translocation of N, translocation efficiency and N absorption after flowering, and N accumulation and distribution rate in grain were lower under rotary tillage.

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Therefore, subsoiling tillage could promote N assimilation and improve nitrogen use efficiency to attain high-efficient and high-yield of wheat [20].

Present results indicated that accumulation of N and the amount of N translocation in the leaves, and glume+spike were correlated with the soil water storage in the middle soil layer and the accumulation of N and the amount of translocation of the stem+sheath were more correlated with the soil storage capacity in the upper middle layer (0-180 cm) and the lower layer (240-280 cm) (Table 3). This may be related to the distribution of wheat roots in the soil and consistent with the results of Zhang et al. [31]. The distribution of wheat root length in different depth soil layer shows "T" shape distribution, but in later stage of growth it represents "8" pattern distribution. The soil water content at sowing stage in 0-300 cm depth was positively correlated to N mobilization amount before anthesis and N accumulation amount after anthesis [31]. Subsoiling improves the depth of rooting in deeper soil by minimizing the compaction of soil and allowing the accumulation of water reserve which in turn improves water and nutrients uptake and drought resistance [33].

Suitable sowing is the main measure to match the growth and development of wheat and the local climate, which is conducive to achieve stable yield [14]. This experiment showed that with the delay of the sowing time for 10 days the accumulated temperature before winter is reduced by about 180 °C. Xu et al. [12] and other studies have shown that with the delay of sowing date, the accumulated temperature in winter is reduced which significantly affected the growth of wheat before winter, and decreased the number of tiller. For each 6-day delay in sowing date, the average daily temperature from sowing to emergence decreased by 1.0-2.5 °C, and the number of tillers decreased by 100-150 million ha^{-1}. In present study both early sowing and medium sowing were beneficial for the formation of more group tillers in winter, but the medium sowing was more favorable for the formation of effective number of tillers, so as to increase the yield. Sun et al. [14] reported that the delayed sowing time would affect the growth duration and reduced the dry matter mobilization efficiency of winter wheat as compared with the medium sowing time. Tillering is determining factor for optimum wheat yield because excessive production of tillers under well fertilized soil ended in increased competition for light and resources leading to tillers mortality and reduced number of effective tillers and grain yield [34].

Sowing at appropriate time can increase the effective accumulative temperature, prolong the effective growth period of wheat and increase the accumulation of N in grains [15, 35, 36]. The results of present experiment showed that medium sowing time significantly increased the contribution of the amount of N in each organ to the yield as compared to early and late sowing (Table 4). Late and early sowing significantly decreased the N translocation. Accumulation and translocation of N in all plant parts was highest under medium sowing time, while the late and early sowing significantly decreased the N accumulation and translocation in leaf, stems+sheaths, glume+spike (Table 2). Medium and late sowing time significantly increased the dry matter accumulation in the vegetative organs before flowering to the grain, thereby increasing yield. Under subsoiling, the normal sowing timing significantly increased the yield by 13%-16% and 5%-10%, in 2012-2013 and 2013-2014 respectively as compared to early and late sowing. The delay in sowing tended to late oncoming of heading and flowering stage and shortening the duration of grain filling stage which causes less dry matter mobilization efficiency and reduced biomass and grain yield [14, 37].

Early and late sowing significantly decreased the N accumulation and translocation before anthesis (Table 1). The contribution rate of N to the grain after anthesis was decreased at early and medium sowing, whereas the contribution rate of N accumulation to grain was significantly improved by late sowing at post-anthesis. This may be because late sowing increases the proportion of N translocation from the glume+spike to grain, and improves the ability of the plant to use already absorbed N for grain production.

Ding et al. [38] showed that the accumulation of N in leaves and stems was significantly linearly correlated with grain yield at flowering stage, and N translocation from leaves and stem + sheath was significant linearly positively correlated with grain yield. The results of this experiment showed that the relationship between the amount of N in various organs before flowering and grain yield was consistent with a significant linear positive correlation. There was a significant relationship between the amount of N translocation in the leaves, stem+sheath and glume+spike and the grain yield. For every 1 kg ha^{-1} of N transported by the leaves, the yield was increased by 109-198 kg ha^{-1}; for every 1 kg ha^{-1} of N transported by the stem+sheath, the yield was increased by 58-179 kg ha^{-1}; for each kg ha^{-1} N translocation from glume+spike, the increase of 233-302 kg ha^{-1} of grain yield could be achieved.

5. Conclusions

Subsoiling during the fallow period can make full use of precipitation, which contributes greatly to the yield of dryland wheat. Subsoiling during the fallow period significantly increased the yield (17%-36%) compared with the conventional tillage. SS increased yield by improving N accumulation and translocation to grain. A significant linear relationship was found for N translocation and grain yield and N translocation from glume+spike contributed most for yield increment followed by leaves. Medium sowing time (October 1) significantly increased the contribution of the amount of N in each organ to the yield as compared to early and late sowing.

Author Contributions: GZ designed and supervised the research project. YFL performed the experiments and collected the data. Sk helped in data collection. SK and SA analyzed the data and wrote the manuscript. GZ revised and edited the manuscript SA provided advice on the experiment. GZ read and approved the final manuscript.

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References

1. An, P.; Inoue, T.; Zheng, M.; Eneji, A.E.; Inanaga, S. Agriculture on the Loess Plateau, in: Tsunekawa, A., Liu, G., Yamanaka, N., Du, S. (Eds.), Restoration and development of the degraded Loess Plateau, China. Springer, Japan, **2014**, pp. 61–74.
2. Li, X.; Philp, J.; Cremades, R.; Roberts, A.; He, L.; Li, L.; Yu, Q. Agricultural vulnerability over the Chinese Loess Plateau in response to climate change: Exposure, sensitivity, and adaptive capacity. *Ambio* **2016**, 45(3), 350-360.
3. Piao, S.; Ciais, P.; Huang, Y.; Shen, Z.; Peng, S.; Li, J.; Zhou, L.; Liu, H.; Ma, Y.; Ding, Y.; Friedlingstein, P. The impacts of climate change on water resources and agriculture in China. *Nature* **2010**, 467(7311), 43-51.
4. He, L.; Cleverly, J.; Chen, C.; Yang, X.; Li, J.; Liu, W.; Yu, Q. Diverse responses of winter wheat yield and water use to climate change and variability on the semiarid Loess Plateau in China. *Agron J* **2014,** 106, 1169–1178, Doi: 10.2134/agronj13.0321.
5. Zhou, X.; He, M.; Dai, X.; Kong, H.; Xiao, L.; Li, C. Effects of sowing time and density on yield and nitrogen utilization efficiency of different wheat varieties. *Shandong Agric Sci* **2013**, 45(09), 65-69 (in Chinese).
6. Su, Z.; Zhang, J.; Wu, W.; Cai, D.; Lv, J.; Jiang, G.; Huang, J.; Gao, J.; Hartmann, R.; Gabriels, D. Effects of conservation tillage practices on winter wheat water-use efficiency and crop yield on the Loess Plateau, China. *Agric Water Manage* **2007**, 87(3), 307-314.
7. Wang, L.F.; Shangguan, Z.P. Water–use efficiency of dryland wheat in response to mulching and tillage practices on the Loess Plateau. *Sci Rep* **2015**, *5*, 12225. Doi: 10.1038/srep12225.
8. Sun, M.; Ren, A.X.; Gao, Z.Q.; Wang, P.R.; Mo, F.; Xue, L.Z.; Lei, M.M. Long-term evaluation of tillage methods in fallow season for soil water storage, wheat yield and water use efficiency in semiarid southeast of the Loess Plateau. *Field Crops Res* **2018**, 218, 24-32.
9. Winter, S.R.; Musick, J.T. Wheat planting date effects on soil water extraction and grain yield. *Agron J* **1993**, 85(4), 912-916.
10. Spink, J.H.; Semere, T.; Sparkes, D.L.; Whaley, J.M.; Foulkes, M.J.; Clare, R.W.; Scott, R.K. Effect of sowing date on the optimum plant density of winter wheat. *Ann Appl Biol* **2000**, 137(2), 179-188.

11. Ren, A.X.; Sun, M.; Wang, P.R.; Xue, L.Z.; Lei, M.M.; Xue, J.F.; Gao, Z.Q.; Yang, Z.P. Optimization of sowing date and seeding rate for high winter wheat yield based on pre-winter plant development and soil water usage in the Loess Plateau, China. *J Integr Agric* **2018**, Doi: 10.1016/S2095-3119(18)61980-X.
12. Xu, H.; Cui, H.; Zhang, W.; Li, C.; Guo, W.; Zhu, X. Effects of sowing date on seedling growth characteristics and accumulated temperature before wintering stage of wheat. *Chin Agric Sci Bull* **2015**, 31(03), 99-105.
13. Zhang, M.; Dong, B.; Qiao, Y.; Zhao, H.; Liu, M.; Chen, Q.; Yang, H.; Zheng, X. Effects of sowing date and seeding density on growth, yield and water use efficiency of 'Xiaoyan 60' wheat under rainfed condition. *Chin J Eco-Agric* **2016**, 24(08), 1095-1102 (in Chinese).
14. Sun, H.; Shao, I.; Chen, S.; Zhang, X. Effects of sowing time and rate on crop growth and radiation use efficiency of winter wheat in the North China Plain. *Int J Plant Prod* **2013**, 7(1), 117-13
15. Qu, H.; Li, J.; Shen, X.; Wei, F.; Wang, C.; Zhi, S. Effects of plant density and seeding date on accumulation and translocation of dry matter and nitrogen in winter wheat cultivar Lankao Aizao 8. *Acta Agron Sin* **2009**, 35(1), 124-131.
16. Liu, S.; Wu, X.P.; Wu, H.J.; Liang, E.; Cai, D.X. Influence of different tillage practices during summer fallow on soil moisture in winter wheat field in Luoyang. *Chin J Agrometeorol* **2007**, 3, 292-295 (in Chinese).
17. Wang, X.B.; Cai, D.X.; Jin, K.; Wu, H.J.; Bai, Z.G.; Zhang, C.J.; Yao, Y.Q.; Lu, J.J.; Wang, Y.H.; Yang, B.; Hartman, R. Water availability for winter wheat affected by summer fallow tillage practices in sloping dryland. *Agric Sci Chin* **2003**, 2(7), 773-778.
18. Wang, Y.; Tao, H.; Zhao, Z.; Lu, L.; Ren, W.; Zhou, Z.; Wang, Z. Effects of subsoiling before sowing on water utilization and dry matter production of winter wheat without irrigation. *J Triticea Crops* **2014**, (01), 64-70 (in Chinese).
19. Zheng, C.Y.; Yu, Z.W.; Wang, D.; Zhang, Y.L.; Shi, Y. Effects of tillage practices on nitrogen accumulation and translocation in winter wheat and NO_3^--N content in soil. *Plant Nutr Fert Sci* **2012**, 18(6), 1303-1311.
20. Wang, J.; Wang, X.; Xiong, S.; Ma, X.; Ding, S.; Guo, J.; Wu, K. Effects of different tillage methods on nitrogen metabolism and nitrogen utilization efficiency of wheat grown in lime concretion black soil region. *J Triticea Crops* **2014**, 34(08), 1111-1117 (in Chinese).
21. Shen, X.S.; Qu, H.J.; Li, S.C.; Huang, G.; Chen, S.H.; Liu D.H. Effects of the maize straw returned to the field and tillage patterns on nutrition accumulation and translocation of winter wheat. *Acta Bot Boreali-Occident Sin* **2012**, 32(01), 143-149 (in Chinese).
22. Jin, K.; Cornelis, W.M.; Schiettecatte, W.; Lu, J.; Yao, Y.; Wu, H.; Gabriels, D.; De Neve, S.; Cai, D.; Jin, J. Effects of different management practices on the soil–water balance and crop yield for improved dryland farming in the Chinese Loess Plateau. *Soil Till Res* **2007**, 96, 131-144.
23. Deng, Z.; Zhang, Q.; Zhang, M.; Wang, R.; Qing, J.; Wang H.; Yu, J. Influence of water storage capacity on yield of winter wheat in dry farming area in the Loess Plateau. *Acta Ecol Sin* **2011**, 31, 5281–5290.
24. Hou, X.Q.; Han, Q.F.; Jia Z.K.; Li Y.P.; Yang B.P. Effects of different tillage practices in summer fallow period on soil water and crop water use efficiency in semi-arid areas. *Agric Res Arid Areas* **2009**, 27(5), 52-58 (Abstract in English).
25. Fu, Z.G.; Du, S.P.; Liao, Y.C. Studies on tillage system of stubble mulching and subsoiling and furrow sowing on side of film mulch for dryland winter wheat in Weibei Plateau. *Agric Res Arid Areas* **2003**, 21(2), 13-17 (in Chinese).
26. Mao, H.; Li, J.; Jia, Z.; Wang, L. Soil water conservation effect, yield and income increments of conservation tillage measures on dryland wheat field. Trans. *Chin Soc Agric Eng* **2010** 26(8), 44-51 (in Chinese).
27. Ren, A.X.; Sun, M.; Zhao, W.F.; Deng, L.F.; Deng, Y.; Gao, Z.Q. Effects of tillage in fallow period on soil water and nitrogen absorption and translocation by wheat plant. *Chin J Appl Ecol* **2013**, 24(12), 3471-3478.
28. Sun, M.; Gao, Z.Q.; Ren, A.X.; Deng, Y.; Zhao, W.F.; Zhao, H.M.; Yang, Z.P.; He L.H.; Zong, Y.Z. Contribution of subsoiling in fallow period and nitrogen fertilizer to the soil-water balance and grain yield of dryland wheat. *Int J Agric Biol* **2015**, 17, 175-180.
29. Wang, H.G.; Guo, Z.J.; Shi, Y.; Zhang, Y.L.; Yu, Z.W. Impact of tillage practices on nitrogen accumulation and translocation in wheat and soil nitrate-nitrogen leaching in drylands. *Soil Tillage Res* **2015**, 153, 20-27.
30. Ren, A.X.; Sun, M.; Gao, Z.; Wang, P.; Xue, J.; Xue, L.; Lei, M. Effects of mulching during the fallow period and nitrogen fertilizer on soil water and plant nitrogen use of dry-land wheat. *Sci Agric Sin* **2017**, 50(15), 2888-2903 (Abstract in English).

Peer-reviewed version available at *Agronomy* **2019**, *9*, 37; doi:10.3390/agronomy9010037

31. Zhang, M.; Sun, M.; Gao, Z.Q.; Zhao, H.M.; Li, G.; Ren, A.X.; Hao, X.Y.; Yang, Z.P. Relationships of water conservation through mulching in fallow period with wheat nitrogen transportation and crop yield in dryland. *Chin J Appl Ecol* **2016**, 27, 117-124 (in Chinese).
32. Ding, S.J.; Xiong, S.P.; Ma, X.M.; Zhang, J.J.; Wang, X.C.; Wu, Y.X.; Du, P.; Zhang, J. Effects of tillage and nitrogen application rate on soil nitrogen transformation and yield in a winter wheat/summer maize multiple cropping system. *J Appl Ecol* **2017**, 28(1), 142-150.
33. Brunel, N.; Seguel, O.; Acevedo, E. Conservation tillage and water availability for wheat in the dryland of central chile. *J Soil Sci Plant Nutr* **2013**, 13(3), 622-637.
34. Yin, L.; Dai, X.; He, M. Delayed sowing improves nitrogen utilization efficiency in winter wheat without impacting yield. *Field Crops Res* **2018**, 221, 90-97.
35. Lu, H.D.; Xue, J.Q.; Hao, Y.C.; Zhang, R.H.; Gao, J. Effects of sowing time on spring maize (*Zea mays* L.) growth and water use efficiency in rainfed dryland. *Acta Agron Sin* **2015,** 41(12), 1906.
36. Liu, P.; Wei, J.; Zhang, D.; Wang, B.; Liu, J.; Liu, J. Effect of seeding rate and sowing date on population traits and grain yield of drip irrigated winter wheat. *J Triticeae Crops* **2013**, 33(6), 1202-1207 (in Chinese).
37. Zhang, X.Y.; Chen, S.Y.; Sun, H.Y.; Shao, L.W.; Wang, Y.M. Dry matter, harvest index, grain yield and water use efficiency as affected by water supply in winter wheat. *Irri Sci* **2008**, 27, 1-10.
38. Ding, J.; Yang, J.; Wang, Y.; Chen, F.; Feng, C.; Zhu, X.; Li, C.; Peng, Y.; Guo, W. Nitrogen accumulation, distribution and utilization characteristics of wheat at yield level of 9000 kg /ha in rice-wheat rotation. *J Plant Nutr Fertil* **2013**, 19(03), 543-551 (in Chinese).