SOIL WATER CONTENT AND PHOTOSYNTHETIC GAS EXCHANGE OF SPRING WHEAT UNDER CONSERVATION TILLAGE SYSTEMS IN THE DRYLAND WESTERN LOESS PLATEAU AREA IN CHINA

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Abstract
The adoption of improved cultivation practices in field crops may mitigate increasing water shortages in many rainfed semi-arid areas. It is not clear whether improved conservation tillage practices can alleviate this issue while increasing crop productivity. Spring wheat (Triticum aestivum L.) was grown using four long-term tillage (CT) systems: conventional tillage with straw removed (T), no-till with straw removed (NT), no-till with straw retention (NTS) and conventional tillage with straw incorporated (TS). These tillage systems were compared for soil water content, crop photosynthesis and grain yield production in semi-arid Loess Plateau of China. Treatments were arranged in a Complete Randomized Block Design with three replications. Results showed that NTS increased soil water content in the 0 – 30 cm depth range by approximately 35% and 27% at anthesis and milking stages, respectively, compared with T ($P < 0.05$). The contribution to increased soil water content was higher on straw treated plots. Stomata conductance and net photosynthesis rate in the NTS treatment increased by approximately 24% to 38% compared to T. The straw treatments also improved leaf water potential and leaf area index ($P < 0.05$), which supported the above results. Water use efficiency in the NTS and TS treatments was approximately 45% higher than T and NT ($P < 0.05$), which translated into increased grain yield. Our results clearly support the long-term advantages of adopting NT practices with residue retention, in rainfed semi-arid regions for better rainwater utilization, enhancing crop photosynthesis and increasing yields.

Keywords
Tillage; straw; soil water content; photosynthesis; crop productivity

Introduction

The Loess Plateau is a dryland area of agricultural importance because of its contribution towards food security and employment for the inhabitants (Zhao et al., 2012). The area is one of the most severely eroded regions in China coupled with its limited precipitation and high evaporation resulting in low crop yield (Wang et al., 2013a). Conventional methods of soil cultivation have increased soil erosion, and contributed to the decline of soil fertility (Lal, 2004). Traditional methods of soil cultivation and the declined soil fertility are key contributing factors to reduced soil resilience and therefore can have long–term implications for food security to the rural communities (McBratney and Field, 2015). According to Yin et al. (2016), subsistence farming of crops is the most common type of agriculture in rural China with wheat and maize being the dominant crops. Agricultural production is heavily dependent on rainfall; however, annual rainfall is both low on average and extremely variable (He et al., 2014). To compensate for low productivity and meet food demand during periods of poor rainfall, conservation farming practices have been introduced. The adoption of conservation agriculture principles has been reported to increase water conservation and crop productivity (Yeboah et al., 2016a). Tillage activity exposes more soil surface area to the atmosphere, providing a greater evaporative area and, consequently, a greater water loss (Yeboah et al., 2017a). In dry environments, soil water availability strongly enhances photosynthesis by increasing the activity of photosynthetic enzymes (Gong et al., 2011). More water enhances not only photosynthesis, by increasing stomatal aperture and activity of photosynthetic enzymes, but also the transpirational water loss (Gong et al., 2011), resulting in uncertain effects on instantaneous and/or long term water-use efficiency (WUE). Hence, the effect of conservation tillage on soil water availability and the consequential effect on crop photosynthesis is still a crucial area of study. There appears to be limited information on the impact of different tillage and straw management practices on soil water content and crop photosynthesis for wheat-cropland soils in arid and semi-arid regions of Northwest China. This study hypothesized that increased straw application couple with reduced soil disturbances would improve soil water conservation and consequently enhanced crop photosynthesis and yield. Therefore, the objectives of the work reported in this article were to: (1) evaluate the effects of different conservation tillage practices on soil water content, leaf water potential and photosynthetic rates, and (2) determine the effects of conservation tillage practices on water use efficiency and grain yield of spring wheat.

Materials and Methods

Study area

The study was conducted at the Rainfed Agricultural Experimental Station of Gansu Agricultural Station, Gansu Province, China (35°28'N, 104°44'E). The semiarid Western Loess Plateau is characterized by a hilly landscape and is prone to erosion. The aeolian soil in that region is locally known as Huangmian (Chinese Soil Taxonomy Cooperative Research Group, 1995), which equates to a Calcaric Cambisol in the FAO (1990) Soil Classification. The initial 0–200 cm soil layer in the study area has a pH of 8.45, soil bulk density was 1.17 gcm^{-3}, soil organic matter was 16.04 gkg^{-1} and available nitrogen was 51.10 $mgkg^{-1}$. Long-term (annual) rainfall and evaporation records for the experimental station show an average of 390.9 and 1531 mm per year. Annual cumulative temperatures >10 °C are 2239.1 °C and annual radiation was 5929 MJm^{-2}, with 2476.6 h of sunshine. The conditions are representative of those commonly found within agricultural areas of semi-arid environments. In-crop rainfall in 2014 and 2015 were 174.6 mm and 252.5 mm, respectively.

Experimental design

The experiment used a complete randomized block design with four treatments and three replications per treatment (n=3). There were two crops, spring wheat (cv. Dingxi 35) and field pea (cv. Yannong) with double sequence rotation (referred to as W→P→W and P→W→P sequence). Measurements were conducted on spring wheat plots only. The treatments were: conventional tillage with straw removed (T), no-till with straw removed (NT), no-till with straw retention on the soil surface (NTS) and conventional tillage with straw incorporated (TS). Conventional tillage included moldboard ploughing immediately after harvesting the previous crop in August, with a second and third ploughing in late August and September, respectively. The corresponding plough depths were 20, 10 and 5 cm, respectively. Harrowing was carried out after the last cultivation in September, and re-harrowed in October before the ground was frozen. In T plots all plant residues were removed before ploughing. This is the typical local farming practice. In the TS plots, all plant material from the previous crop was returned to the original plots immediately after threshing and then incorporated into the soil with ploughing. In NT plots, all the plant material was removed at harvest, whereas in NTS plots, all the plant material from the previous crop was returned to the original plots after threshing and spread evenly on the soil surface. All the crops and treatments were sown with the same no-till seeder. Plot size was 4 × 17 m for Block 1 and 4 × 21 m for Blocks 2 and 3.

Crop sowing and basal fertilizers

Spring wheat was sown in mid-March at a rate of 187.5 $kgha^{-1}$ with a row spacing of 20 cm and harvested in late July to early August. Nitrogen and Phosphorus fertilizer were applied at 105 kg N ha^{-1} as urea (46 % N) and 45.9 kg P ha^{-1} as ammonium hydrogen phosphate for spring wheat. The phosphorus and nitrogen fertilizer were applied synchronously with the sowing of spring wheat using the same no-till seeder and incorporated into the soil to about ≈20 cm deep. All the fertilizer was applied at sowing with the no-till seeder.

Soil water content

Soil water content (%, ww^{-1}) was measured four times during the crop cycle, as follows: sowing, anthesis, milking and maturity stages, and at seven depth intervals: 0–5, 5–10, 10–30, 30–50, 50–80, 80–110 and 110–140 cm, respectively. The soil water content in the 0–5 and 5–10 cm depth intervals was gravimetrically determined based on the method described by Jia et al. (2012). Gravimetric water content at these depths was multiplied by mean soil bulk density to obtain the volumetric water content. Trime-Pico IPH (Precise Soil Moisture Measurement, IMKO Micromodultechnik GmbH, Ettlingen, Germany) was used to measure volumetric soil water content in 10–110 cm depth intervals described above. Subsequently, soil water storage was estimated from the volumetric soil water content by multiplying this value by the soil layer depth.

Leaf Area Index, Leaf Water Potential and Leaf N content

Five spring wheat plants were sampled from each plot using the "S" type method described by Yin et al. (2016). Sampling was conducted at anthesis and milking stages. Leaf area index (LAI) was determined using Equation (1) described in Yin et al. (2016):

$$LA = L_l \times L_w \times 0.78 \tag{1}$$

where: LA is leaf area, L_l is leaf length, L_w is leaf width and 0.78 is a constant. Values of LA reported herein represent the mean value (n=4) recorded at anthesis and milking. Measurements of leaf water potential (Ψ_w) was conducted with a pressure chamber (Decagon, model WP4C Potentiameter). The leaf water potential was measured on the first fully–expanded leaf and near the leaves used for measurements of the photosynthetic parameters. Water potential was measured at anthesis and milking stages on three leaves between 06:00 and 09:00 h to minimize adverse effects of evaporative losses on Ψ_w readings.

Photosynthetic Gas exchange

Stomata conductance (gs), leaf net photosynthetic rate (Pn), transpiration rate (Tr), and intercellular CO_2 concentration (Ci,) were measured on cloudless days. Measurements were conducted between 08:00 h to 10:00 h using a Portable Gas exchange Fluorescent System (GFS-3000, Heinz Walz GmbH. Eichenring, Germany). Stomata limitation (L_S) was estimated using Equation (2) (Yin et al., 2006):

$$L_s = 1 - \frac{C_i}{C_a} \tag{2}$$

where: L_s is stomata limitation, Ci is intercellular CO_2 concentration, and Ca is ambient CO_2 concentration. The conditions in the gas exchange device were set as follows: flow rate of air through the chamber: 750 μmols^{-}1, CO_2 concentration 393.3 ppm, H_2O concentration 14,598 ppm, Area 4 cm^2, and temperature 24.7°C, respectively. Measurements were conducted at anthesis and milking on three representative plants from the inner rows of the plots and by selecting one leaf per plant. Measurements were always conducted on the middle portions of a fully-developed leaf, which had full exposure to sunlight.

Grain Yield and Water Use Efficiency

The whole plot was harvested manually using sickles at 5 cm above-ground. The edges (0.5 m) of the plot were trimmed and discarded. Grain yield was determined on a dry-weight basis after oven-drying the plant material at 105 °C for 45 min and then to constant weight at 85 °C. Water use efficiency (WUE) was determined using Equation (3) described in Wang et al. (2013a), as follows:

$$WUE = \frac{Y}{ET} \tag{3}$$

where: WUE is grain water use efficiency, Y is grain yield (kg $ha^{-}1$), and ET is total evapotranspiration over the entire growing season (mm). Evapotranspiration (ET) was estimated using Equation (4), as follows:

$$ET = P - \Delta W \tag{4}$$

where: ET is total evapotranspiration, P is total precipitation for the growing season, and ΔW is the difference between soil water storage at sowing and harvest, respectively. All parameters are expressed in mm. Previous studies conducted at the study site reported no significant runoff or drainage during the growing season (Huang et al., 2008). Water use efficiency (WUE) at the leaf level was calculated using Equation (5), described in Polley (2002), as follows:

$$WUE = \frac{P_N}{E} \tag{5}$$

where: WUE is water use efficiency at the leaf level, P_N is net photosynthesis rate, and E is transpiration rate, respectively.

Statistical analyses

Statistical analyses were undertaken with the Statistical Package for the Social Sciences 22.0 (IBM Corporation, Chicago, IL, USA) with the treatment as the fixed effect and year as random effect. Differences between the means were determined using the Least Significant Difference ($P < 0.05$). The data analyzed were pooled for bivariate correlation analysis (two–tailed) using Pearson's correlation coefficients. All statistical significance differences were declared at the probability level of 5% ($P < 0.05$)

Results

Soil water content

Soil water content at anthesis and milking development stages of spring wheat showed an increase with soil depth irrespective of the treatments evaluated in this study (Fig. 1). The soil water content in almost any specific depth and stage in the NTS plots was higher than that in the NT and T plots. The largest significant variations in soil water content between the treatments were observed in the 0–30 cm soil depth. In this layer, NTS and TS had the greatest soil water content of 10.64 and 10.21%, ww^{-1} at anthesis (Fig. 1a) and 14.16% ww^{-}1 and 12.68% ww^{-1} at milking (Fig. 1b), respectively in 2014. This was significantly greater than NT (8.34%, ww^{-1}) and T (7.31%, ww^{-1}) at anthesis and 10.10% ww^{-1} and 11.08% ww^{-1} at milking. Similar trend was observed in 2015 at both stages of harvest (Fig. 1c and d). On average, NTS and TS treatments increased soil water content by 28.12% and 34.64% relative to T treatment (Table 1).

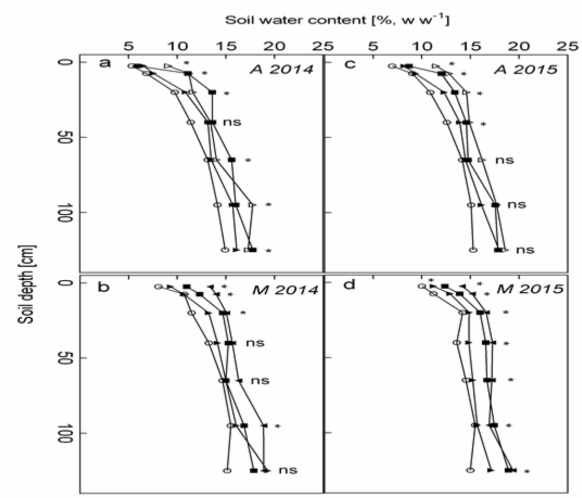

Figure 1. Soil water content at 0 – 140 cm depth range recorded at anthesis [A] and milking [M] as affected by different tillage practices. Symbols are: (○) T; (■) TS; (▲) NT; (△) NTS. Mean values ±SE (n = 3), and means comparison based on Duncan's multiple range test ($p < 0.05$). Significance ($p < 0.05$) is indicated with an asterisk

Leaf Area Index, Leaf Water Potential and Leaf N content

There was no significant treatment interactions ($P < 0.05$) effect on leaf area index, leaf water potential and leaf N content (Table 2), but treatment factors independently influenced these variables. Significant ($P < 0.05$) differences were observed in leaf area index, leaf water potential and leaf N content in at the various stages of measurement; this was consistent in both study years. Straw treated soils had significant effect on Leaf area index, leaf water potential and leaf N content, but the greatest effect was recorded by no tillage combined with

Table 1. Average soil water content [%, ww^{-1}] over the study period

Treatment	Soil water content [%, ww^{-1}]		
	2014	2015	Mean
T	10.74c	13.17c	11.95c
TS	14.97a	15.64ab	15.31ab
NT	13.63b	14.43bc	14.03b
NTS	15.48a	16.67a	16.09a
Factors			
Tillage		*	
Straw		**	
Year		*	
T x S		ns	
T x Y		ns	
S x Y		ns	

Values with different letters within a column are significantly different at $P < 0.05$. $*, (**)$ indicate significant difference at $P < 0.05$ and $P < 0.01$, respectively.

straw retention. On average, NTS increased leaf area index by 43.00% compared with conventional tillage with straw removed. Water potential was highest in the NTS treatment whereas the lowest Φw values were recorded in conventional tillage with straw removed plots. Similarly, straw-amended soils increased Leaf N content by 25% compared with non-straw treated soils (Fig. 2).

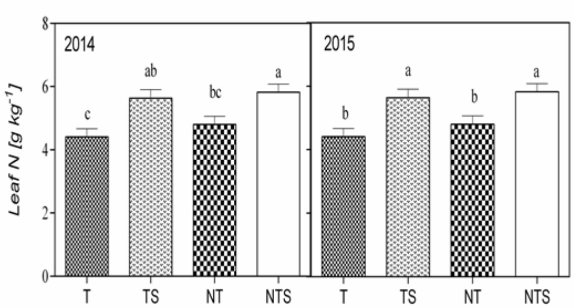

Figure 2. Leaf N content of spring wheat as affected by different tillage practices. Different letters denote statistically different values at $P < 0.05$. Error bars represent the standard error (SE) (n = 3)

Photosynthetic Parameters

The analysis of variance indicated a significant ($P < 0.05$) effect of treatment factors on photosynthetic parameters (Table 3). In addition, interaction between tillage, straw and year were significant at $P < 0.05$ in affecting transpiration rate. The trends of the photosynthetic parameters were consistent for all the treatments and similar peak times and daily patterns were observed. This trend was also consistent for 2014 and 2015 cropping season. Straw amended plots had significant increases in average gs, Pn and Tr compared with T in all cases (Fig. 3), but the effect of NTS was greater. NTS treatment has the greatest gs in 2014 (120.79 mmol m^{-2} s^{-1}) and 2015 (140.23 mmolm^{-2}s^{-1}) compared to T (94.40 and 117.36 mmolm^{-2}s^{-1} in 2014 and 2015, respectively). Similarly, straw treated soils had the greatest Pn, but tillage removal soils had the greatest effect. The application of NTS practices boosted Pn (4.85 and 5.56 μmol m^{-2} s^{-1} in 2014 and 2015, respectively) compared with T treatment. The treatments had no significant effect on Ci and Ls in both years of the study. Generally, treatments with high gs, Pn and Tr had lower Ci and Ls.

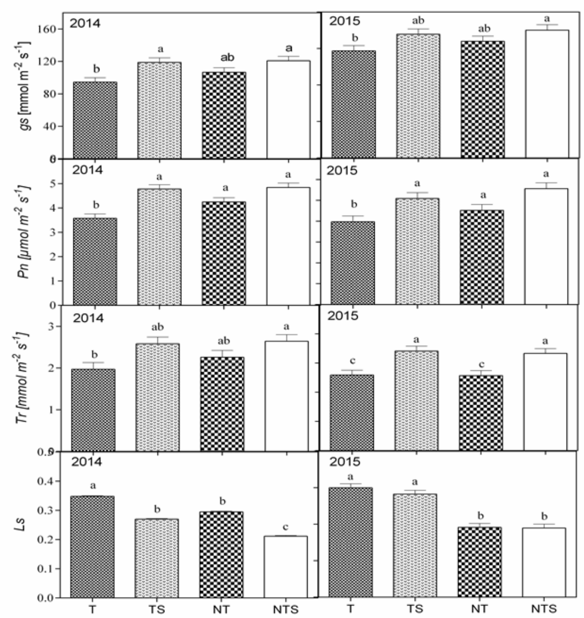

Figure 3. Stomatal conductance [gs], Net photosynthesis [Pn], Transpiration rate [Tr] and Stomatal limitation [Ls] of spring wheat as affected by different tillage practices. Different letters denote statistically different values at $P < 0.05$. Error bars represent the standard error (SE) (n = 3)

Stubble and Grain Yield

There was no significant tillage and straw interaction on stubble and grain yield, but tillage, straw and year individually had a significant effect on stubble and grain yield (Table 4). No tillage treatments had greater stubble yield of 3799 kgha^{-1} in 2014, 5612 kgha^{-1} in 2015 or 18.44% and 6.76% more compared to soils under tillage treatments, respectively (3208 kgha^{-1} in 2and 5257 kgha^{-1} in 2015) (Table 4). Stubble yield varied significantly ($P < 0.05$) among the treatments in each year of the study. On average, the NTS and TS treatments significantly increased ($P < 0.05$) stubble yield compared to T treatment. No significant differences occurred between NT and T treated soils. Overall, treatments in which stubble was retained had greater stubble yield than those that had the

Table 2. Leaf area index (LAI) and leaf water potential of spring wheat as affected by different tillage practices

Treatment	LAI			LWP [Ψw]		
	2014	2015	Mean	2014	2015	Mean
T	3.86b	4.18b	4.02b	-2.06c	-1.61b	-1.83b
TS	4.73ab	5.53a	5.13ab	-1.93b	-1.51ab	-1.72b
NT	4.42ab	4.55b	4.48b	-1.60ab	-1.38ab	-1.49ab
NTS	5.52a	6.04a	5.78a	-1.46a	-1.28a	-1.37a
Factors						
Tillage (T)			*			*
Straw (S)			**			**
Year (Y)			*			**
T x S			ns			ns
T x Y			ns			ns
S x Y			ns			*

Values with different letters within a column are significantly different at $P < 0.05$. $*, (**)$ *indicate significant difference at* $P < 0.05$ *and* $P < 0.01$*, respectively.*

Table 3. Analysis of variance of photosynthetic variables

Factors	Photosynthetic Variables			
	gs	Pn	Tr	Ls
Tillage (Y)	**	*	*	*
Straw (S)	**	**	**	**
Year (Y)	**	*	**	*
T x S	ns	ns	ns	Ns
T x Y	ns	ns	*	Ns
S x Y	ns	ns	*	Ns

**, (**) indicate significant difference at* $P < 0.05$ *and* $P < 0.01$*, respectively*

stubble removed from plots. The grain yield recorded under plots with straw returned were the greatest compared to straw removed plots (Table 4). No tillage with straw retained (NTS) treatments produced the greatest grain yield of 1809 kgha^{-1} on average, representing a significant increase of 41.25% and 35.23% compared to T and NT treatments (1280 kg ha^{-1} and 1337 kg ha^{-1}, respectively (Table 4). At a lesser magnitude, TS treatment increased grain yield by 35.63% and 14.89% in 2014 and 2015 compared to T, respectively. Similarly, TS treatment increased grain yield by 55.29% and 47.10% compared to NT treatments, respectively. Overall differences in grain yield between NTS and TS were not significant.

Evapotranspiration and Water Use Efficiency

There was a significant straw effect ($P < 0.05$) on ET and WUE (Table 5), but tillage had no effect on ET and WUE. In addition, tillage, straw and year had no interactive effect on ET and WUE. Straw treated plots had the greatest effect on both ET and WUE throughout the study period. However, the effect was greater on tillage removal plots. On average, application of NTS and TS treatments decreased ET by 15.58% and 9.81% respectively as compared to T treatment. On the same note, NTS significantly increased WUE by 78.31% and 45.63% respectively as compared to T. In both years, there was no significant difference between NTS and TS in affecting ET and WUE.

Correlation Analyses

The Pearson correlation coefficient is presented in Table 6. Leaf area (LA) showed a significant (positive) correlation with Gs and Pn (r^2=0.96* and 0.976*, respectively). Significant correlations were also observed between soil water content and gs, P_N and Tr. Highly significant correlations were observed between soil water content, grain yield (r^2=0.99*), WUE (r^2=0.94*, $p < 0.01$) and WUE (r^2=0.90**). Significant ($p < 0.05$) correlations were also observed between gs, P_N Tr and grain yield.

Discussion

Soil water content was increased in straw treated plots, especially NTS treatment in the entire soil profile (0 -110 cm depth). However, the largest variations in soil water content were found in the 0–30 cm depth in both study years. Improving soil water content, especially in the 0–30 cm layer is important for crop production in the Western Loess plateau. The increased soil water content in the 0–30 cm depth at different growth stages of spring wheat by the NTS could be related to the increased soil surface cover (Yeboah et al., 2017b) and reduced water consumption of crop (Wang et al., 2010). Soil water content in plots applied with straw treated

Table 4. Stubble and grain yield of spring wheat as affected by tillage practices

Treatment	Stubble yield ($kgha^{-1}$)			Grain yield ($kgha^{-1}$)		
	2014	2015	Mean	2014	2015	Mean
T	2802c	4485c	3794b	1075c	1275b	1280b
TS	3613b	6028b	4597ab	1458a	1980a	1704a
NT	3091bc	4782c	3966b	1269b	1346b	1337b
NTS	4507a	6442a	5282a	1528a	2074a	1809a
Factors						
Tillage (T)			**			*
Straw (S)			**			**
Year (Y)			**			**
T x S			ns			Ns
T x Y			ns			Ns
S x Y			x			x

Values with different letters within a column are significantly different at $P < 0.05$. $*, (**)$ indicate significant difference at $P < 0.05$ and $P < 0.01$, respectively

Table 5. Evapotranspiration [ET] and Water-use efficiency [WUE]

Treatment	ET (mm)			WUE ($kgha^{-1}mm^{-1}$)		
	2014	2015	Mean	2014	2015	Mean
T	139.1a	199.2a	169.1a	6.96b	6.31b	6.64b
TS	127.0b	181.1b	154.0b	9.52ab	9.82a	9.67a
NT	138.4a	198.3a	168.4a	8.12ab	7.59b	7.85b
NTS	120.8b	171.8b	146.3b	12.24a	11.44a	11.84a
Factors						
Tillage (T)			Ns			ns
Straw (S)			**			*
Year (Y)			**			ns
T x S			Ns			**
T x Y			Ns			ns
S x Y			Ns			ns

Values with different letters within a column are significantly different at $P < 0.05$. (*), (**) indicate significant difference at $P < 0.05$ and $P < 0.01$, respectively

soils, as observed, may be attributed to improved surface cover and therefore relatively lower evaporative losses from those treatments. Similar observations were reported by Wang et al. (2013b). Increased water availability in deeper layers of the soil profile (30–80 cm), as recorded in the NTS and TS treatments, explains the higher yields in those treatments due to relatively less restricted soil water supply to the crop during formation of grains and grain filling. The increased soil moisture content under no-till and tillage treatments with straw application could be related to the straw mulch effect on the soil surface. The result was in agreement with Hobbs et al. (2008), who found that no tillage with residue retention generally had higher surface soil water contents compared to tilled soils. This pattern indicates that tillage systems that involve less physical disturbance help to maintain or conserve soil moisture. The findings suggest NTS and TS practices could increase available soil water and possibly enhance the resilience of spring wheat to terminal drought, hence promoting NTS especially as a means to ameliorate plant water status. The tillage activity exposed more soil surface area to the atmosphere, providing a greater evaporative area and, consequently, a greater water loss.

Leaf area index is an important agronomic parameter which reflects crop growth and predicts crop yield (Fageria et al., 2006). Differences in leaf area can affect plant spatial distribution and the microenvironment within crops population (Fageria et al., 2006), which plays a significant role in the photosynthetic efficiency of crops. The results showed that the crop physiological parameters were greater under NTS application, indicating the potential of NTS to increase plant's

Table 6. Correlation coefficients between soil water content (SWC), leaf area (LA), leaf water potential (Ψw), stomatal conductance (gs), net photosynthesis rate (Pn), transpiration rate (E), water use efficiency (WUE), stubble yield (SY) and grain yield (GY)

Indexes	LAI	Ψw	LN	gs	Pn	Tr	WUE	SY	GY
SWC	.95*	.89*	.99**	.98**	.97**	.97**	.90*	.99**	.99**
LAI		-0.85ns	.95*	.99**	.99**	.99**	.99**	.91*	.90*
Ψw			-.91*	-.91*	-0.87 ns	-.89*	-0.77 ns	-.89*	-.89*
LN				.98**	.97**	.97**	.89*	.99**	.99**
Gs					.99**	.99**	.96*	.95*	.95*
Pn						.99**	.98**	.93*	.93*
Tr							.97**	.93*	.93*
WUE								0.84 ns	0.84 ns
SY									.99**

Non-significant (ns), Significant (*) at $p < 0.05$*, and Significant (**) at* $p < 0.01$

physiological status. The increased crop physiological indices implied higher photosynthetic activity under those treatments, which may result in marked increase in grain yield.

Stomata are the main portal for carbon dioxide (CO_2) and vapor water exchange between plant leaves and atmosphere, thus stomata conductance directly controls photosynthesis and transpiration. The findings of photosynthetic parameters in this experiment under field conditions demonstrated that improved soil water contents led to an increase in gs, Pn, and Tr in both years. Moreover, reduced soil water content led to increased Ls, and this may be due to plant stress (Rosales-Serna et al., 2004). Reduced soil water content causes loss of leaf turgor and reduction of stomatal aperture limits photosynthetic CO_2 uptake, (Cramer et al., 2008). Increased soil water content improved plant water status and leaf water potential. NTS had higher values of gs, Pn and Tr than the other treatments, indicating the potential of NTS to enhanced crop's photosynthetic capacity. This could be related to the increased soil water content that improved plant water status by increasing leaf water potential. This is confirmed by the observed increase in photosynthetic traits as soil water deficit is known to induce gs and Pn reduction in response to decrease in leaf water potential. Soil water content and leaf water potential accounted for more than 90% of variations in gs, Pn and Tr.

Previous research works have shown that conservation tillage can improve crop yields (Huang et al., 2008; Yeboah et al., 2016b). In our study, straw treated soils improved grain yield by 49.78% on average compared to conventional tillage system with residue removed. The differences in grain and stubble yield could relate to the improved soil quality, in terms of soil water content (Huang et al., 2008; Zhang et al., 2013). A possible explanation could be that conservation tillage with residue retention promoted wheat growth by increasing soil water availability that enhances root penetration. There was a direct and significant relation between the soil water content status and the crop yield, and no tillage with crop residue retention showed the highest crop yields as well as the highest soil water content. In contrast, the soil under no tillage and conventional tillage with crop residue removal showed the lowest soil water content and thus produced the lowest yields. Water use efficiency was significantly improved in NTS and TS compare to T; but the effect of NTS was greater. The increased grain yield and water use efficiency were obtained under low water consumption, a phenomenon that is significant for sustainable crop production on the Western Loess plateau. Improving water use may be suitable for crop production in environments where water is the limiting factor. In this study, soil water content, stomata conductance and net photosynthesis rate were responsible for more than 90% of the variations in grain yield, an indicative of soil water content and photosynthesis effect on crop productivity.

Conclusion

In the present study, different tillage and straw management practices were carried out to evaluate the variances of soil water content, plant photosynthesis and stubble and grain yield, and water use efficiency of spring wheat in semi-arid environment. Straw application, particularly NTS increased soil water content especially in the 0–30 cm depth than the other treatments. In addition, NTS applications significantly increase spring wheat grain yield and water use efficiency. Compared to the other treatments, higher Gs, Pn and E were increased under NTS treatments. Increased soil water retention had a beneficial effect on leaf water potential and photosynthetic activity, which translated into higher grain yield and water use efficiency. Improved soil water availability at anthesis and milking reduced water stress, which therefore contributed to formation of grains and concomitant increase in yield. Significant positive correlation were observed between Gs, Pn, E, soil water content and leaf water potential, indicating that the photosynthetic increase can be attributed to the soil water content and leaf water potential.

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