Article

Characteristics of the Water Consumption Components of Winter Wheat Fields and Their Effects on the Loess Plateau under Climate Change: An Example at Xifeng Station, Gansu, China

Jianying Jia 1,*, Junfang Zhao 2,*, Heling Wang 3, Feng Fang 1, Lanying Han 1 and Funian Zhao 3

1 Lanzhou Regional Climate Center, Lanzhou 730020, China
2 Chinese Academy of Meteorological Sciences, Beijing 100081, China
3 Key Laboratory of Arid Climatic Change and Disaster Reducing of Gansu Province, Key Laboratory of Arid Climatic Change and Disaster Reducing of China Meteorological Administration, Institute of Arid Meteorology China Meteorological Administration, Lanzhou 730020, China

* Correspondence: jiajianying2014@163.com (J.J); zhaojf@cma.gov.cn (J.Z.)

Abstract: Understanding the components of water consumption plays a critical role in agricultural management in arid regions. This study aimed to analyze the characteristics of the components of the water consumption of winter wheat on the Loess Plateau in China to investigate their effects on yield and water use efficiency (WUE). Winter wheat observation data were collected from 1981 to 2020 at the Xifeng Agrometeorological Station on the Loess Plateau. The results show that over the past 40 years, the average water consumption of the winter wheat fields was 315 mm, but there were large differences between years. The soil water was first converted from precipitation (P) during the growing season, accounting for 69.4%, and then consumed via soil water storage (ΔW) in the fallow period, accounting for 30.6%. The yield of winter wheat varied from 1057 to 6914 kg·ha⁻¹. The correlation between winter wheat yield and P during the growth period was stronger than the correlation between winter wheat yield and ΔW. The average WUE was 11.0 kg·ha⁻¹·mm⁻¹ from 1981 to 2020, with the highest value of 13.7 kg·ha⁻¹·mm⁻¹ occurring in the 2010s and the lowest value of 9.6 kg·ha⁻¹·mm⁻¹ occurring in the 2000s. The WUE was positively correlated with P (p < 0.01) during the growth period and negatively correlated with ΔW (p < 0.05). Therefore, P can increase yield and WUE more effectively than ΔW. These findings provide a theoretical basis for the efficient utilization of water resources on the Loess Plateau and the sustainable development of dry farming.

Keywords: precipitation during the growing period; soil water storage; fallow period; Loess Plateau

1. Introduction

Arid areas account for 41% of the earth's land area and support 38% of the global population; in these areas, water is the most essential limiting resource for agricultural production [1–3]. The semiarid Loess Plateau is a traditional dryland agricultural area in China, and precipitation is the source of water for crop production [4,5]. Due to the special location of the plateau in the semiarid climatic zone of China and the marginal zone affected by the Asian summer monsoon, precipitation fluctuates greatly between years, and its spatial and temporal distributions are uneven, resulting in frequent droughts in the grain growing season [6]. With global warming, the Loess Plateau has shown an obvious trend of warming and drying, especially in spring and summer, and water shortages have become an important factor restricting the sustainable development of agriculture [7,8]. Therefore, analyzing the components of the water consumption of crop fields to effectively use water and sustain productivity is crucial for dryland farming on the Loess Plateau.

Dryland winter wheat is widely grown on the Loess Plateau and covers an area of 4.3 million ha, accounting for 20% of the total land area [6,7]. Winter wheat is sown in
mid to late September and harvested in late June or early July the following year. The growing season, which accounts for 30–40% of annual precipitation, does not coincide with the rainy season [9]. The fallow period, which is from July to September, falls within the rainy season, during which water can be stored in the soil and used by the following wheat crop [5,10]. The predominant constraining factor for winter wheat production is the limited and unevenly distributed annual precipitation on the Loess Plateau [11]. Generally, crop yield in water-limited areas is linearly related to crop water use, which is the sum of the variation in soil water between sowing and harvest and the precipitation during the growing season [12,13]. Therefore, the water consumption of winter wheat fields is mainly composed of precipitation (P) in the growth period and soil water storage (ΔW) consumption in the fallow period, and yield depends on both in-season precipitation and the amount of water stored in the soil before the growing season, as in other systems [14,15]. Previous researchers have shown that the production of plants in arid and semiarid areas is heavily dependent on growing season precipitation, and P has a linear relationship with dryland crop yield [16,17]. Soil water storage (ΔW) is another important water resource for dryland crop growth, and previous researchers found that dryland crop yield increased with an increase in ΔW [14,18]. Artificial precipitation intervention showed that the contribution of precipitation in the growth period to the consumption of water in winter wheat fields was more than 50% at the Changwu agro-ecological experimental station on the Loess Plateau [19]. On the basis of different tillage experiments, soil water storage in the fallow period and precipitation in the growth period were equally important for winter wheat production on the Loess Plateau, and the changes in yield and water use efficiency (WUE) were closely related to the distribution of precipitation and soil evaporation before and after flowering [9]. Both the soil water storage before sowing and different water supplies during the growth period influenced the yield of winter wheat, and equal, incremental supplies of water via soil water storage or irrigation in different growth periods had basically the same effect on yield when the total water supply was the same on the Loess Plateau [20]. Precipitation (P) in the growth period and soil water storage (ΔW) in the fallow period are equally important to winter wheat on the Loess Plateau [10].

However, due to the lack of long-term observational data, especially with respect to soil water content, the characteristics of the water consumption components of winter wheat fields and their effects on yield and WUE are not clear, and there is a lack of systematic research on the Loess Plateau. Based on field observational data on winter wheat collected from 1981 to 2020 at the Xifeng Agrometeorological Experimental Station on the Loess Plateau, the interannual and decadal characteristics of the water consumption components of winter wheat fields against the background of climate change were analyzed, the relationships between the components of water consumption, yield, and WUE were revealed, and a theoretical basis for the sustainable development of dry agriculture on the Loess Plateau was provided.

2. Materials and Methods
2.1. Experimental Site and Meteorological Conditions

This study was conducted from 28 June 1981 to 18 June 2020 at the Xifeng Agrometeorological Station (35°44′ N, 107°38′ E) on the Dongzhi Table Plateau of the Loess Plateau in Gansu Province, China (Figure 1). The Dongzhi Tableland is the largest original surface on the Loess Plateau. The thickness of the loess layer is 150–200 m, the elevation is 1200–1400 m, and most of the groundwater is found at 50–100 m. The climate is semiarid, with an average annual temperature of 9.1 °C and 568 mm of precipitation (1991–2020) which mainly falls from July to September. The frost-free period lasts 202 days, and the duration of the annual sunshine is 2424.3 h. Precipitation and temperature data were obtained from the Xifeng Meteorological Station, which is 20 m from the experimental site.
2.2. Field Experiments

The experimental area was 0.07 ha. Precipitation was reasonably taken as the sole water source because the experimental area was surrounded by border dikes, there was no irrigation, and the underground water tables were deep. The varieties of winter wheat (Changle and Qingfeng series in the 1980s, Changwu and Xifeng series in the 1990s, Xifeng series in the 2000s, and Longyu series in the 2010s) were mainly planted in the local area. The wheat was planted in rows from 11 to 29 September at 193 to 225 kg·ha$^{-1}$ and harvested from 17 June to 8 July the following year. The wheat field was fallow from July to September. In the 1980s, the main fertilizer used was farm manure. Since the 1990s, the fertilizers used were N and P fertilizers. Crop cultivation and field management, including pest and weed control, among others, have changed little and have been carried out according to local farming practices in the past 40 years.

The soil moisture content was measured every 10 days from March to November via the soil drilling method. The measuring depth was 1 m, and a soil sample was taken once every 10 cm with four repetitions.

At the end of the growing season, 1 m$^2$ quadrats of wheat were harvested by cutting the wheat at the soil surface level. The wheat was dried in an oven (70 °C for 48 h) and weighed. After separating the plants into straw (leaves and stem) and ears, grains were selected from the ears and weighed. The final grain yield was obtained by harvesting four replicates.

2.3. Methods

The field water balance can be written as [10,21]:

$$\text{ET} = R + U - D - F - \Delta W$$  \hspace{1cm} (1)

where ET is the total water consumption, including soil evaporation and crop transpiration (mm), R is the precipitation during the crop growth period (mm), U is the groundwater recharge (mm), D is the runoff (mm), F is the deep leakage (mm), and $\Delta W$ is the change in the stored soil water in the upper 100 cm of the soil between planting (soil water at planting, SWP) and harvest (soil water at harvest, SWH). As 60% of the total length or amount of the winter wheat roots was concentrated in the upper layer above 40 cm and the root water absorption depth was mainly concentrated above 70 cm [22,23], observation data on the soil water above 100 cm were selected to reflect most of the soil water consumed by the winter wheat fields. The groundwater in the experiment was 15 m below the surface, and runoff was prevented from entering the experimental ridge. Therefore, U, D, and F can be ignored. Therefore, the water balance was calculated as follows:

$$\text{ET} = R - \Delta W$$  \hspace{1cm} (2)
The water use efficiency (WUE) was defined as [10,24]:

\[ \text{WUE} = \frac{Y}{ET} \]  

(3)

where WUE represents the water use efficiency for the winter wheat yield (kg ha\(^{-1}\) mm\(^{-1}\)), Y is the yield of winter wheat (kg ha\(^{-1}\)), and ET is the water consumption of a winter wheat field (mm).

3. Results

3.1. Climate Change

In the present study, the annual precipitation was calculated as the rainfall within the previous fallow period (from wheat harvest to wheat planting) plus the precipitation that occurred during the following wheat season. Over the 40 years of the study, the annual precipitation varied from 316 to 807 mm (average 548 mm). Growing season precipitation accounted for 40–79% (average 60%) of the annual precipitation (Figure 2a). There were no significant increasing trends in precipitation in either the fallow period or the growing season. The ten-year average growing season precipitation was 227 mm in the 1980s, 214 mm in the 1990s, 196 mm in the 2000s, and 233 mm in the 2010s. The ten-year average fallow period precipitation was 328 mm in the 1980s, 278 mm in the 1990s, 349 mm in the 2000s, and 368 mm in the 2010s (Figure 2b). Thus, precipitation showed great variability, as some years could be very dry or very wet. The average growing season temperature was 19.2 °C, increasing at a rate of 0.77 °C/year, and the average fellow period temperature was 6.3 °C, increasing at a rate of 0.46 °C/year (Figure 2c).

![Figure 2](image-url)

**Figure 2.** Interannual (a) and decadal (b) changes in precipitation and interannual temperature changes (c) in the fallow and growth periods from 1981 to 2020.

3.2. Soil Water Storage

From 1981 to 2020, the SWP varied from 137 to 317 mm (average 255 mm), the amount of soil water storage at harvest (SWH) varied from 93 to 230 mm (average 154 mm), and the soil water storage consumption in the growth period varied from 3 to 190 mm (average 97.5 mm) (Figure 3a). There were no significant increasing trends in either the SWP or SWH. The ten-year average SWP was 236 mm in the 1980s, 205 mm in the 1990s, 264 mm in the 2000s, and 248 mm in the 2010s. The ten-year average SWH was 145 mm in the 1980s, 141 mm in the 1990s, 119 mm in the 2000s, and 166 mm in the 2010s (Figure 3b). There was good consistency between the SWP and precipitation in the fallow period (R = 0.728) and between the SWH and precipitation in the growth period (R = 0.591).

3.3. Characteristics of Water Consumption Components

The average ET of the winter wheat fields during the entire growth period over the past 40 years was 315 mm, but there was a high level of variability between years, with a maximum of 453 mm in 2002, which is 2.9 times that of the year with the lowest ET (158 mm in 2000) (Figure 4a). According to the analysis of the water consumption components, the average contributions of P (average: 217 mm) and ∆W (average: 98 mm) to ET in the whole
growth period were 69% and 31%, respectively. ET increased with increasing SWP and P, with correlation coefficients of 0.6540 and 0.6115, respectively ($p < 0.05$).

![Figure 3](image3.png)

**Figure 3.** Interannual (a) and decadal (b) changes in the SWP and SWH from 1981 to 2020. SWP indicates the amount of soil water storage at planting. SWH indicates the amount of soil water storage at harvest.

![Figure 4](image4.png)

**Figure 4.** Interannual (a) and decadal (b) changes in water consumption components of winter wheat fields. P indicates precipitation in the growth period. ΔW indicates soil water storage consumption in the fallow period. ET indicates the total water consumption of winter wheat fields. P% indicates contributions of P to ET. ΔW % indicates contributions of ΔW to ET.

In the 1980s, the average contributions of P (average: 227 mm) and ΔW (average: 90 mm) to ET (average: 317 mm) were 71% and 29%, respectively. ET was the lowest (278 mm) in the 1990s because the lowest ΔW (64 mm) occurred in this decade, accounting for only 22% of the total ET. In the 2000s, P was the lowest at 196 mm, but the fallow period precipitation reached 349 mm, the ΔW contribution to ET was the highest at 43%, and ET (average: 341 mm) was the highest over the 40 years. In the 2010s, P was the highest, and the average contributions of P (average: 232 mm) and ΔW (average: 90 mm) to ET (average: 322 mm) were 72% and 28%, respectively, similar to those in the 1980s (Figure 4b).

3.4. Relationships between Water Consumption Components

Among the components of water components, P and ΔW were balanced, and P was dominant. The proportion of ΔW relative to ET decreased linearly with P and the SWH ($p < 0.05$) and increased linearly with the SWP ($p < 0.05$) (Figure 5). When P exceeded 270 mm, the proportion of ΔW relative to ET was less than 10%, and the SWH reached more than 60% of the field’s water-holding capacity. When P was 230–270 mm and the SWP was 200–230 mm, the contribution of ΔW was 10–26%, and that of the SWH was 50–60% of the field water capacity. When P was 193–230 mm and the SWP was 230–255 mm, the contribution of ΔW was 26–40%, and the SWH reached 40–50% of the field water capacity. When P ranged from 141 to 193 mm and the SWP ranged from 230 to 255 mm, the contribution of ΔW was usually 40–60%, and the SWH reached 30% to 40% of the field water capacity.
Figure 5. Relationships between the proportion of ΔW relative to ET and P, SWP, and SWH. P indicates precipitation in the growth period. ΔW indicates the soil water storage consumption in the fallow period. ET indicates the total water consumption of winter wheat fields. SWP indicates the amount of soil water storage at planting. SWH indicates the amount of soil water storage at harvest.

3.5. Effect on Yield

The components of water consumption components are important factors that determine the final yield. As shown by the interannual and interdecadal variations in the yield of winter wheat (Figure 6a), the yield reached a minimum of 2795 kg ha⁻¹ in the 1990s, followed by 3247 kg ha⁻¹ in the 2000s, 3389 kg ha⁻¹ in the 1980s, and a maximum of 4502 kg ha⁻¹ in the 2010s. Compared with that of the 1980s, 1990s, and 2000s, the average yield in the 2010s increased by 32.8%, 61.1%, and 38.7%, respectively (p < 0.01). From 1981 to 1993, the planted varieties were the Qingfeng and Changwu series. After 1994, the main varieties were Xifeng No. 20 (from 1995 to 2002), Xifeng No. 24 (from 2003 to 2008), Longyu No. 218 (from 2009 to 2010, 2014, and 2016), Longyu No. 386 (from 2011 to 2013), and so on. The yield differences in the main varieties in different years showed that the Longyu series planted in the 2010s significantly differed (p < 0.05) from Changwu No. 1 in the 1980s, Xifeng 20 in the 1990s, and Xifeng 24 in the 2000s.

Figure 6. Variation in winter wheat yield (a) and its relationship with ET (b). ET indicates the total water consumption of winter wheat fields.

Based on the trends of variation in the winter wheat yield over the last 40 years, the yield data were divided into two groups with a boundary of 2010 to carry out regression fitting between the yield and ET, which were both consistent with the quadratic function relationship model and passed the significance test (Figure 6b). In the first 30 years, the yield of winter wheat varied from 1057 to 4755 kg ha⁻¹. When the water consumption reached 250 mm, 350 mm, and 450 mm, the yield reached 2683, 3551, and 3645 kg ha⁻¹, respectively. When ET increased by 1 mm, the yield increased by 8.2 kg ha⁻¹. In the
last 10 years, the yield of winter wheat reached 1975–6914 kg·ha\(^{-1}\). When ET reached values of 250 mm, 350 mm, and 450 mm, the yields were 2643 kg·ha\(^{-1}\), 5233 kg·ha\(^{-1}\), and 7441 kg·ha\(^{-1}\), respectively. The yield increased significantly with increases in ET. When ET increased by 1 mm, the yield increased by 24.6 kg·ha\(^{-1}\), which was three times the increase in the previous 30 years. According to the correlations between the yield and the components of water consumption, the correlation of winter wheat yield with \(P\) \((r = 0.5567)\) was higher than the correlation of winter wheat yield with \(\Delta W\) \((r = 0.3535)\).

3.6. Relationships between Water Consumption Components and WUE

The average WUE over the 40-year period was 11.0 kg·ha\(^{-1}\)·mm\(^{-1}\) on the Loess Plateau. The ten-year average WUE was 10.9 kg·ha\(^{-1}\)·mm\(^{-1}\) in the 1980s, 9.8 kg·ha\(^{-1}\)·mm\(^{-1}\) in the 1990s, 9.6 kg·ha\(^{-1}\)·mm\(^{-1}\) in the 2000s, and 13.7 kg·ha\(^{-1}\)·mm\(^{-1}\) in the 2010s (Figure 6a). Figure 3 shows that in the 2010s, \(P\) was the highest (232.6 mm), \(\Delta W\) was 81.6 mm less than in the 1990s, and ET was 322 mm more than in the 1990s. In the 2000s, \(P\) was the lowest (196 mm), \(\Delta W\) was the highest (145 mm), and ET was the highest. In the 1990s, \(P\) was 214 mm higher than in the 2000s, \(\Delta W\) was the lowest (64 mm), and ET was the lowest. In the 1980s, the water consumption components were similar to those in the 2010s. According to the interdecadal variations in the WUE and water consumption components, WUE was positively correlated with \(P\) \((R = 0.8159; p < 0.01)\) and negatively correlated with \(\Delta W\) \((R = 0.3584, p < 0.05)\). At the same time, the trend of variation in the WUE was consistent with that of the SWH \((R = 0.9034; p < 0.05)\). Overall, these results show that \(P\) can increase WUE more effectively than \(\Delta W\) (Figure 7).

![Figure 7. Relationships between precipitation during the growth periods, soil water storage after harvest, and water use efficiency (WUE). P indicates precipitation in the growth period. SWH indicates the amount of soil water storage at harvest.](image)

4. Discussion

4.1. Water Consumption Components of Winter Wheat Fields

The water consumption components strongly influence the water balance and cycle of crop fields [21,23]. The average water consumption of winter wheat fields was 315 mm from 1981 to 2020, higher than the average of 305 mm from 1987 to 2000 on the Loess Plateau [25], indicating an increase in water consumption under the conditions of climate change. The contribution of precipitation in the growth period to the water consumption of the winter wheat fields was more than 50% on the Loess Plateau [12]; this was basically consistent with the finding of this study that the proportion of \(P\) relative to ET was 69.4%. Winter wheat first uses soil water transformed from current rainfall events and then uses early soil water [26], and the precipitation during growth periods is dominant on the Loess Plateau.

However, the relative importance of \(\Delta W\) and \(P\) with respect to crop growth and final yield is highly variable for different crops. \(\Delta W\) plays a more important role than \(P\) in determining the spring wheat yield in Northwest China [27], and \(\Delta W\) even explained more than 50% of the yield variation for several short-duration dryland crops compared with...
long-duration crops [28]. $P$ supplies a higher percentage of water for the use of crops with longer growth durations, especially at the reproductive stage [17]. The growth duration of winter wheat was longer than that of other crops, with values of 240 days for winter wheat [29] versus 90 days for both bean and millet, 115 days for sunflower, and 150 days for corn [28]. Therefore, the importance of $P$ and $ΔW$ with respect to crop growth and final yield depends on the different crops and lengths of the growing season.

4.2. Water Consumption Components and Variety Effect on Yield

In the first 40 years, the yield of winter wheat varied from 1057 to 6914 kg·ha$^{-1}$ on the Loess Plateau, while it ranged from 818 to 7900 kg·ha$^{-1}$ in another study [9], and the winter wheat yield in the central Great Plains of the USA, which is also an arid region, varied from 870 to 4040 kg·ha$^{-1}$ [14]. The water consumption components were closely related to the yield of winter wheat, and such correlations can be described in terms of quadratic functions as many researchers reported linear water–yield relations for crops over a long period in water-limited areas [18,30]. With the increase in $P$ during the growth period in the last 10 years, when ET increased by 1 mm, the yield increased by 24.6 kg·ha$^{-1}$, which was three times the increase in the previous 30 years. Moreover, the correlation of winter wheat yield with $P$ was higher than the correlation if winter wheat yield with $ΔW$. Therefore, $P$ played a more important role in determining the final winter wheat yield than other environmental factors in the current study [16,31]. However, $ΔW$ was more important than $P$ during the growing season in determining the spring wheat yield [27]. In fact, the importance of $P$ and $ΔW$ to yield depends on their proportions relative to ET. Wheat yield is influenced not only by the environment but also by the variety of wheat, as demonstrated in many studies [9,32,33]. The yield differences in the main varieties in different years show that the Longyu series planted in the 2010s significantly differed ($p < 0.05$) from other varieties in the current study region. The emergence of varieties belonging to the Longyu series played an important role in the yield of winter wheat on the Loess Plateau [34,35]. According to regional experiments, the new drought-resistant and high-yield variety Longyu No. 4 increased the yield by 15.2% compared with the yield of Xifeng No. 27 [34]. The grain yield level increased by 71.3 kg·ha$^{-1}$ per year, with an annual growth rate of 2.2%, according to a variety evaluation experiment on winter wheat from different test lines on the Loess Plateau from 2000 to 2019 [35]. From the experimental records of field management practices, the planting pattern changed little over the past 40 years, but the type of fertilization changed from farm fertilizer in the 1980s to the use of chemical fertilizers such as N and P since the 1990s. However, the average yield and WUE in the 1980s were higher than those in the 1990s and 2000s. Therefore, fertilizer was not the main controlling factor limiting the increase in winter wheat yield on the Loess Plateau.

In conclusion, this study determined that the components of water consumption and variety were the main limiting factors affecting the increase in the yield of winter wheat on the Loess Plateau.

4.3. Water Consumption Component Effects on WUE

The winter wheat WUE ranged from 3.4 kg·ha$^{-1}$·mm$^{-1}$ to 23.4 kg·ha$^{-1}$·mm$^{-1}$ on the Loess Plateau [9], whereas it ranged from 5.0 kg·ha$^{-1}$·mm$^{-1}$ to 13.0 kg·ha$^{-1}$·mm$^{-1}$ [4]. In the current study, the ten-year average WUE was 10.9 kg·ha$^{-1}$·mm$^{-1}$ in the 1980s, 9.8 kg·ha$^{-1}$·mm$^{-1}$ in the 1990s, 9.6 kg·ha$^{-1}$·mm$^{-1}$ in the 2000s, and 13.7 kg·ha$^{-1}$·mm$^{-1}$ in the 2010s, consistent with the global average WUE for wheat of 10.9 kg·ha$^{-1}$·mm$^{-1}$ [36]. Many studies have been conducted to address the remarkable negative correlation between crop WUE and annual precipitation [37,38]. However, the production of plants in arid and semiarid areas was heavily dependent on growing season precipitation [16,17], and WUE was positively correlated with $P$ and negatively correlated with $ΔW$ in the current study region. $ΔW$ might be used less by crops if the $P$ during the growth period is large and adequate for crop growth, which would lead to a lower response of crop WUE to $ΔW$. Therefore, $P$ might become a more determining factor than $ΔW$ for crop WUE when the
P is large [27]. Over the decades in the region, the maximum WUE was observed under the maximum P in the 2010s, and the minimum WUE was found under the minimum P and the maximum ET in the 2000s. Therefore, WUE was influenced not only by the total water consumption but also by the seasonal pattern of water use under the conditions of climate change.

Some researchers have indicated that the variety of crops has no impact on the relationship between WUE and crop yield [14,30]. However, other studies showed that the WUE–yield relation changed for different varieties, even when considering the same crop [31]. In the current study, the WUE significantly increased in the 2010s, correlating with the increase in precipitation during the growth period and the emergence of the drought-resistant and high-yield Longyu variety [34,35]. Therefore, variety had a certain influence on the WUE and crop yield.

Many researchers have found that the SWP is a very useful indicator for agricultural management in water-limited areas, and dryland crop yield increases with an increase in the SWP [14,18,27,30]. The proportion of $\Delta W$ relative to ET increased linearly with the SWP in the current study. Moreover, there was good consistency between the SWP and precipitation in the fallow period. Therefore, a soil management regime that increases the SWP is required to increase the sustainability of the winter wheat–summer fallow system on the Loess Plateau, China. Fortunately, some researchers have shown that mulching appears to be the best management practice for the winter wheat–summer fallow system on the Loess Plateau, according to simulations. Increasing the soil organic matter may be the best option if mulching cannot be implemented [9,10].

4.4. Limitations and Implications

This study focused on exploring the effects of the components of water consumption on the yield and WUE of winter wheat on the Loess Plateau. The results provide a scientific basis for sustainable winter wheat production on the Loess Plateau to adapt to future climate change. However, the impacts of water consumption components on winter wheat in arid areas are complex and have many uncertainties. First, as the measured depth of the soil water was only 1 m, the lack of deeper observations had a certain impact on the analysis of the components of water consumption. Second, due to the rapid variety replacement and lack of variety comparison field experiments in the past 40 years, it was difficult to isolate the degree of influence of variety on the yield and WUE. Third, there are many factors affecting winter wheat yield, and the method in this study could not fully consider various factors, such as intense weather events and field management. In subsequent related studies, the effects of changes in various factors on the yield of winter wheat should be considered simultaneously.

5. Conclusions

The observation data on winter wheat were collected from 1981 to 2020 at the Xifeng State Agrometeorological Experimental Station on the Loess Plateau. The results show that the average water consumption was 315 mm in the winter wheat fields over the past 40 years. The soil water was first converted from the precipitation that fell during the growing season, accounting for 69.4%, and then consumed for soil water storage in the fallow period, accounting for 30.6%. The correlation between the yield of winter wheat and the P during the growth period was higher than the correlation between the yield of winter wheat and $\Delta W$. The WUE was positively correlated with P ($p < 0.01$) and negatively correlated with $\Delta W$ ($p < 0.05$) during the growth period.

Author Contributions: Conceptualization, F.F.; Methodology, J.J. and L.H.; Software, F.Z.; Validation, F.F.; Formal analysis, F.Z.; Investigation, L.H.; Resources, J.Z.; Writing—original draft, J.J.; Supervision, J.Z.; Funding acquisition, H.W. All authors have read and agreed to the published version of the manuscript.
References


33. Sinebo, W. Trade off between yield increase and yield stability in three decades of barley breeding in a tropical highland environment. *Field Crops Res.* 2005, 92, 35–52. [CrossRef]


Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.