agronomy

Article

Optimizing Crop Systems: Integrating Forage Triticale into the Fallow of Peanut Monoculture in the North China Plain

Yongliang You [1,2,†], Jianqiang Deng [1,3,†], Guibo Liu [2], Xianlong Yang [1], Zhixin Zhang [4] and Yuying Shen [1,*]

1 College of Pastoral Agriculture Science and Technology, Lanzhou University, Lanzhou 730020, China; youyl18@lzu.edu.cn (Y.Y.); dengjq15@lzu.edu.cn (J.D.); yangxl@lzu.edu.cn (X.Y.)
2 Dryland Farming Institute, Hebei Academy of Agricultural and Forestry Sciences, Hengshui 053000, China; lgb2884@126.com
3 School of Agriculture, Ningxia University, Yinchuan 750021, China
4 College of Grassland Agriculture, Northwest A & F University, Yangling 712100, China; zhixin@nwafu.edu.cn
* Correspondence: yy.shen@lzu.edu.cn; Tel.: +86-891-5263-0931
† These authors contributed equally.

Abstract: Integrating a forage crop into the fallow (F) of the peanut (*Arachis hypogaea* L.) (P) mono-cropping system is a practical approach to provide forage yield and increase the resource use efficiency. However, little information about the comprehensive assessment of water utilization and economic benefits in the crop–livestock system exists for the North China Plain (NCP). This study aims to identify the crop rotation for optimizing water management and enhance economic benefit. The field experiment was performed over three years (2011–2014) to assess production, water utilization, and economic benefits when inserting forage triticale (*X Triticosecale* Wittmack) (T) into the peanut mono-cropping system. Results showed that replacing the fallow F-P cropping system with forage triticale provided a substantial amount of forage (the average of 9.8 t ha^{-1} per year) and enhanced the average system productivity by 85.1%. Cultivation of forage triticale during the fallow period decreased the subsequent peanut pod yield by 8.3% due to a 19.3% decline in soil water storage capacity during the sowing stage of peanut. Replacing fallow with forage triticale increased the system net income by 1016.2 US$ ha^{-1} and the water use efficiency (WUE) by 30.0%, while not affecting the economic efficiency of water use (EEWU), and thus can be recommended as a better option for maintaining relatively high system production, economic benefit, and WUE in NCP.

Keywords: fallow–peanut cropping system; forage triticale; water use efficiency; economic efficiency of water use; net income

check for updates

Citation: You, Y.; Deng, J.; Liu, G.; Yang, X.; Zhang, Z.; Shen, Y. Optimizing Crop Systems: Integrating Forage Triticale into the Fallow of Peanut Monoculture in the North China Plain. *Agronomy* **2022**, *12*, 1138. https://doi.org/10.3390/agronomy12051138

Academic Editor: Carlo Leifert

Received: 20 March 2022
Accepted: 5 May 2022
Published: 9 May 2022

1. Introduction

The North China Plain (NCP) is the main peanut production region, which accounts for 64% of the total peanut productivity in China [1]. As an important economic crop and oil crop, peanut plays a vital role in national oil safety for NCP [2]. Continuous peanut cropping is one of the common cropping systems in NCP, characterized by a fallow period of about eight months (from peanut harvest in mid-September to sowing in mid-May). Fallowing helps increase soil water storage for subsequent crops [3–5] resulting in lower economic cost than successive cropping [6]. Nevertheless, fallowing can also result in some negative impacts on sustainable production [7,8], such as the costs of chemical input due to weed pressure during the fallow period [9] and the decline of resource use efficiency (i.e., land, water, and solar) [10]. Previous research has shown that peanut can meet part or all of its nitrogen needs through biological dinitrogen fixation and also provide nitrogen for subsequent crops [11]. Wan [12] reported that intercropping peanuts with wheat (*Triticum aestivum* L.) can effectively improve the utilization of land and solar energy resources and also improve pod and seed quality. Nielsen et al. [13] reported that increasing the cropping cycle by planting a cover crop in place of a fallow period can enhance output without posing a risk to the subsequent wheat yield. The economic benefit can also be increased with intensive planting in during a fallow period [9]. Gabriel et al. [14] has shown that agricultural systems with summer cash crops can be intensified by winter cover crops, especially in regions where there is a relatively mild winter with good soil moisture conditions. Therefore, it is necessary to consider replacing fallow with additional crops to improve the efficiency of land, water, and solar energy utilization in NCP.

Crop production and economic income are important criteria for the assessment of crop rotations [15]. Wang [16] found that weed management and maintaining forage yield could be achieved efficiently with the use of fallow crops. Nielsen et al. [17] also reported that integrating forage triticale into a wheat–maize–fallow system increased forage production by 4845 kg ha^{-1} and enhanced economic benefit by 17%. Christiansen et al. [18] showed that the gross income increased by an average of US$126 ha^{-1} per year when common vetch (*Vicia sativa* L.) was used instead of fallow. However, planting a forage crop in the fallow period also has a negative impact on sustainable agricultural development if the water condition and precipitation fail to match crop demand [19].

In NCP, annual precipitation fluctuates considerably, ranging from 500 to 600 mm [20], with 70% concentrated during a portion of the peanut growing season (July to September). Therefore, it is necessary to explore the impact of water, fertilizer, and precipitation distribution on forage yield, system production, and economic benefits of intensive production of forage crops during the fallow period. Meanwhile, the income of farmers in this region has been relatively unstable, due to fluctuations in product market prices and water cost. It is crucial to evaluate the economic efficiency of water use (EEWU) when a continuous peanut cropping system is intensified with annual forage triticale. However, the effect of fallow crops on the system EEWU is still unclear in NCP. Likewise, water use efficiency (WUE) is essential for developing water footprints for crop products [21]. Given restrictions of irrigated land expansion in NCP, increasing WUE in both irrigated agriculture and dryland farming through water conservation and improved precipitation use efficiency is essential to food security.

The objectives of this trial were to (1) investigate soil water content, water use (WU), and yield of peanut and forage triticale when forage triticale was integrated into peanut monoculture; and (2) determine the effect of a forage triticale fallow crop of on system economic benefit and EEWU.

2. Materials and Methods

2.1. Experimental Site

A three-year field experiment was conducted during 2011–2014 at the research station near Ren County, Xingtai, Hebei, China (37°04′ N, 114°30′ E; 77.3 m elevation above sea level). The site is located in NCP, which is characterized by a temperate semi-humid monsoon climate. It has an average annual air temperature of 13.2 °C and average annual precipitation of 498 mm. According to the U.S. classification system, the soil texture of the experimental site was a clay loam [22]. The initial characteristics of 0–40 cm soil depth are shown in Table 1. The previous crop was maize, and no differences were observed in initial water conditions among the experimental plots in October 2011. Meteorological parameters (i.e., precipitation and air temperature) were obtained at the onsite agriculture meteorological station placed within 50 m of the experimental field.

Table 1. Physiochemical properties of the 0–20 and 20–40 cm soil layers at the beginning of the experiment in October 2011.

Soil Layer (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g cm^{-3})	Organic Matter (g kg^{-1})	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	pH
0–20	31.2	43.7	25.1	1.49	17.4	96.4	7.7	89.4	7.88
20–40	28.7	41.8	29.5	1.55	12.4	47.9	4.2	87.2	8.01

2.2. Experimental Design

The experiment was a randomized complete block design with three replications. The treatments were (1) fallow–peanut (F-P) and (2) forage triticale–peanut (T-P). Each plot was 20 m^2 (4 m $\times$ 5 m). The cultivars and sowing dates, harvest dates, irrigation, and fertilization practices are listed in Table 2. All experimental plots were tilled to a depth of 30 cm with a chisel plow, followed by harrowing just before sowing. Forage triticale and peanut seeds were sown at 150 kg ha^{-1} and 300,000 plants ha^{-1}, respectively and a 20-cm and 40-cm row spacing, respectively. Weed management was by hand.

Table 2. Crop cultivars, sowing dates, harvest dates, irrigation, and fertilizer for each crop during 2011–2014.

Crop	Cultivar	Sowing Date	Harvest Date	Date of Irrigation	Amount of Each Irrigation (mm)	Fertilizer $N/P_2O_5/K_2O$ (kg ha^{-1})
Forage triticale	Zhongsi 1048	11 October 2011	14 May 2012	17 April 2012	60	215/120/113
		15 October 2012	13 May 2013	3 April 2013	60	215/120/113
		15 October 2013	11 May 2014	5 March 2014	60	215/120/113
Peanut	Jihua 5	15 May 2012	16 September 2012	2 June 12	60	105/120/113
		15 May 2013	19 September 2013	11 June 13	60	105/120/113
		13 May 2014	13 September 2014	6 June 13	60	105/120/113

2.3. Dry Matter and Grain Yield Measurements

Forage triticale was harvested manually at the milk stage after removing two edge rows in each plot. The 14.4 m^2 (3.6 m $\times$ 4 m) area was weighed, and duplicates of 1 kg were subsampled for further processing. Peanut within a 20 m^2 (4 m $\times$ 5 m) area of each plot was sampled at physiological maturity. Subsamples of 20 plants were threshed and winnowed manually to measure yield components, including seed yield, pod number per plant, 100 pod weights, and 100-seed weight. All subsamples were processed in a drying oven at 65 °C for 72 h to constant weight for dry matter (DM) yield.

2.4. Soil Water and Water Use Efficiency

Soil water content was achieved by using a 35-mm diameter soil auger within each plot before sowing and after harvesting of forage triticale and peanut. Soil samples were collected in 20-cm increments at a soil depth of 0–120 cm. The samples were placed in a drying oven at 105 °C for 48 h to a constant weight to determine soil water content. Crop water use (WU, mm) was determined by the following formula [23]:

$$\mathrm{WU} = \mathrm{P} + \Delta\mathrm{S} + \mathrm{I} - \mathrm{R} - \mathrm{DP} + \mathrm{CR} \quad (1)$$

where P represented precipitation during the growing season (mm), ΔS represented the difference of soil water content from sowing to harvest stage (mm), I represented the amount of irrigation applied during crop establishment [24] and irrigation amounts are given in Table 2, R represented surface runoff (mm), which was omitted due to the flat terrain of the experimental site, DP represented the infiltration of soil water into the deep root zone (mm), which was also omitted since precipitation rarely infiltrated to 120 cm depth over a short time [16], and CR represented soil pore water capillary rise. Since the groundwater table at this site was approximately 10 m depth, this term was also omitted from the equation [25].

Water use efficiency of dry matter yield (WUE_{DM}; kg ha^{-1} mm^{-1}) and economic efficiency of water use (EEWU; US$ ha^{-1} mm^{-1}) were calculated according to the equations:

$$\mathrm{WUE}_{\mathrm{DM}} = \frac{\mathrm{DM}}{\mathrm{WU}} \quad (2)$$

$$\mathrm{EEWU} = \frac{\text{Gross income}}{\mathrm{WU}} \quad (3)$$

where DM represented dry matter yield of peanut and forage triticale and WU was calculated according to Equation (1).

2.5. Production Costs and Economic Benefit

Table 3 presented the production costs for the economic benefit analysis. The costs mainly include seeds, fertilizers, irrigation, herbicides, labor, and machinery. The cost of the machine mainly included fossil fuels, equipment repair, and maintenance. The system economic return was calculated according to the difference between the total income and the cost among the cropping system. The economic analysis was conducted in U.S. dollars, and the crop prices were taken from online (Available online: http://datacenter.cngrain.com (accessed on 12 March 2015); Table 4).

Table 3. Production cost analysis for the fallow–peanut (F-P) and forage triticale–peanut (T-P) during 2011–2014.

Year	Cropping System	Crop	Seeds	N and P Fertilizer	Irrigation	Herbicides	Labor	Machine	Total Input
			US$ ha^{-1}						
2012	F-P	Peanut	452.38	323.81	19.05	80.95	1595.24	666.67	3138.10
2012	T-P	Peanut	452.38	323.81	19.05	80.95	1595.24	666.67	3138.10
2011–2012		Forage triticale	190.48	304.76	38.10	0.00	47.62	285.71	866.67
2013	F-P	Peanut	405.41	331.48	19.08	81.08	1633.55	691.57	3162.16
2013	T-P	Peanut	405.41	331.48	19.08	81.08	1633.55	691.57	3162.16
2012–2013		Forage triticale	190.78	310.02	38.16	0.00	71.54	310.02	920.51
2014	F-P	Peanut	376.22	322.48	19.54	78.18	1734.53	723.13	3254.07
2014	T-P	Peanut	376.22	322.48	19.54	78.18	1734.53	723.13	3254.07
2013–2014		Forage triticale	195.44	317.59	39.09	0.00	73.29	342.02	967.43

Table 4. Prices received for forage triticale and peanut produced during 2011–2014 in China (US$ kg^{-1}).

Crop	2012	2013	2014
Forage triticale	0.222	0.238	0.244
Pod of peanut	1.048	0.827	0.814
Straw of peanut	0.119	0.119	0.122

2.6. Statistical Analysis

The GenStat statistics software 17.0 (Lawes Agricultural Trust, Roth Amsted Experimental Station, Harpenden, UK) was used to achieve the statistical analyses at $p < 0.05$. Fixed effects in the general linear model included year, cropping system, and their interaction. When fixed effects were significant, the corresponding means were compared using LSD.

3. Results

3.1. Weather Conditions

Annual precipitation for 2011 and 2013 was 11.8 and 12.9% greater than that for long-term average (LTA, 496 mm), while for 2012 and 2014, annual precipitation was 5.8 and 23.5% lower than that for the LTA, respectively (Figure 1a). Compared with the LTA, Forage triticale had more precipitation during the growth period of 2011–2012, while peanut had more precipitation during the growing period of 2012–2013 (Table 5). Lower precipitation occurred in the forage triticale growing seasons in 2012–2013 and 2013–2014. For the peanut growing seasons, lower precipitation occurred in 2011–2012 and 2013–2014. The mean annual air temperature was 14.0, 13.3, 13.8, and 14.6 °C in 2011, 2012, 2013, and 2014, respectively (Figure 1b). The mean annual maximal air temperature was 27.4 °C and found in July.

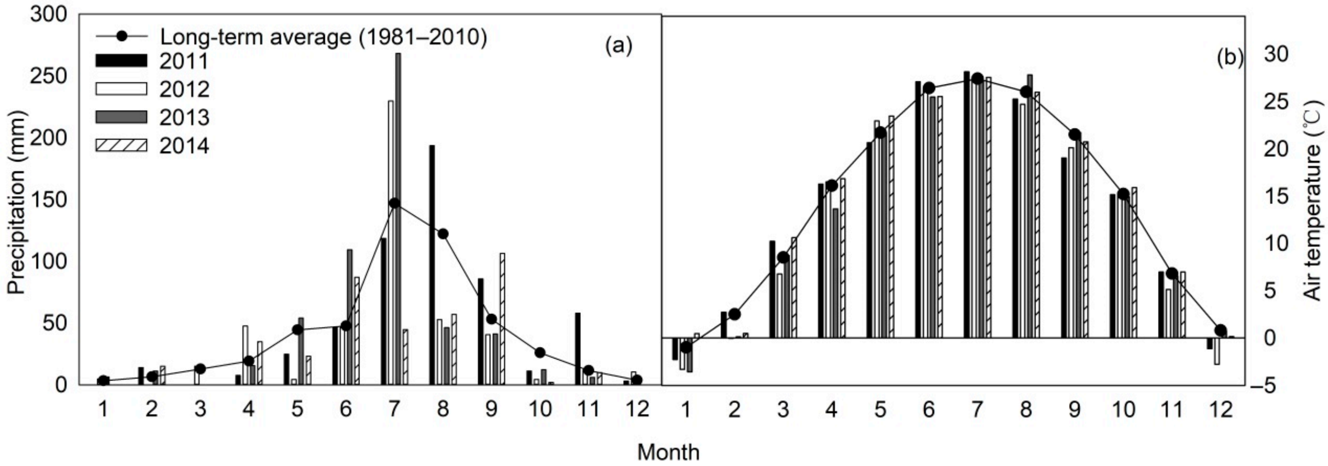

Figure 1. Monthly and long-term average precipitation (**a**) and air temperature (**b**) during the experimental periods of 2011–2014 at Ren County, Hebei, China.

Table 5. Precipitation (mm) during the growing season and the long-term average (LTA) (1981–2010) at Ren County, Hebei, China.

Crop	Growing Season	Precipitation (mm)			
		2011–2012	2012–2013	2013–2014	LTA
Forage triticale	October–May	132.0	63.5	72.2	126.9
Peanut	May–September	372.3	493.2	221.8	413.9

3.2. Production Performance

DM of forage triticale showed a significant difference among years (Table 6), with an average of 9.8 t ha^{-1} in across experimental years. The cropping system affected the annual yield of peanut pod significantly. Pod yield in the F-P cropping system averaged 7.7 and 15.5% greater than that in the T-P cropping system in 2012–2013 and 2013–2014, respectively. A significant cropping system effect was obtained in peanut straw yield. Straw yield in the F-P cropping system averaged 6.1 and 14.2% greater than that in the T-P cropping system in 2012–2013 and 2013–2014, respectively. There was a significant interaction effect on the DM of the total system, and total system DM in the T-P cropping system averaged 85.1% greater than that in the F-P cropping system over the growing seasons.

There was an interaction effect of year and cropping system on seed yield (Table 7). Except for the growing season of 2011–2012 (averaged 4.2 t ha^{-1}), seed yield in the F-P cropping system averaged 11.6% greater than that in the T-P cropping system. Plants per hectare had a significant year effect without the effect of cropping system, and the average was 2.9 × 10^5 plants per ha^{-1} during the test period. There was a significant interaction effect in pod number per plant. Pod number per plant in the F-P cropping system was 10.0 and 9.4% greater than that in the T-P cropping system in 2013 and 2014, respectively, but there was no significant cropping system effect in 2012. There was no significant interaction effect on the 100-pod weight. Peanut 100-pod weight in the F-P cropping system was 0.7 and 0.7% greater than that in the T-P cropping system in 2013 and 2014, respectively. The interaction of years and cropping system had a significant effect on 100 seed weight. In the growing season of 2013 and 2014, the 100 seed weight of F-P cropping system was 0.8 and 1.5% higher than that of T-P cropping system.

Table 6. Dry matter yield (DM) for forage triticale, peanut, and total system over growing seasons for the fallow–peanut (F-P) and forage triticale–peanut (T-P).

Year	Cropping System	DM of Forage Triticale ($t\ ha^{-1}$)	Peanut ($t\ ha^{-1}$)		DM of Total System ($t\ ha^{-1}$)
			Pod Yield	Straw Yield	
2012	F-P	-	5.25 ± 0.02	5.27 ± 0.02	10.52 ± 0.03
2011–2012	T-P	10.01 ± 0.07	5.01 ± 0.07	5.06 ± 0.02	20.09 ± 0.08
2013	F-P	-	5.57 ± 0.08	5.73 ± 0.07	11.30 ± 0.14
2012–2013	T-P	8.41 ± 0.04	5.17 ± 0.06	5.40 ± 0.05	18.98 ± 0.15
2014	F-P	-	4.91 ± 0.09	5.06 ± 0.02	9.97 ± 0.11
2013–2014	T-P	11.12 ± 0.12	4.25 ± 0.05	4.43 ± 0.01	19.78 ± 0.09
LSD		0.28	0.21	0.12	0.33
Analysis of variance results ($P > F$)					
Year (Y)		<0.001	<0.001	<0.001	<0.001
Cropping system (CS)		-	<0.001	<0.001	<0.001
Y × CS		-	0.001	<0.001	<0.001

"-" represents none because forage triticale did not appear in all rotation systems in all years.

Table 7. Yield and pod yield components of peanut over growing seasons for the fallow–peanut (F-P) and forage triticale–peanut (T-P).

Year	Cropping System	Seed Yield of Peanut ($t\ ha^{-1}$)	Plants per Hectare ($\times 10^5$)	Pod Number per Plant	100-Pod Weight (g)	100-Seed Weight (g)
2012	F-P	4.17 ± 0.03	2.94 ± 0.04	11.50 ± 0.11	175.30 ± 0.61	93.11 ± 0.31
2011–2012	T-P	4.19 ± 0.04	2.94 ± 0.02	12.10 ± 0.10	178.71 ± 0.80	94.20 ± 0.14
2013	F-P	3.88 ± 0.06	2.95 ± 0.02	11.00 ± 0.14	180.62 ± 0.21	95.01 ± 0.23
2012–2013	T-P	3.60 ± 0.04	2.95 ± 0.02	10.00 ± 0.12	179.40 ± 0.23	94.22 ± 0.10
2014	F-P	3.44 ± 0.06	2.96 ± 0.03	10.50 ± 0.06	178.63 ± 0.22	95.01 ± 0.11
2013–2014	T-P	2.96 ± 0.03	2.95 ± 0.03	9.60 ± 0.10	177.32 ± 0.19	93.63 ± 0.13
LSD		0.15	0.08	0.32	1.27	0.57
Analysis of variance results ($P > F$)						
Year (Y)		<0.001	0.003	<0.001	<0.001	<0.001
Cropping system (CS)		<0.001	0.07	<0.001	<0.001	<0.001
Y × CS		0.001	0.584	<0.001	0.919	<0.001

3.3. Soil Water Content and Water Use Efficiency

The soil water content in the 0–120 cm layer during the sowing and harvesting stage of each crop over the experimental period was shown in Figure 2. The soil water content in the 0–120 cm soil layer was 18.1% at the beginning of the experiment on 11 October 2011, and there was no significant difference in soil water content in each layer among treatments. Soil water content of F-P cropping system was increased after a fallow (11 October 2011 through 15 May 2012), significantly greater than that of T-P cropping system of 0–50 cm soil layer. No significant difference was found in the 0–50 cm layer on 15 October 2012, while soil water content of 50–100 cm soil layer decreased when the fallow period was replaced by forage triticale. On 15 May 2013, there was a significant difference in soil water, except for the 0–10 cm soil layer, the soil water of F-P cropping system was higher than that of T-P cropping system in all soil layers. There was no significant difference in soil water content of each soil layer during the peanut harvest period. On 13 May 2014, soil water in the F-P cropping system in the 0–50 cm layers averaged 19.7% greater than that in the T-P cropping system, but soil water content of 50–90 cm soil layer was 17.0% greater without significant difference. Soil water content was about 14.7% in all soil layers on 13 September 2014 with no significant difference.

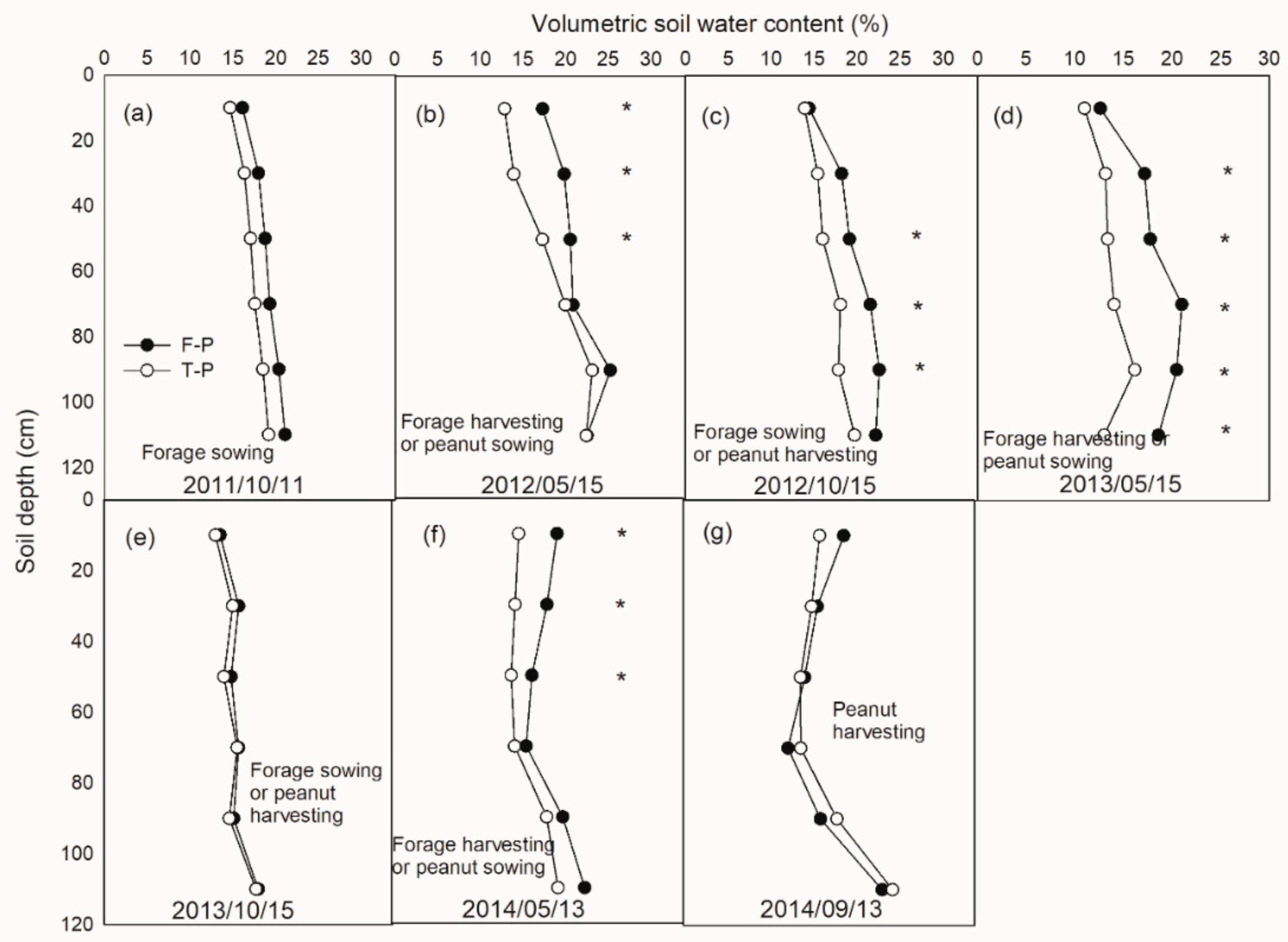

Figure 2. Vertical distribution of volumetric soil water content in the 0–120 cm soil layers of different sowing and harvesting dates of each crop during the experimental period. Within the same soil layer, an asterisk "*" indicates significant difference ($p < 0.05$) of volumetric soil water content between the treatments. (F-P), fallow–peanut, (T-P), forage triticale–peanut.

No significant effect of year was found on WU of forage triticale and the average across the experimental years was 246.1 mm (Table 8). However, WUE_{DM} of forage triticale was affected by year ($p < 0.002$), and the average across the experimental years was 40.1 kg mm^{-1} ha^{-1}. There was a significant interaction effect on WU of peanut. The WU of peanut in the T-P cropping system was significantly lower be an average of 16.1% compared to the T-P cropping system significantly across the experimental years. A significant cropping system effect was found on WUE_{DM} of peanut. The WUE_{DM} of peanut in the F-P cropping system was 8.6, 11.4, and 6.8% less than that in the T-P cropping system in the experimental period of 2011–2012, 2012–2013, and 2013–2014, respectively.

Table 8. Water use (WU) and water use efficiency (WUE) of dry matter yield (DM) of each crop over the growing seasons for the fallow–peanut (F-P) and forage triticale–peanut (T-P) at Ren County, Hebei, China.

Year	Cropping System	WU of Forage Triticale (mm)	WUE_{DM} of Forage Triticale (kg ha^{-1} mm^{-1})	WU of Peanut (mm)	WUE_{DM} of Peanut (kg ha^{-1} mm^{-1})
2012	F-P	-	-	453.85 ± 7.34	23.19 ± 0.41
2011–2012	T-P	232.94 ± 4.49	43.03 ± 0.82	396.90 ± 9.83	25.38 ± 0.50
2013	F-P	-	-	608.83 ± 11.07	18.56 ± 0.11
2012–2013	T-P	251.69 ± 13.33	33.60 ± 1.67	504.82 ± 6.27	20.95 ± 0.46
2014	F-P	-	-	356.92 ± 7.50	27.96 ± 0.55
2013–2014	T-P	253.69 ± 2.74	43.77 ± 0.95	289.63 ± 5.47	29.99 ± 0.66
LSD		28.62	4.17	20.96	1.49
Analysis of variance results ($P > F$)					
Year (Y)		0.227	0.002	<0.001	<0.001
Cropping system (CS)		-	-	<0.001	<0.001
Y × CS		-	-	0.025	0.914

"-" represents none, because forage triticale did not appear in all rotation systems in all years.

3.4. Net Income

Forage triticale net income has a significant year effect, and the average across the experimental years was 1436.9 US\$ ha^{-1} (Table 9). Peanut net income was significantly affected by year. The average net income of peanut in the F-P cropping system was 24.2% greater than that in the T-P cropping system across the experimental years. Planting year and cropping system had a significant interaction effect on the net income of the total system, and net income of total system for the T-P cropping system averaged 47.1% greater than that for the F-P cropping system across the growing seasons.

Table 9. Net income of forage triticale, peanut, and the total system during the growing seasons for the fallow–peanut (F-P) and forage triticale–peanut (T-P).

Year	Cropping System	Forage Triticale (US\$ ha^{-1})	Peanut (US\$ ha^{-1})	Total Cropping System (US\$ ha^{-1})
2012	F-P	-	2988.8 ± 26.2	2988.8 ± 26.2
2011–2012	T-P	1359.4 ± 14.5	2710.7 ± 68.0	4070.2 ± 63.8
2013	F-P	-	2125.6 ± 75.3	2125.6 ± 75.3
2012–2013	T-P	1133.6 ± 88.8	1758.1 ± 58.1	2891.7 ± 66.8
2014	F-P	-	1362.1 ± 76.4	1362.1 ± 76.4
2013–2014	T-P	1817.5 ± 29.4	745.7 ± 41.1	2563.2 ± 21.1
LSD		67.9	186.0	183.0
Analysis of variance results ($P > F$)				
Year (Y)		<0.001	<0.001	<0.001
Cropping system (CS)		-	0.007	<0.001
Y × CS		-	0.410	0.009

"-" represents none, because forage triticale did not appear in all rotation systems in all years.

3.5. Economic Efficiency of Water Use

The EEWU of the two cropping systems varied notably among the observation years (Figure 3a); however, the system EEWU had no significant difference between F-P and T-P systems across the experimental years, and the average value was 11.6 US$ ha^{-1} mm^{-1}. In the total WUE_{DM} system, there was a significant interaction between year and cropping system (Figure 3b). The system WUE_{DM} in the T-P cropping system was averagely 34.0% greater than that in the F-P cropping system across the experimental years.

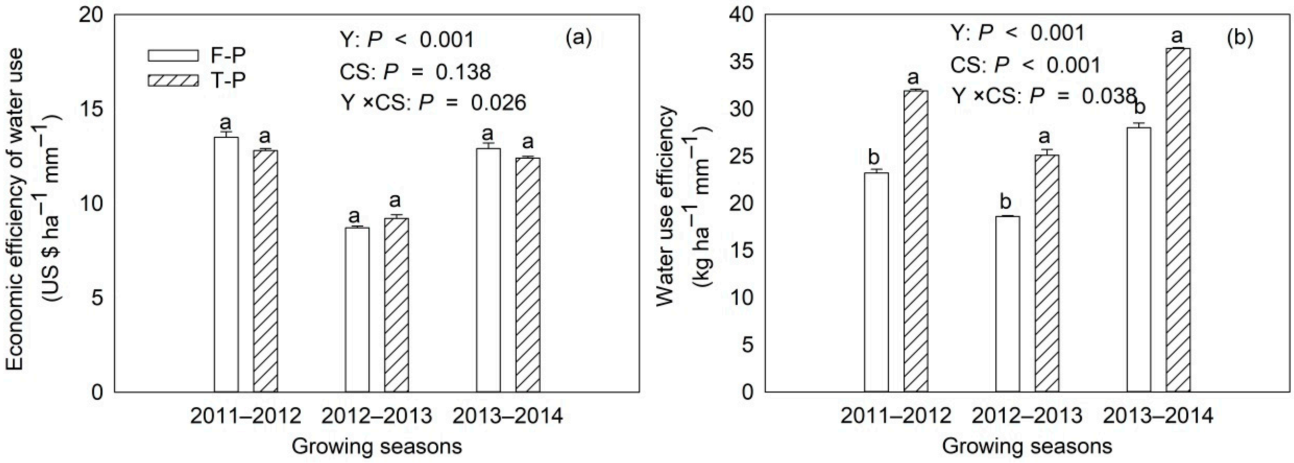

Figure 3. System economic efficiency of water use (**a**) and water use efficiency (**b**) over growing seasons for the fallow–peanut (F-P) and forage triticale–peanut (T-P). Analysis of variance results are for the effects of year (Y), cropping system (CS), and their interaction on the system economic efficiency of water use.

4. Discussion

4.1. Production and Water Utilization

An important criterion for the selection of sustainable cropping systems in an environment with limited water resources is higher water productivity or efficiency [26]. Wallance and Batchelor [27] reported that there is still considerable opportunity to for enhance WUE, because only about 30% of available water (such as precipitation or groundwater) can be used to grow food in dryland and irrigated agriculture. Intensified continuous cropping with a forage crop in place of a fallow period is an effective approach for increasing the use efficiency of resources (i.e., land, water, and radiation) and providing additional forage yields [28,29]. Our study showed that planting forage triticale in improved fallow WUE of the subsequent peanut crop and overall cropping system by 8.9 and 34.0%, respectively (Table 8, Figure 3b). This was mainly because that system production was enhanced by 85.1% when forage triticale was planted in the fallow period (Table 6), while WU increased by 35.9% (Table 8) across the experimental years. Huang [25] also reported that fallow crop obviously increased the system WUE due to good crop coverage duration during rainy season compared with the fallow–winter wheat system. Similarly, Gan [30] reported that Dry pea (*Pisum sativum* L.), pulse crops (i.e., Lentil (*Lens culinaris* Medikus), and Chickpea (*Cicer arietinum* L.)) grown during the summer fallow period increased system production by 35.5%. St. Luce et al. [31] also reported that the system yield of wheat–canola (*Brassica napus* L.)–wheat–field pea (*Pisum sativum* L.) rotation was 37.8% higher than that of continuous wheat. In terms of the WUE of peanut, the reason for the increase was that peanut DM in the T-P cropping system decreased by 7.8%, while the WU decreased by 16.1% during the experimental period. Planting forage triticale during the fallow period decreased the average subsequent peanut pod and straw yields by 10.1 and 8.9%, respectively, during the experiment period except for 2011–2012 (Table 6). The reason for the reduction in the subsequent peanut pod yield was that forage triticale had a negative impact on the pod yield components (Table 7). Our study found that forage triticale water consumption averaged 246.1 mm across the experimental years, greater than the precipitation in the fallow period (average = 89.2 mm). Nielsen et al. [32] showed that intensifying the wheat–maize–fallow system with forage triticale decreased the following wheat productivity by 17% resulting from the decline of 47 mm in water storage of wheat at sowing stage. Sufficient soil water storage during the sowing period is crucial to establish the crop canopy well in the water stress environment [13,33]. The amount and distribution of rainfall and the water depletion due to the growth of the preceding crop have an obvious impact on the soil water condition at the sowing stage [34,35]. Norwood [36] has reported that significant effects of preceding crops on dryland winter wheat were caused by different soil water storage at the sowing stage of wheat. Our soil water data also supported this view (Figure 2b,d,f). Precipitation during the forage triticale growing season in 2012–2013 and 2013–2014 was 49.9 and 43.1% less than the LTA, respectively, resulting in insufficient soil water supply (Figure 1a, Table 5). Although precipitation in the growing season of peanut in 2013 (79.3 mm) was greater than that of the LTA, 87.5% of the precipitation was concentrated in the early stage of peanut from May to July. Lv et al. [37] reported that the NCP is governed by a subtropical monsoon climate with great precipitation variability, and precipitation occurring during the fallow period plays an important role to fill up the soil water depletion to support the subsequent crop. Wang [16] reported that if there is sufficient rainfall during the fallow period, the soil water content will be replenished well, that this supplement will not be affected by cropping patterns, and that planting common vetch or soybean (*Glycine max* L. Merr.), from early-July to late September, have no obvious impact on water condition, because crop development primarily related to seasonal precipitation.

4.2. Economic Benefit

Integrating forage crops into the grain production cropping system might have an obvious impact on grain and livestock enterprise balances, economic returns, and labor demands [38]. In our study, planting forage triticale enhanced the system's net income by 47.1% regardless of growing conditions (Table 9). A similar result was reported by Nielsen [17] that the economic benefit of a wheat–maize-triticale system was 17.0% greater than that of a wheat–maize–fallow system. A similar result was also obtained by Khan [39], who reported that fallow crops increased the economic benefit by 80%. However, the opposite result was found by Deng [40]: that the economic benefit of planting forage rape (*Brassica napus* L.) and common vetch in the wheat continuous cropping fallow period decreased by 25%, because the economic return generated from forage production could not offset the reduction in economic return from wheat production resulting from the decline of subsequent winter wheat production. In our study, although the planting of forage triticale also decreased the economic return of peanut because of the reduction in peanut yield, the economic return generated by forage triticale could compensate the reduction in economic return from peanut (Table 9).

4.3. EEWU

In NCP, dominated by irrigated agriculture, the EEWU is crucial to balancing farmers' income and output in order to choose a sustainable rotation system. The EEWU refers to the economic benefits and water use, which can be improved by increasing economic benefits under the same water consumption, reducing water consumption under the same economic benefits, or a combination of both. Our study showed that the system water use and economic benefits was enhanced by 35.9 and 35.4% respectively, when forage triticale was planted in the fallow period. Therefore, our study showed that planting of forage triticale during the fallow period had no effect on the EEWU compared with peanut monoculture (Figure 3a). However, Li [41] reported that intensifying continuous wheat cropping with fallow crops can increase the average system EEWU by 43.2% (fallow crops included sesame (*Sesamum indicum* L.), sorghum (*Sorghum bicolor* (L.) Moench), soybean, and maize), which explains the increase in average economic benefit and WU by 42.2% and 5.5%, respectively. Therefore, the forage triticale–peanut cropping system is a feasible way to obtain higher economic benefit and system production, which can greatly enhance the sustainability of agriculture in NCP. However, there has been a little study about the effect of fallow crop on the system EEWU in NCP. Tan and Zheng [42] reported on the influence of crop structure on the EEWU in northwestern of China. Additionally, considering the fact that it is difficult to predict future precipitation distribution and market prices may change annually, more long-term experiments combined with modeling should be carried out to further study the impact of fallow crops on system production, soil water utilization, economic benefits, and EEWU.

5. Conclusions

Planting of forage triticale during the fallow period reduced the average yield of subsequent peanut pod and straw by 8.3 and 7.3%, respectively, but the average yield of forage increased by 9.8 t ha^{-1}, and the annual yield of the system increased by 85.1%. Compared with peanut monoculture, water use efficiency and net income of the forage triticale–peanut cropping system was increased by 34.0 and 47.1%, respectively, but had no effect on the economic efficiency of water use. It is suggested that the forage triticale–peanut cropping system should be adopted in order to maintain higher forage yield, WUE, and economic benefits in NCP.

Author Contributions: Y.Y.: Conceptualization, Methodology, Writing original draft; J.D.: Data curation, Software, Writing—review and editing; G.L.: Supervision, Funding acquisition; X.Y.: Investigation, Formal analysis; Z.Z.: Software, Resources; Y.S.: Project administration, Funding acquisition. All authors have read and agreed to the published version of the manuscript.

Funding: This study was jointly supported by China Agriculture Research System of MOF and MARA (CARS-34).

Acknowledgments: We are grateful to the Qingyang Research Station of Lanzhou University for their assistance with the field research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. National Bureau of Statistics of China (NBSC). *China Statistical Yearbook*; China Statistics Press: Beijing, China, 2005.
2. Liu, Z.X.; Liu, T.R.; Liu, Y.; Yang, J.Q.; Zhen, X.Y.; Li, X.X.; Yang, D.Q.; Li, X.D. Effect of row spacing on physiological characteristics and yield of intercropped peanut with wheat. *Chin. J. Appl. Ecol.* **2018**, *29*, 1951–1959. (In Chinese)
3. Nielsen, D.C.; Vigil, M.F. Precipitation Storage Efficiency during Fallow in Wheat-Fallow Systems. *Agron. J.* **2010**, *102*, 537–543. [CrossRef]
4. Campbell, C.A.; Zentner, R.P.; Basnyat, P.; De Jong, R.; Lemke, R.; Desjardins, R. Nitrogen mineralization under summer fallow and continuous wheat in the semiarid Canadian prairie. *Can. J. Soil Sci.* **2008**, *88*, 681–696. [CrossRef]
5. Grant, C.A.; Peterson, G.A.; Campbell, C.A. Nutrient considerations for diversified cropping systems in the northern Great Plains. *Agron. J.* **2002**, *94*, 186–198. [CrossRef]
6. Greb, B.W. *Reducing Drought Effects on Croplands in the West Central Great Plains*; Department of Agriculture, Science and Education Administration: Washington, DC, USA, 1979.
7. Farahani, H.J.; Peterson, G.A.; Westfall, D.G. Dryland cropping intensification: A fundamental solution to efficient use of precipitation. *Adv. Agron.* **1998**, *64*, 197–223.
8. Unger, P.W.; Schomberg, H.; Dao, T.H.; Jones, O.R. Tillage and crop residue management practices for sustainable dryland farming systems. *Ann. Arid Zone* **1997**, *36*, 209–232.
9. Norwood, C.A.; Dhuyvetter, K.C. An economic comparison of the wheat-fallow and wheat-sorghum-fallow cropping systems. *J. Prod. Agric.* **1993**, *6*, 261–266. [CrossRef]
10. Zhu, Z.X.; Stewart, B.A.; Fu, X.J. Double cropping wheat and corn in a subhumid region of China. *Field Crop Res.* **1994**, *36*, 175–183.
11. Ofori, F.; Stern, W.R. The combined effects of nitrogen fertilizer and density of the legume component on production efficiency in a maize/cowpea intercrop system. *Field Crop Res.* **1987**, *16*, 43–52. [CrossRef]
12. Wan, S.B. *Peanut Cultivation in China*; Shanghai Science and Technology Press: Shanghai, China, 2003. (In Chinese)
13. Nielsen, D.C.; Vigil, M.F.; Anderson, R.L.; Bowman, R.A.; Benjamin, J.G.; Halvorson, A.D. Cropping system influence on planting water content and yield of winter wheat. *Agron. J.* **2002**, *94*, 962–967. [CrossRef]
14. Ryan, J.; Pala, M.; Harris, H.; Masri, S.; Singh, M. Rainfed wheat-based rotations under Mediterranean-type climatic conditions: Crop sequences, N fertilization, and stubble grazing intensity in relation to cereal yields parameters. *J. Agric. Sci. Camb.* **2010**, *148*, 205–216. [CrossRef]
15. Grabriel, J.L.; Quemada, M. Replacing bare fallow with cover crops in a maize cropping system: Yield, N uptake and fertiliser fate. *Eur. J. Agron.* **2011**, *34*, 133–143. [CrossRef]

16. Wang, Z.K.; Jiang, H.L.; Shen, Y.Y. Forage production and soil water balance in oat and common vetch sole crops and intercrops cultivated in the summer-autumn fallow season on the Chinese Loess Plateau. *Eur. J. Agron.* **2020**, *115*, 126042. [CrossRef]
17. Nielsen, D.C.; Lyon, D.J.; Miceli-Garcia, J.J. Replacing fallow with forage triticale in a dryland wheat-corn-fallow rotation may increase profitability. *Field Crop Res.* **2017**, *203*, 227–237. [CrossRef]
18. Christiansen, S.; Ryan, J.; Singh, M.; Ates, S.; Bahhady, F.; Mohamed, K.; Youssef, O.; Loss, S. Potential legume alternatives to fallow and wheat monoculture for Mediterranean environments. *Crop Pasture Sci.* **2015**, *66*, 113–121. [CrossRef]
19. Yuan, Z.; Yan, D.H.; Yang, Z.Y.; Yin, J.; Breach, P.; Wang, D.Y. Impacts of climate change on winter wheat water requirement in Haihe River Basin. *Mitig. Adapt. Strateg. Glob. Chang.* **2016**, *21*, 677–697. [CrossRef]
20. Cao, G.L.; Han, D.M.; Song, X.F. Evaluating actual evapotranspiration and impacts of groundwater storage change in the North China Plain. *Hydrol. Process.* **2014**, *28*, 1797–1808. [CrossRef]
21. Zhang, Q.P.; Bell, L.W.; Shen, Y.Y.; Whish, J.P.M. Indices of forage nutritional yield and water use efficiency amongst spring-sown annual forage crops in north-west China. *Eur. J. Agron.* **2018**, *93*, 1–10. [CrossRef]
22. Zhu, X.M.; Li, Y.S.; Peng, X.L.; Zhang, S.G. Soils of the loess region in China. *Geoderma* **1983**, *29*, 237–255.
23. Zhang, Z.X.; Whish, J.P.M.; Bell, L.W.; Nan, Z.B. Forage production, quality and water-use-efficiency of four warm-season annual crops at three sowing times in the Loess Plateau region of China. *Eur. J. Agron.* **2017**, *84*, 84–94. [CrossRef]
24. Liu, C.M.; Zhang, X.Y.; Zhang, Y.Q. Determination of daily evaporation and evapotranspiration of winter wheat and maize by large-scale weighing lysimeter and micro-lysimeter. *Agric. For. Meteorol.* **2002**, *111*, 109–120. [CrossRef]
25. Huang, M.B.; Shao, M.A.; Zhang, L.; Li, Y.S. Water use efficiency and sustainability of different long-term crop rotation systems in the Loess Plateau of China. *Soil Tillage Res.* **2003**, *72*, 95–104. [CrossRef]
26. Neal, J.S.; Fulkerson, W.J.; Hacker, R.B. Differences in water use efficiency among annual forages used by the dairy industry under optimum and deficit irrigation. *Agric. Water Manag.* **2011**, *98*, 759–774. [CrossRef]
27. Wallace, J.S.; Batchelor, C.H. Managing water resources for crop production. *Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci.* **1997**, *352*, 937–947. [CrossRef]
28. Blanco-Canqui, H.; Shaver, T.M.; Lindquist, J.L.; Shapiro, C.A.; Elmore, R.W.; Francis, C.A.; Hergert, G.W. Cover crops and ecosystem services: Insights from studies in temperate soils. *Agron. J.* **2015**, *107*, 2449–2474. [CrossRef]
29. Aiken, R.M.; O Brien, D.M.; Olson, B.L.; Murray, L. Replacing fallow with continuous cropping reduces crop water productivity of semiarid wheat. *Agron. J.* **2013**, *105*, 199–207. [CrossRef]
30. Gan, Y.T.; Hamel, C.; O'Donovan, J.T.; Cutforth, H.; Zentner, R.P.; Campbell, C.A.; Niu, Y.N.; Poppy, L. Diversifying crop rotations with pulses enhances system productivity. *Sci. Rep.* **2015**, *5*, 14625. [CrossRef]
31. St. Luce, M.; Lemke, R.; Gan, Y.T.; McConkey, B.; May, W.; Campbell, C.; Zentner, R.; Wang, H.; Kroebel, R.; Fernandez, M.; et al. Diversifying cropping systems enhances productivity, stability, and nitrogen use efficiency. *Agron. J.* **2020**, *112*, 1–20. [CrossRef]
32. Nielsen, D.C.; Vigil, M.F. Intensifying a semi-arid dryland crop rotation by replacing fallow with pea. *Agric. Water Manag.* **2017**, *186*, 127–138. [CrossRef]
33. Zhang, Y.Q.; Kendy, E.; Yu, Q.; Liu, C.M.; Shen, Y.J.; Sun, H.Y. Effect of soil water deficit on evapotranspiration, crop yield, and water use efficiency in the North China Plain. *Agric. Water Manag.* **2004**, *64*, 107–122. [CrossRef]
34. Fang, Q.X.; Ma, L.; Green, T.R.; Yu, Q.; Wang, T.D.; Ahuja, L.R. Water resources and water use efficiency in the North China Plain: Current status and agronomic management options. *Agric. Water Manag.* **2010**, *97*, 1102–1116. [CrossRef]
35. Nielsen, D.C.; Lyon, D.J.; Hergert, G.W.; Higgins, R.K.; Calderón, F.J.; Vigil, M.F. Cover crop mixtures do not use water differently than single-species plantings. *Agron. J.* **2015**, *107*, 1025–1038. [CrossRef]
36. Norwood, C.A. Dryland winter wheat as affected by previous crops. *Agron. J.* **2000**, *92*, 121–127. [CrossRef]
37. Lv, L.H.; Yao, Y.R.; Zhang, L.H.; Dong, Z.Q.; Jia, X.L.; Liang, S.B.; Ji, J.J. Winter wheat grain yield and its components in the North China Plain: Irrigation management, cultivation, and climate. *Chil. J. Agric. Res.* **2013**, *73*, 233–242. [CrossRef]
38. Komarek, A.M.; Bell, L.W.; Whish, J.P.M.; Robertson, M.J.; Bellotti, W.D. Whole-farm economic, risk and resource-use trade-offs associated with integrating forages into crop-livestock systems in western China. *Agric. Syst.* **2015**, *133*, 63–72. [CrossRef]
39. Khan, M.A.H.; Zaman, M.S.; Hasan, M.K.; Khan, A.S.M.M.R. Increasing cropping intensity and productivity through boro T.aus-T.aman-mustard cropping pattern in Bangladesh. *SAARC J. Agric.* **2018**, *15*, 103–112. [CrossRef]
40. Deng, J.Q.; Zhang, Z.X.; Liang, Z.T.; Li, Z.; Yang, X.L.; Wang, Z.K.; Jeffrey, A.C.; Shen, Y.Y. Replacing summer fallow with annual forage improves crude protein productivity and water use efficiency of the summer fallow-winter wheat cropping system. *Agric. Water Manag.* **2020**, *230*, 10598. [CrossRef]
41. Li, L.; Yang, L.; Liao, Y.C.; Wen, X.X. Study on soil water effect of double cropping in the dryland of subhumid areas of the Loess Plateau. *Agric. Res. Arid. Areas* **2010**, *28*, 145–151. (In Chinese)
42. Tan, M.H.; Zheng, L.Q. Increase in economic efficiency of water use caused by crop structure adjustment in arid areas. *J. Environ. Manag.* **2019**, *230*, 386–391. [CrossRef]