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Optimum Water and Fertilizer Management for Better Growth and Resource Use Efficiency of Rapeseed in Rainy and Drought Seasons

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Abstract: Optimum water–fertilizer management in rainfed agriculture is an important factor in improving crop productivity and the ecological environment under fluctuating climate conditions, especially in Southwest China, where seasonal drought and waterlogging occur frequently. In order to investigate the effects of different cultivation technologies on growth and the water and fertilizer use efficiency of rapeseed (*Brassica napus* L.), a two-year field study was conducted in rainy (2016–2017) and drought (2017–2018) seasons which included three cultivation patterns: (1) conventional flat planting (FP); (2) straw mulching (SM); (3) ridge-furrow rainfall harvesting system (RF), and three fertilization patterns: (1) conventional fertilization (CF); (2) reduced slow-release fertilizer (SR); and (3) no fertilizer as a control treatment. The results indicated that the yield and its composition values were lower in the rainy year than in the seasonal dry year. The single water-saving technology had no significant effect on yield increase when seasonal drought occurred. The two technologies (SM + SR and RF + SR) improved the height, leaf SPAD value and dry matter of the rapeseed and adjusted the root–shoot ratio under two different climate conditions. In the rainy season, these technologies reduced the loss of nutrients, while in the seasonal drought year, it increased the soil moisture. The SM + SR and RF + SR increased the yield of rapeseed by 7.71% and 29.93% and enhanced oil content by 4.64% and 7.91%, respectively, compared with the local cultivation pattern. Meanwhile, these treatments decreased the total water consumption during whole growth stages and promoted water use efficiency by 14.84% and 28.71%, respectively. The combination of SM + SR and RF + SR also increased the accumulation of N, P, and K and significantly promoted the utilization efficiency of fertilizer. In the future, the adverse effects of environmental factors could be relieved, and the goal of cost savings and increasing efficiency could be achieved by adopting the optimal cultivation technologies in rapeseed production of Southwest China.

Keywords: climate condition; straw mulching; ridge-furrow mulching; slow-release fertilizer; water and fertilizer utilization; rapeseed (*Brassica napus* L.)

1. Introduction

Rapeseed is the second most important source of vegetable oil in the world and it occupies a pivotal position in the oil supply in China [1]. In the tremendous demand for edible oil, the Chinese government had paid great attention to the rapeseed industry development [2]. With mountainous rapeseed-planting areas, Southwest China faces great challenges which, under the background of global climate change, seasonal drought, and waterlogging, are often caused by uneven precipitation distribution. The natural condition of Southwest China is usually characterized by erratic rainfall, hilly gullies, and infertile soil [3]. In order to pursue high plant yield with a barren environment in Southwest China, excessive fertilization in common, which can cause serious pollution problems. Excessive accumulation of chemical fertilizer in the soil can lead to eutrophication and underground water pollution, threatening the food security [4,5]. As the biggest producer and consumer of synthetic N fertilizers in the world, China's agricultural use of organic matter resources is only 25%, while the use of inorganic fertilizers is 75% [6]. Moreover, the improper use of chemical fertilizers in the agricultural field has caused non-point source pollution which has greatly threatened people's health via the air, water, and food. It not only has polluted the soil with heavy metals but also deteriorated the quality of major lakes and ground water and increased the nitrogen concentrations in recent years [7,8]. Estuaries and coastal water near cities have been polluted and the annual frequency of the red tide has increased from 28 in 2000 to 68 in 2008 with a cumulative area of 13,738 km^2 [9,10]. For environmental security, Chinese Ministry of Agriculture (MOA) proposed a national strategy with the aim of zero growth of synthetic fertilizer application by using more organic fertilizer to replace chemical fertilizers in 2020.

Some researchers have shown that the integration of water and fertilizer is a viable way to balance the requirements of water and fertilizer in crop production and promote their efficiency. Actually, this technique is widely used in arid and semi-arid regions of the world for proper use of water and fertilizer [11–14]. Broad utilization of drip irrigation technologies in Israel has contributed to a 1600 percent increase in the value of production in the past sixty years [15]. Sprinkling and drip irrigation technology has also been tried in North and Northwest China by planting cotton, maize, potato, etc. [16–18]. But these technologies did not obtain enough environmental and economic effects as desired in Southwest China. However, Southwest China is characterized by hilly gullies and is not suitable for facility agriculture establishment and irrigation pipes construction are costly for farmers. Moreover, a lack of a rural labor force has become a new barrier in Southwest China's agricultural development which suggests that professional technologies should be promoted.

Considering all these problems, the integrative techniques of water and fertilizer application for improving crop quality and yield, water savings, and fertilizer have become imperative in rainfed Southwest China. With regard to fertilization, slow-release fertilizer (SR) has low-cost characteristics with high-efficiency and is eco-friendly compared to conventional fertilizer [19]. Previous studies have shown that nitrification and urease inhibitor in SR decreases the volatilization of NH_3 and N_2O, while enhanced nitrogen use efficiency and crop yield [20,21]. Slow-release fertilizer application reduced nutrient leaching and cut down the fertilization frequency and dosage which are helpful to lower the risk of environmental pollution [22]. Straw mulching (SM) and ridge-furrow rainfall harvesting systems (RF), as water-saving technologies, have extensively been applied in dryland agriculture in arid and semi-arid regions of China [23,24]. Straw mulching is not only useful to restrain soil evaporation but also to improve soil perviousness and soil retention of water and fertilizer. Through adjusting the temperature and moisture of soil, it can increase water and fertilizer use efficiency along with enhancement in yield [25]. Ridge Furrow (RF) as a mature technology was established over the last two decades in the Loess Plateau of China [26]. The ridges and furrows are used to collect and store rainwater. The mulching materials serve as the media to prevent soil water evaporation and moderate the thermal balance. By virtue of its multiple advantages of low cost and simple operation, the RF was easily adopted by Chinese smallholder farmers. Since the early 2000s, RF has been extensively used in maize production in northern China, owing to its high efficiency in rainwater collection, soil water conservation, and field productivity improvement [27,28].

So far, the research on cultivation techniques under different climates is rather small. Most trials focus only on the plant physiology phenomenon on the simulant drought or waterlogging conditions. There were also many experiments on fertilizer or water savings, a factor in crop cultivation, but studies rarely combined multiple technologies in one experiment [29–31]. In this study, we tried to introduce SM and RF integrating SR in Southwest China, with the aim to solve the problem of fertilizer and water savings in the rainfed agricultural region with different growing seasons (i.e., drought and rainy). At the same time, we made a comprehensive evaluation of the experiment on both economic and ecological aspects. Through the evaluation of the economic benefits and carbon footprint of the different treatments, we could make further improvements on water and fertilizer management. The primary objectives of this study were to select an optimum water–fertilizer management for rapeseed production in Southwest China. The technology not only would meet the requirements of high yield and environmental protection but would also be generally suitable for ordinary farmers in rainfed agricultural regions.

2. Materials and Methods

2.1. Study Area

The experiments were carried out at Jiangnan village, Yunyang county of Chongqing, China (latitude 30°55′ N, longitude 108°54′ E, and altitude 650.6 m), over two growing seasons in 2016–2017 and 2017–2018. The research site is characterized by typical hilly stereo climate of Southwest China with an annual rainfall of 900 mm and mean annual temperature of 18.7 °C. The physico-chemical properties of the soil (0–20 cm) prior to the start of experiment in 2016–2017 were: pH 7.5, soil organic carbon 9.29 g kg^{-1}, total soil nitrogen 0.90 g kg^{-1}, total soil phosphorus 0.34 g kg^{-1}, total soil potassium 21.70 g kg^{-1}, soil available N 72.40 mg kg^{-1}, soil available P 4.60 mg kg^{-1}, soil available K 94.00 mg kg^{-1}, and average bulk density 1.24 g cm^{-3}. While in 2017–2018, the soil had pH 7.8, soil organic carbon 9.79 g kg^{-1}, total soil N 0.83 g kg^{-1}, total soil P 0.34 g kg^{-1}, total soil K 23.50 g kg^{-1}, soil available N 66.40 mg kg^{-1}, soil available P 5.30 mg kg^{-1}, soil available K 89.00 mg kg^{-1}, and average bulk density 1.23 g cm^{-3}.

2.2. Experimentation

The research was conducted in 3 × 3 factorial layouts using a randomized complete design with three replicates. The seed of rapeseed (San Xiayou No. 5) was obtained from local government agriculture department and the slow-release fertilizer was taken from Yishizhuang Agriculture Science Co., Ltd. Hubei China. Its formulation comprised nitrification/urease inhibitor and humic acid. The three farming patterns were: (1) a ridge-furrow rainfall harvesting system (ridges-furrow mulched with transparent polyethylene film which was 0.006 mm thick and 0.8 m wide); (2) straw mulching (SM) cultivation (with chopped sorghum straw 3750 kg ha^{-1}); and (3) conventional flat planting (FP) were applied as given in (Figure 1).

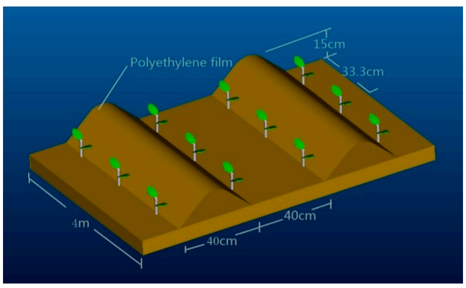


Figure 1. *Cont.*

Figure 1. The schematic diagram of ridge-furrow rainfall harvesting system. Photo captured by Jun Feng.

Three levels of fertilization (i.e., 100%, 80%, and 0%) combined with two types of fertilizer (i.e., conventional fertilizer (CF) and slow-release fertilizer (SR)) were used for each cultivation. The fertilizer was applied as shown in Table 1. The 100 + CF used the conventional fertilizer with 100% application amount, and 80 + SR was slow release fertilizer with 80% use level. For conventional fertilizer (CF), the urea was divided two times to use with equal amounts each time, 50% of it was before sowing with total P_2O_5 and K_2O together, and the remaining 50% was top-dressed in the bolting period. The slow-release fertilizer (SR) was applied completely once before sowing.

Before sowing, rotary tillage was implemented by the land preparation machine, and the ridge-furrow units in some plots were then manually built up. A total of 21 plots were established, and each plot was 4 m long by 4 m wide. Meanwhile, weeds were manually cleaned in all plots, and we applied herbicides to control it. Every plot had 120 holes for sowing at a 40 cm line spacing and 33.3 plant distance (every plot had 10 rows and 12 lines), and fertilizer was put in the hole. The seeds were sown after fertilizer was applied in the furrows by hole-sowing at a planting density of 240 plants plot^{-1} (every hole had two plants, equal to 10,005 plants ha^{-1}). In the first growing season, the crop was sown on 25 October 2016 and harvested on 14 May 2017; in the second growing season, the crop was sown on 20 October 2017 and harvested on 9 May 2018.

Table 1. Irrigation and fertilizer application with different treatments.

Cultivation	Amount of Fertilizer (%)	Type of Fertilizer	Rate of Fertilizer Application (kg hm^{-2})		
			N	P	K
SM	100	CF	225	63	72
	80	SR	180	50	58
	0	No fertilizer	0	0	0
RF	100	CF	225	63	72
	80	SR	180	50	58
	0	No fertilizer	0	0	0
FP	100	CF	225	63	72
	80	SR	180	50	58
	0	No fertilizer	0	0	0

0: no fertilizer, as a blank control; CF: conventional fertilizer (components with urea 46%, P_2O_5 12%, and K_2O 60%); SR: slow-release fertilizer (25-7-8, N 25%, P 7%, K 8%).

2.3. Data Recorded

2.3.1. Temperature and Rainfall

The season was rainy in 2016–2017, and there was a drought during the nutritional growth stage in 2017–2018. Rainfall and temperature during the two rapeseed seasons were shown in (Figure 2). The mean rainfall during the period of duration was 295.1 mm over the last 30 years at the research area. The period from the 2016–2017 was considered to have climate abnormities in that the precipitation (510.5 mm) was 173% of the long-term mean. Especially, from November 2016 to January 2017, the precipitation (136.8 mm) reached 203.3% of the long-term mean (67.3 mm), and the temperature was significantly higher than the mean level. But, it in the same period (52.7 mm) of 2017–2018, it was only 38.6% of the last grown season. In particular, the precipitation (2.3 mm) in December 2017, it was merely 16.01% of long-term mean (14.3 mm) which indicated it was in severe seasonal drought according to the criteria of the China Meteorological Administration. There was, however, a spurt of rains that happened in March 2018, where precipitation (82.6 mm) was 240.82% of the long-term mean (34.3 mm), and the temperature was also significantly higher than the mean level. This showed that there was an obviously maladjusted precipitation in these seasons, and both of these meteorological factors were not good for rapeseed growth.

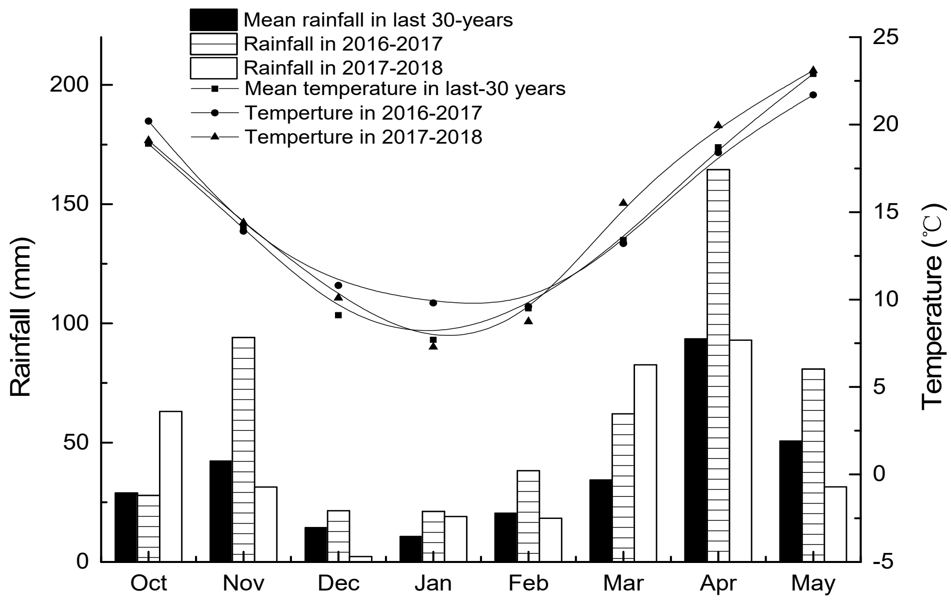


Figure 2. Monthly total rainfall and monthly mean temperature during the experimental seasons of 2016–2017 and 2017–2018 and the long-term mean (1981–2010) at the experimental site. The data were taken from the national meteorological scientific data sharing service platform in China.

2.3.2. Growth and Yield Measurement

The main physiological characters of rapeseed were determined at the seedling stage. Plant height was measured from the soil level to the upper most visible main stem node. SPAD is relative content chlorophyll (MINOLTA 502, Japan). Ten whole plant samples were obtained randomly in each plot. The plants, with roots, were removed carefully out of the soil via a hand spade and brought back to the lab with soil. After cleaning, all tissue samples were dried in an oven at 105 °C for 1 h and then at 60 °C to a constant weight to determine dry matter accumulation and to calculate the root-to-shoot ratio. The crop was harvested at the maturity stage and then the seed yield was recorded.

Twenty plants in each plot were sampled randomly to measure the yield components including the 1000 seed weight, pod number, and seed number per pod. Seed quality and main quality (i.e., oil content, glucosinolates, and erucic acid) were measured by a FOSS multifunctional near infrared analyzer (NIRS DS2500, Sweden)

2.3.3. Soil Water Storage and Water Use Efficiency

Total soil water storage (SWS, mm) at a 0–60 cm soil layer was calculated from soil gravimetric moisture content (GSW, %). At the main growth stages, such as sowing, seedling, bolting, flowering, and maturity, soil samples were collected at each 20 cm increment within a depth of 60 cm using a 0.08 m diameter hand auger by randomly selecting five points every plot in the center of two plants.

Soil samples were placed in aluminum specimen boxes to be oven dried and then the soil water content was calculated. Soil water storage was calculated as follows:

$$\mathrm{SWS(mm)} = \mathrm{GSW(\%)} \times \ \rho\mathrm{b}\left(\mathrm{g\ cm^{-3}}\right) \times \mathrm{SD(mm)} \tag{1}$$

where ρb is soil bulk density and SD refers to soil depth.

The Water Use efficiency (WUE) (kg hm^{-2} mm^{-1}) was calculated using the following formula:

$$\mathrm{WUE} = \mathrm{Y/ER} \tag{2}$$

where Y is yield (kg hm^{-2}), and ER (mm) is water evapotranspiration in the crop growing season. The study was carried out under rainfed conditions with no irrigation during the growth stages. Local rainfall during the experiment season did not cause drainage below 100 cm underground. The ER was calculated using the following formula:

$$\mathrm{ER(mm)} \ = \ \mathrm{P} \ + \ \Delta\mathrm{SWS(mm)} \tag{3}$$

where P (mm) was the total rainfall during the growing stage, and ΔSWS (mm) is the difference in soil water storage (0–60 cm) between the two growing stages.

2.3.4. Plant Nutrients Accumulation and Fertilizer Use Efficiency

The methods to determine the accumulation of N, P, and K in plants were the Kjeldahl method, Mo–Sb colorimetric method, and the flame photometer method, respectively. Fertilizer use efficiency was calculated as follows:

$$\begin{gathered}\text{N recovery efficiency (NRE, \%)} = \\ (\text{N uptake of treatment with N fertilizer applied} - \\ \text{N uptake of treatment with no N fertilizer applied})/ \\ \text{N application rate} \times 100\%\end{gathered} \tag{4}$$

$$\begin{gathered}\text{N agronomic efficiency}\left(\text{NAE}, \mathrm{kg \cdot kg^{-1}}\right) \\ = (\text{Seed yield of treatment with N fertilizer applied} \\ - \text{Seed yield of treatment with no N fertilizer applied}/\text{N application rate}\end{gathered} \tag{5}$$

$$\begin{gathered}\text{N physiological efficiency(NPE, \%)} \\ = (\text{Seed yield of treatment with N fertilizer applied} \\ - \text{Seed yield of treatment with no N fertilizer applied}) \\ /(\text{N uptake of treatment with N fertilizer applied} \\ - \text{N uptake of treatment with no N fertilizer applied}) \times 100\%\end{gathered} \tag{6}$$

The methods to determine P and K use efficiency were the same as N.

2.3.5. Carbon Footprint

The system boundary of this research was the greenhouse gas emission in the whole growth stages of rapeseed. The methods to estimate of greenhouse gas (GHG) field emissions and the carbon footprint (CFP) of rapeseed produce in this study were referred to the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006a) [32]. The emission factors and index were from the Chinese Reference Life Cycle Database (CLCD v0.7) and the Ecoinvent Database Version 2.2 (Ecoinvent 2.2) (Table 2). The carbon footprint of the rapeseed product was calculated as follows:

$$\mathrm{CF}_a = \sum_{i=1}^{n} (\partial m)_i + \mathrm{GHG}_{\mathrm{N_2O}} \tag{7}$$

where CF_a ($CO_2eq{\cdot}hm^{-1}$) is the carbon footprint per unit area in the rapeseed growth, *n* are the types of carbon sources in the production process, ∂ is the amount of carbon source used, and *m* is the index of carbon emission. GHG_{N2O} ($kg{\cdot}hm^{-2}$) was calculated using the following formula:

$$GHG_{N_2O} = F_N + \delta_N \times \frac{44}{28} \times 298 \quad (8)$$

where GHG_{N2O} is the farmland N_2O direct emission amount, F_N is the nitrogen amount, δ_N is N_2O direct emission index, 44/28 is the ratio of N_2O and N_2 the molecular weight, and 298 is the global warming trend by the scaling of 100 years that N_2O converts to CO_2.

$$CF_y = CF/Y \quad (9)$$

where CF_y ($kgCO_2eq{\cdot}kg^{-1}$) is carbon footprint per unit yield, and Y is the yield (kg hm^{-2}).

Table 2. Greenhouse gases emissions' coefficients of different agricultural materials for rapeseed production.

Item	Index of Carbon Emissions	Source
N	1.53 $kgCO_2eq{\cdot}kg^{-1}$	CLCD v0.7
P_2O_5	1.63 $kgCO_2eq{\cdot}kg^{-1}$	IPCC
K_2O	0.65 $kgCO_2eq{\cdot}kg^{-1}$	CLCD v0.7
Farmland N_2O	0.01 $kgN{\cdot}kg^{-1}$	CLCD v0.7
Plastic film	22.72 $kgCO_2eq{\cdot}kg^{-1}$	CLCD v0.7
Herbicide	10.15 $kgCO_2eq{\cdot}kg^{-1}$	Ecoinvent v2.2
Rapeseed	0.83 $kgCO_2eq{\cdot}kg^{-1}$	LIU et al. [32]
Labor	0.86 $kgCO_2eq{\cdot}d^{-1}{\cdot}person^{-1}$	Gan et al. [32]

2.3.6. Statistical Analysis

Data were statistically analyzed by the two-way factorial analysis of variance (ANOVA) technique using the SPSS17.0 software program (IBM, New York, NY, USA) separately for each growing season, and comparisons among treatments were performed using Duncan's multiple range test at the 0.05 probability level. Graphics were prepared using Origin 9.0 software program (OriginLab, Massachusetts, MA, USA).

3. Results

3.1. Comparisons of Agronomic Traits at the Seedling Stage in Different Climates

Plant height, SPAD, dry matter, and the root/shoot ratio at the seeding stage were significantly affected by cultivation ($\rho < 0.05$) and fertilization treatments ($\rho < 0.01$) in the wet season of 2016–2017; all the traits were significantly affected by both treatments and the interaction ($\rho < 0.01$) during the drought season in 2017–2018 (Figure 3).

In general, compared with local cultivation (FP + CF), SM + SR and RF + SR treatments increased the average plant height, SPAD, and dry matter than traditional cultivation (FP + CF) in the two experimental seasons. The large amount of rainfall in the seedling stage had more serious impact on the growth of rapeseed than seasonal drought. The root shoot ratio in 2017–2018 at the seedling stage increased by 83.55% on average than in 2016–2017, and the dry matter in the rainy season was on average 32.13% lower than that in the drought season. These finding indicates that the precipitation had more influence on root development than on plant growth. The negative environmental effects could be alleviated by water and fertilizer savings technology.

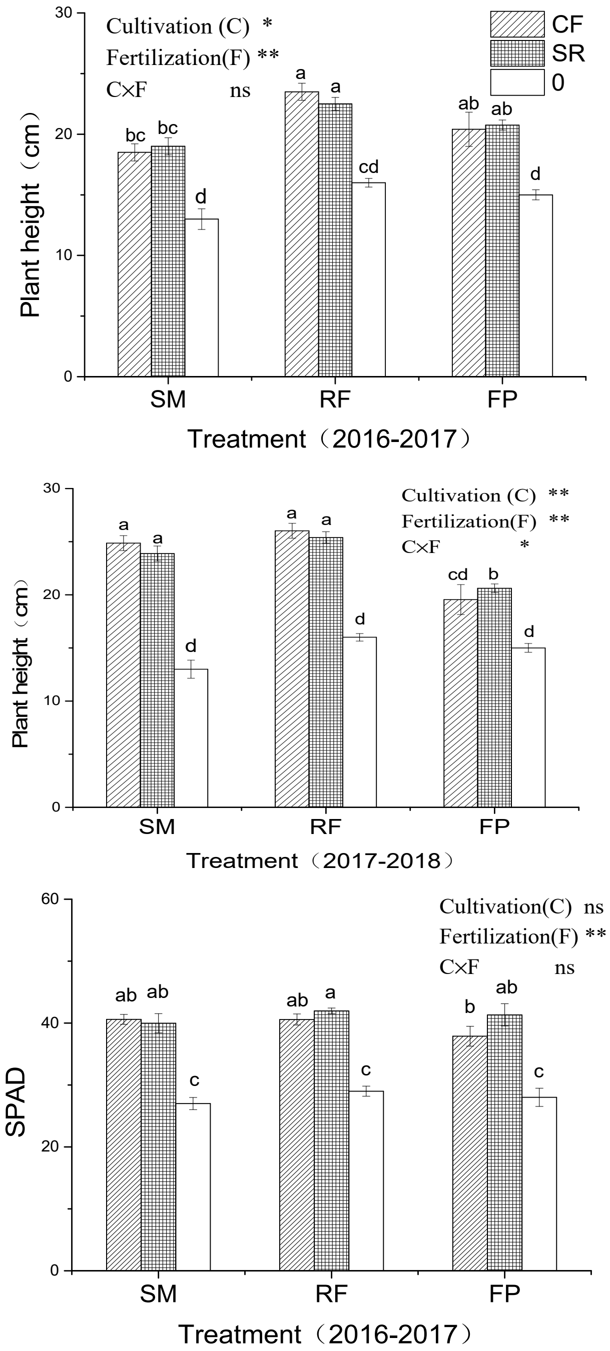
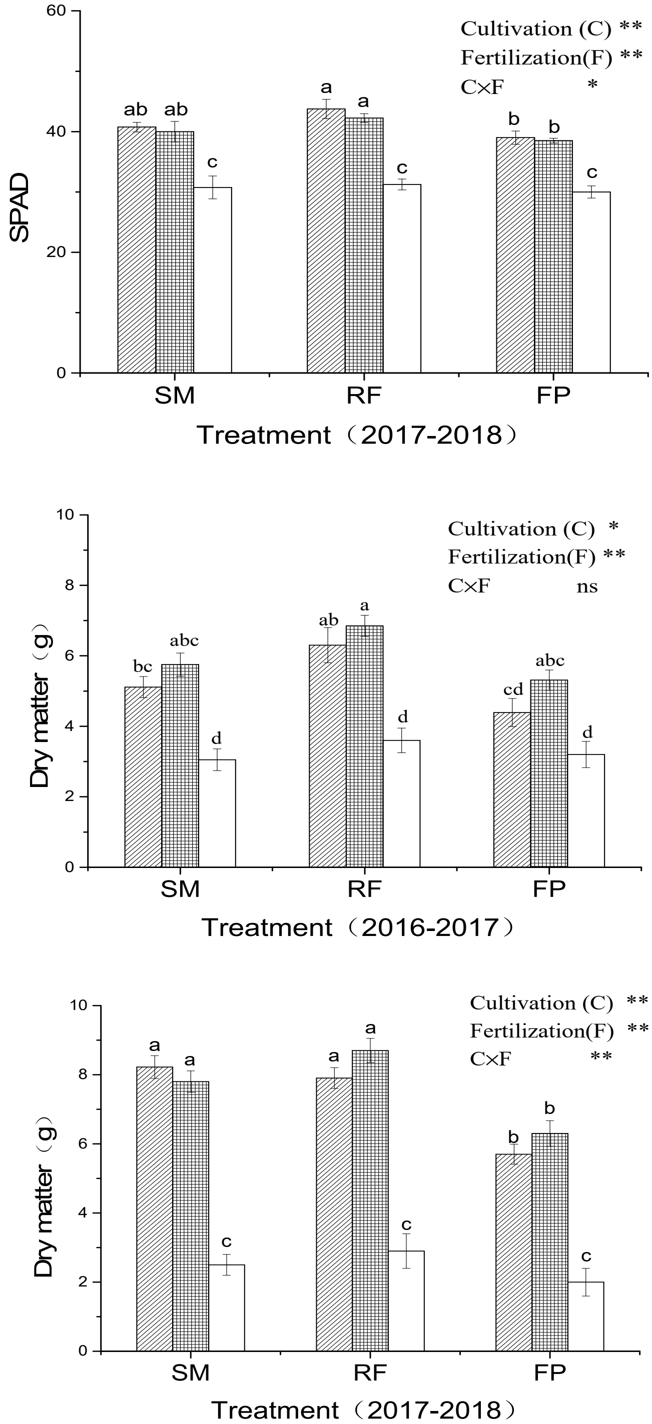


Figure 3. *Cont.*



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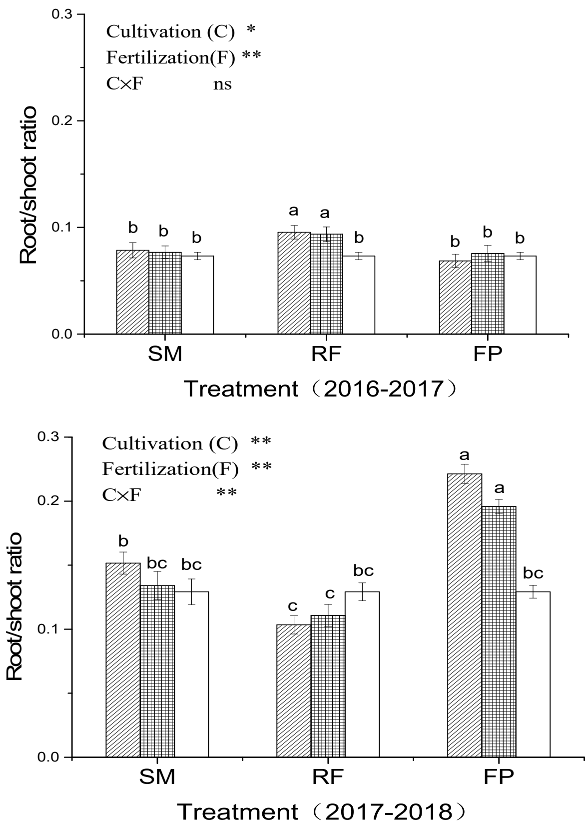

Figure 3. Rapeseed agronomic traits at the seedling stage as affected by different cultivations (SM, alternative straw mulching; RF, alternative ridge-furrow rainfall harvesting system; and FP, alternative flat plant) and fertilizations (CF, alternative conventional fertilizer; SR alternative slow-release fertilizer; and no fertilizer) in two experimental seasons in 2016–2017 and 2017–2018. Different lowercase alphabetical letters indicate the significant difference among treatments at 5% probability level. Values followed by the same letters in each treatment are not significantly different at $\rho < 0.05$ level. * and ** are significant at the $\rho < 0.05$ and 0.01 level, respectively; ns, not significant.

3.2. Seed Yield and Quality

Yield-related components were significantly affected by fertilization treatments ($\rho < 0.01$), while yield and pod number were significantly affected by cultivation treatments ($\rho < 0.01$) and the interaction in both seasons (Table 2). The treatments of SM + SR and RF + SR could keep the yield stability and significantly changed the values of yield components, particularly for the effective pod number in abnormal climate. In both growth seasons, compared to local cultivation, SM + SR and RF + SR increased the average seed yield by 14.79% and 21.57%, respectively. In 2016–2017, under the same cultivation, SR significantly promoted seed yield by 12.48% compared to CF. Under the same rate of fertilizer, RF and SM increased yield significantly by 22.06% compared to FP. In 2017–2018, the differences in yield between SR and CF were not significant; however, SM and RF also significantly promoted the yield compared to FP.

The quality was significantly affected by fertilization treatments ($\rho < 0.01$). Glucosinolate and erucic acid content in fertilizer treatments were significantly higher than with no fertilizer. The differences between CF and SR were not appreciable. The oil content showed more sensitivity to fertilizer and climate. It was on average higher by 5.80% in 2018–2017 than that in 2016–2017. Both SM + SR and RF + SR were significantly higher by 5.95% and 8.35% than that of habit cultivation in the two growth seasons, respectively (Table 3). This indicates that SM + SR and RF + SR can keep the production and quality stable in different climates.

Table 3. Yield and its quality as affected by different cultivations (SM, alternative straw mulching; RF, alternative ridge-furrow rainfall harvesting system; and FP, alternative flat plant) and fertilizations (CF, alternative conventional fertilizer; SR alternative slow-release fertilizer; and no fertilizer) in two experimental seasons in 2016–2017 and 2017–2018.

Year	Cultivation	Fertilization	Pod Number (Number/Plant)	Seeds Number (Number/Pod)	1000 Grain Weight (g)	Yield ($kg \cdot hm^{-2}$)	Glucosinolates/($\mu mol \cdot g^{-1}$)	Erucic Acid/(%)	Oil Content/(%)
2016–2017	SM	CF	225.5c	22.3a	3.42a	1847.25d	34.87a	0.95a	41.68b
		SR	240.7b	22.5a	3.48a	2078.75c	33.19ab	0.98a	42.46a
		0	86.4f	18.6b	3.15b	450.34g	21.15c	0.91b	35.32e
	RF	CF	237.3b	21.2a	3.57a	2144.54b	34.55a	1.01a	41.93b
		SR	252.5a	22.6a	3.55a	2290.25a	34.69a	1.03a	42.98a
		0	85.6f	19.5b	3.17b	452.50g	23.25c	0.92b	36.78d
	FP	CF	202.1e	21.1a	3.38a	1687.65f	33.06b	1.04a	39.83c
		SR	217.5d	21.9a	3.40a	1804.75e	33.92ab	0.96a	42.69a
		0	80.2f	18.7b	3.14b	445.73g	22.05c	0.91b	34.76e
ANOVA									
Cultivation (C)			**	Ns	ns	**	ns	ns	Ns
Fertilization (F)			**	**	**	**	**	*	**
C × F			**	Ns	ns	**	ns	ns	Ns
2017–2018	SM	CF	277.4b	24.3a	3.67a	2593.25a	34.01ab	1.57a	45.35b
		SR	275.9b	24.1a	3.49a	2579.43a	33.75b	1.53a	47.14a
		0	103.3d	21.9b	2.64b	452.43c	24.15c	1.21b	36.52d
	RF	CF	283.5a	25.2a	3.77a	2592.55a	35.83a	1.63a	44.54b
		SR	285.7a	24.5a	3.72a	2603.23a	33.02b	1.56a	47.05a
		0	104.5d	21.5b	2.67b	455.82c	24.25c	1.22b	36.77d
	FP	CF	262.3c	23.8a	3.49a	2424.62b	35.41a	1.51a	43.47c
		SR	259.1c	23.2a	3.37a	2390.03b	35.98a	1.46a	43.84c
		0	102.2d	21.8c	2.53b	447.55c	24.05c	1.20b	35.89d
ANOVA									
Cultivation (C)			**	Ns	ns	**	*	ns	Ns
Fertilization (F)			**	**	**	**	**	**	**
C × F			**	Ns	ns	**	ns	ns	Ns

Different lowercase alphabetical letters indicate the significant difference among treatments at 5% probability level. Values followed by the same letters in each treatment are not significantly different at the $\rho < 0.05$ level. * and ** are significant at the $\rho < 0.05$ and 0.01 level, respectively; ns, not significant.

3.3. Soil Water Use Efficiency (WUE)

Water consumption was significantly (ρ < 0.01) affected by cultivation and fertilization at early growth stages (sowing to flowering) but not a late stages (flowering–maturity) (Table 4). Due to the different precipitation seasons with different rapeseed transpirations and soil evaporations, the total water consumption decreased by 31.43% more in 2017–2018 than in 2016–2017. The period from sowing–bolting was the vegetative growth, and the main style of water consumption was soil evaporation. It led to no significant difference among the treatments with different fertilizer levels (except RF). The SM and RF technologies could maintain soil moisture. As a result, on the same fertilizer level, the water consumption by SM and RF were significantly lower than the FP treatment (ρ < 0.05). When in the reproductive stage, crop transpiration turned to the main style of water consumption. There was no significant difference in water consumption among the different cultivations, while the WUEs were significantly (ρ < 0.01) affected by cultivation and fertilization. The WUE of the SM + SR and RF + SR treatments were significantly higher than the local cultivation by 24% and 40%, respectively, in 2016–2017 and 8% and 15%, respectively, in 2017–2018.

Table 4. Plant water consumption (0–60 cm soil layer) and Water Use Efficiency (WUE)as affected by different cultivations (SM, alternative straw mulching; RF, alternative ridge-furrow rainfall harvesting system; and FP, alternative flat plant) and fertilizations (CF, alternative conventional fertilizer; SR alternative slow-release fertilizer; and no fertilizer) in two experimental seasons in 2016–2017 and 2017–2018. Different lowercase alphabetical letters indicate the significant difference among treatments at 5% probability level. Values followed by the same letters in each treatment are not significantly different at the ρ < 0.05 level. * and ** are significant at the ρ < 0.05 and 0.01 level, respectively; ns, not significant.

Year	Cultivation	Fertilization	Consumption (mm)					WUE (kg $mm^{-1} \cdot hm^{-2}$)
			Sowing–Seedling	Seedling–Bolting	Bolting–Flowering	Flowering–Maturity	Total Consumption	
2016–2017	SM	CF	144.12 [b]	61.43b	105.55ab	170.12a	481.21b	3.83d
		SR	143.49b	60.83b	106.21a	173.24a	483.77b	4.29c
		0	138.34c	55.32e	92.32c	165.67a	451.65e	0.99g
	RF	CF	142.28b	60.26c	103.28ab	175.46a	481.28b	4.45b
		SR	140.28b	58.95d	101.63b	170.74a	471.61c	4.85a
		0	138.67c	55.48e	90.17c	163.46a	447.78f	1.01g
	FP	CF	158.74a	61.82a	108.51b	168.71a	497.78a	3.47f
		SR	152.46a	62.41a	108.63b	165.28a	488.78a	3.73e
		0	151.21c	55.24e	94.33dc	162.12a	462.91d	0.96g
ANOVA								
Cultivation (C)			**	**	**	ns	**	**
Fertilization (F)			**	**	**	ns	**	**
C × F			**	**	ns	ns	**	**
2017–2018	SM	CF	150.69b	63.49b	96.07a	27.27ab	337.52c	7.68d
		SR	149.54b	63.13b	94.01ab	26.24abc	332.92d	7.74c
		0	157.56e	55.21d	83.87c	25.12bc	321.76f	1.40g
	RF	CF	148.16c	61.25bc	92.56b	24.76c	326.73e	7.93b
		SR	142.42d	59.01c	90.58b	24.84c	316.85g	8.21a
		0	157.21e	53.32d	80.79c	25.58abc	316.91g	1.43g
	FP	CF	155.61a	68.63a	97.67a	27.71a	349.62a	7.16e
		SR	155.48a	67.96a	98.19a	26.28abc	347.91b	7.12f
		0	157.98e	54.78d	81.34	21.03c	315.13h	1.42g
ANOVA								
Cultivation (C)			**	**	**	ns	**	**
Fertilization (F)			**	**	**	ns	**	**
C × F			**	**	ns	ns	**	**

3.4. Fertilizer Use Efficiency

Fertilizer use efficiency was significantly affected by both fertilization and cultivation treatments (ρ < 0.01) (Table 5). In general, because of leaching, fertilizer use efficiency in 2016–2017 (rainy season) was lower than that in 2017–2018 (drought season). During rainy conditions, compared to habit cultivation (FP + CF), signal water-saving technology (SM + CF and RF + CF) promoted N recovery efficiency (NRE), N agronomic efficiency (NAE), and N physiological efficiency (NPE) by 15.11%, 32.85%, and 11.21%, respectively. Fertilizer-saving technology (FP + SR) promoted that by 23.78%, 40.63%, and 11.35%, respectively. While water and fertilizer technology (SM + SR and RF + SR) could increase that by 53.57%, 71.12%, and 24.37%. The changing trends of P and K were similar to N. In drought conditions, the performances of SM + SR and RF + SR were also better than signal or habit cultivation. When precipitation was very little, water-saving technology showed more advantages than signal fertilizer-saving technology (FP + SR), while SM + SR and RF + SR could overcome the water limits and strengthen plant nutrient uptake. This indicates that optimized managements could promote rapeseed fertilizer use efficiency over the conventional style.

Table 5. Fertilizer use efficiency (NRE, N recovery efficiency; NAE, N agronomic efficiency; NPE, N physiological efficiency; For P and K, it's similar as N) as affected by different cultivations (SM, alternative straw mulching; RF, alternative ridge-furrow rainfall harvesting system; and FP, alternative flat plant) and fertilizations (CF, alternative conventional fertilizer; SR alternative slow-release fertilizer; and no fertilizer) in two experimental seasons in 2016–2017 and 2017–2018. Different lowercase alphabetical letters indicate the significant difference among treatments at 5% probability level. Values followed by the same letters in each treatment are not significantly different at the ρ < 0.05 level. * and ** are significant at the ρ < 0.05 and 0.01 level, respectively; ns, not significant.

Year	Cultivation	Fertilization	NRE (%)	NAE (kg·kg^{-1})	NPE (kg·kg^{-1})	PRE (%)	PAE (kg·kg^{-1})	PPE (kg·kg^{-1})	KRE (%)	KAE (kg·kg^{-1})	KPE (kg·kg^{-1})
2016–2017	SM	CF	34.51e	4.87e	15.34e	54.51d	17.40e	31.93f	41.64e	15.23e	36.59e
		SR	44.68b	7.38b	18.07c	55.45c	26.34b	47.51b	61.62b	23.06b	37.42c
	RF	CF	35.40d	6.19c	18.76b	57.38b	22.12c	38.54c	50.99c	19.36c	37.98d
		SR	48.06a	8.56a	19.61a	58.82a	30.54a	51.92a	69.39a	26.73a	38.52a
	FP	CF	27.59f	4.16f	15.33e	40.98f	14.87f	36.28e	33.89f	13.01f	36.26f
		SR	38.15c	5.85d	17.07d	42.32e	20.91d	37.41d	48.08d	18.30d	38.07b
ANOVA											
Cultivation (C)								**			
Fertilization (F)								**			
C × F								**			
2016–2017	SM	CF	39.82c	6.78c	17.01d	55.14d	24.17c	45.49d	55.05d	21.16c	38.45c
		SR	46.15b	8.38b	18.18a	60.40b	29.93b	49.56a	65.90a	26.20b	39.76b
	RF	CF	39.38c	6.76c	17.18c	55.37c	24.16c	43.64e	55.59c	21.15c	38.04d
		SR	49.56a	8.54a	17.96a	62.89a	30.49a	48.49b	65.04b	26.69a	41.04a
	FP	CF	38.67d	6.37d	17.87b	48.06f	22.77d	47.38c	52.61e	19.93d	38.55c
		SR	37.42e	6.26e	16.75e	51.70e	22.37e	40.91f	52.56e	19.59e	37.27e
ANOVA											
Cultivation (C)								**			
Fertilization (F)								**			
C × F								**			

3.5. Economic Benefits

In this study, we also conducted an econometric analysis on the output-to-input ratio regarding different treatments (Table 6). According to the local labor price level, SM + SR and RF + SR groups had more labor input on mulching work but less on topdressing. Thus, the total labor input was roughly equal to habit cultivation (FP + CF). In the two growth seasons, an extra input (84.8 US$ ha^{-1}) of commercial plastic film was involved in the RF groups. As a result, the total inputs were 113.23 and 28.43 US$ ha^{-1} higher in the RF and SM groups than that of habit cultivation in the two growth seasons, respectively. Regarding the output in 2016–2017 (rainy season), the highest value was found in RF and the lowest one was habit cultivation. Consequently, the highest net economic income of RF + SR was 327.92 US$ ha^{-1} than FP + CF. For the output in 2017–2018 (drought season), the difference in economic benefit among treatments was not statistically significant. The SM treatment obtained the greatest net income, up to approximately 1355 US$ ha^{-1}.

Table 6. Economic benefits as affected by different cultivations (SM, alternative straw mulching; RF, alternative ridge-furrow rainfall harvesting system; and FP, alternative flat plant) and fertilizations (CF, alternative conventional fertilizer; SR alternative slow-release fertilizer; and no fertilizer) in two experimental seasons in 2016–2017 and 2017–2018.

Year	Tillage Pattern	Fertilization	Input Values of Consumable Items (US$·ha^{-1})					Output Values of Consumable Items (US$·ha^{-1})	Net Income (US$·ha^{-1})
			Seed	Fertilizer	Labor	Plastic Film	Herbicide		
2016–2017	SM	CF	16.09	220.05	249.90	0.00	28.60	1330.02	815.38
		SR	16.09	241.20	214.20	0.00	28.60	1496.70	996.61
	RF	CF	16.09	220.05	249.90	84.80	28.60	1544.07	944.63
		SR	16.09	241.20	214.20	84.80	28.60	1648.98	1064.09
	FP	CF	16.09	220.05	214.20	0.00	28.60	1215.11	736.17
		SR	16.09	241.20	178.50	0.00	28.60	1299.42	835.03
2017–2018	SM	CF	16.09	220.05	249.90	0.00	28.60	1867.14	1352.50
		SR	16.09	241.20	214.20	0.00	28.60	1857.19	1357.10
	RF	CF	16.09	220.05	249.90	84.80	28.60	1866.64	1267.20
		SR	16.09	241.20	214.20	84.80	28.60	1874.33	1289.44
	FP	CF	16.09	220.05	214.20	0.00	28.60	1745.73	1266.79
		SR	16.09	241.20	178.50	0.00	28.60	1720.82	1256.43

Price per unit for rapeseed: 0.72 US$ kg^{-1}.

3.6. Carbon Footprint

In order to evaluate the ecological effect of the experiment, we calculated the carbon footprint of different treatments (Table 7). The results showed that fertilizer, labor, and N_2O emission were the main carbon sources for rapeseed production. They accounted for more than 90% of the total carbon footprint. The amount of nitrogen fertilizer played a pivotal role for farmland N_2O emission and total carbon footprint per unit area. Because of this, the carbon footprint per unit area (CF_a) was 18.68% on average lower for the SR treatment than that of the CF during the two growth seasons. As a result, the carbon footprint per unit yield (CF_y) were also 25.09% and 18.41% on average lower for the SR treatment than that of habit cultivation in the two growth seasons, respectively. This also shows that CF_y was 22.78% on average lower in 2017–2018 (drought season) than in 2016–2017 (rainy season). This was caused by the yield fluctuation in different climates.

Table 7. Composition of carbon footprint of rapeseed production as affected by different cultivations (SM, alternative straw mulching; RF, alternative ridge-furrow rainfall harvesting system and FP, alternative flat plant) and fertilizations (CF, alternative conventional fertilizer; SR alternative slow-release fertilizer and no fertilizer) in two experimental seasons in 2016–2017 and 2017–2018.

Year	Tillage Pattern	Fertilization	Farm Input (kg CO_{2eq}·hm^{-2})					Farmland N_2O	Carbon Footprint Per Unit Area (CF_a)	Carbon Footprint Per Unit Yield (CF_y)
			Rapeseed	Fertilizer	Labor	Herbicide	Plastic Film			
2016–2017	SM	CF	3.11	493.74	94.60	1.02	0	1053.00	1645.47	0.89
		SR	3.11	395.00	86.00	1.02	0	842.40	1327.53	0.64
	RF	CF	3.11	493.74	94.60	1.02	181.76	1053.00	1827.23	0.85
		SR	3.11	395.00	86.00	1.02	181.76	842.40	1509.29	0.66
	FP	CF	3.11	493.74	86.00	1.02	0	1053.00	1636.87	0.97
		SR	3.11	395.00	77.40	1.02	0	842.40	1318.93	0.73
2017–2018	SM	CF	3.11	493.74	94.60	1.02	0	1053.00	1645.47	0.63
		SR	3.11	395.00	86.00	1.02	0	842.40	1327.53	0.51
	RF	CF	3.11	493.74	94.60	1.02	181.76	1053.00	1827.23	0.70
		SR	3.11	395.00	86.00	1.02	181.76	842.40	1509.29	0.58
	FP	CF	3.11	493.74	86.00	1.02	0	1053.00	1636.87	0.68
		SR	3.11	395.00	77.40	1.02	0	842.40	1318.93	0.55

4. Discussion

Improving rainwater resource use efficiency and crop yield has always been a focus in the southwest of China. Ridge-furrow mulching (RF) and straw mulching (SM) as effective water-saving measures are widespread to an extent. Some studies [21,28,33] show that the regulatory mechanisms of RF and SM are attributable to increasing crop yield due to the accelerated plant growth and, ultimately, leading to reproductive success. At the same time, it promotes water availability at critical stages of crop water demand and increases leaf area and biomass. Slow-release fertilizer (SR), as a new type of fertilizer, began to evolve in a promising direction, offering an excellent means to improve management of fertilizer application and by this reducing significantly environmental threats while maintaining high crop yields [31]. We tried to introduce RF and SM in combination with a reduced rate of SR, integrating both water-saving and fertilizer-saving technologies applied in a field under two different climates.

Some studies show that the interannual fluctuation of rapeseed yield is volatile in China, and that meteorological factors are the main cause of this phenomenon by more than 70% [32]. Seasonal drought and waterlogging caused by irregular rainfall are the main weather problems which usually happen in the rapeseed seedling stage. This prejudicial effect always goes through the entire rapeseed growth period. For the drought, previous studies have shown that RF and SM are effective in improving soil water in drought condition [34]. But for wet conditions, research on water-saving technology application is less, and comparative studies under different precipitation conditions are even fewer. Some research shows that rational fertilizing can relieve the damage to plants caused by excessive soil moisture [35], because it accelerates the transition of dry matter accumulation in vegetative organs during wet conditions and adds fertilizer amounts that can satisfy the crop growth period's nutritional requirements. Our study comparing the rapeseed seedling traits discovered that SM + SR and RF + SR can on average promote plant height, SPAD, and dry matter by 2.33%, 5.82%, and 36.67%, respectively, in the rainy season during 2016–2017. The SR significantly increased WUE in many plants [36]. We also observed that compared with local cultivation that both SM and RF treatments increased WUE by 18.63% and 2.53%, respectively, in the two growth seasons. This meant that the integrated technologies (SM + SR and RF + SR) were better able to handle the diverse growing conditions.

Some studies have shown that the advantages of water-saving technologies, such as SM and RF, may be restricted. Especially for RF, some experiments have pointed out that the crop yield performance decreased accompanying an increasing percentage of precipitation during the rainy season [37]. Our data showed similar results in that the rapeseed yield in the rainy season in 2016–2017 was 18.72% lower than during the drought in 2017–2018. But we did need not to pay attention to that in our study, as RF technology also increased the rapeseed yield during the rainy season in 2016–2017. If the effect of increasing yield is less than the loss caused by the area reduction in the rainy season, the yield should be decreased. In our experiment design, the size of the furrow-ridge in the RF treatment was kept the same with the line spacing in the CF. The plant area did not decrease compared with the CF, and the precipitation did not cause serious waterlogging problems; thus, RF was also better than CF. Water-saving technologies, such as RF and SM, can promote rapeseed population numbers and yield; for RF, this may be explained by the fact that polyethylene film mulching helps increase soil temperature and collect rainwater. For SM, straw covering can decrease the soil temperature fluctuation and suppress loss through evaporation. All these measures are favorable for the development of a source-sink structure, which then increases the rapeseed economic yield. Our study combined the SR technology with RF and SM which reduced the loss of fertilizer in rainy conditions and strengthened the benefits of integrated technologies.

Compared with developed countries, the research on fertilizer saving technologies in China usually focuses on a single technique and is less concerned about integrated technology. The result is that many ordinary farmers cannot correctly select the optimal crop cultivation pattern and are less motivated to plant. Rational fertilizing is environmentally friendly, and both RF/SM technology has functions to promote soil preservation [38]. Because of these reasons, integrated technologies (SM + SR and RF + SR) with less fertilizer still increased the production latent capacity. We also discovered that a single fertilizer saving technology (FP + SR) was better than local cultivation (FP + CF) during the 2016–2017 season, but its advantages were limited in the drought season during 2017–2018. This may be because the SR needed more water to release its potential [38]. This means that the integrated technology (SM + SR and RF + SR) performs better than the use of a single technology in adverse environments.

Through evaluating the social and ecological effects of different treatments, we found an interesting phenomenon. Better economic efficiency did not mean better ecological benefit. Carbon efficiency (carbon footprint per unit yield) change was usually determined by the crop yield. A high yield always meant high carbon efficiency. Crop yield had a close relationship with climate. Both rainy and drought weather were not good for the yield. The climate were greatly affected by greenhouse gas emissions. The most abnormal climate was led by the greenhouse effect. So it was an ecological cycle. If we always pursued economic benefit only—the overuse of nitrogen fertilizer for high yield—it would ultimately lead to environment deterioration, and we would not obtain a high yield because of extreme climates. This shows the great significance of decreasing fertilizer use in the agricultural industry.

As aforementioned, due to the multiple restrictions, such as engineering investment, terrain conditions, and insufficient socioeconomic capability, the extension area and yield-increasing contribution of fertigation technologies are largely limited in Southwest China. Under the extreme changes induced by the global climate, drought and waterlogging will become threats to agriculture development in Southwest China. The technologies combining water and fertilizer savings (SM + SR and RF + SR) tested in this study not only overcame the obstacle of rainwater storage within the growing season, they also had the advantages of simple operation, low cost, and efficient output, and they can be widely utilized by local farmers. Our findings for water and fertilizer management strategies shows large potential for rapeseed production in the Southwest region of China. Based on this study, we could try to integrate more technologies, such as pest control, and extend the slow-release method's application. We hope to establish a perfect cultivation system in the future. To sum up, we exerted an important farming application of value for the local farming system and farmers in Southwest China.

5. Conclusions

The introduced integrated technologies (SM + SR and RF + SR) of optimum water–fertilizer levels significantly increased rapeseed yield and water and fertilizer use efficiency compared with conventional planting patterns. The reasons behind these differences can be assigned to the fact that improved soil moisture and nutrition conditions accelerated crop vegetative development, ultimately leading to the optimized reproduction distribution. This study also identified the optimum combinations between tillage and fertilization patterns. Both of the application of straw mulching and ridge-furrow mulching with slow release fertilizer (SM + SR and RF + SR) performed better than local conventional planting in wet and drought seasons. In conclusion, the introduction of this attempt could serve as a promising beneficial practice to improve rainfed farming areas, rapeseed productivity, and hence farmers' livelihoods in Southwest China.

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References

1. Fu, D.H.; Jiang, L.Y.; Mason, A.S.; Xiao, M.L.; Zhu, L.R.; Li, L.Z.; Huang, C.H.; Zhou, Q.H.; Shen, C.J. Research progress and strategies for multifunctional rapeseed: A case study of China. *J. Integr. Agric.* **2016**, *15*, 1673–1684. [CrossRef]
2. Qiong, H.; Wei, H.; Yan, Y.; Xue, K.; Han, Z.W. Rapeseed research and production in China. *Crop. Sci.* **2017**, *5*, 127–135.
3. Intergovernmental Panel on Climate Change. Climate change 2014: Impacts, adaptation, and vulnerability, Part B: Regional aspects. In *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014.
4. Deng, O.P.; Zhang, S.R.; Deng, L.J.; Zhang, C.L.; Fei, J.B. Wet nitrogen deposition across the urban-intensive agricultural–rural transect of a small urban area in southwest china. *Environ. Sci. Pollut. Res. Int.* **2018**, *25*, 7866–7874. [CrossRef]
5. Omar, A.; Saddam, H.; Muhammad, R.; Muhammad, R.; Guo, L. Increasing water productivity, nitrogen economy, and grain yield of rice by water saving irrigation and fertilizer-n management. *Environ. Sci. Pollut. Res. Int.* **2018**, *25*, 1–15.
6. Gao, S.; Xu, P.; Zhou, F.; Yang, H.; Zheng, C.; Cao, W. Quantifying nitrogen leaching response to fertilizer additions in china's cropland. *Environ. Pollut.* **2016**, *211*, 241–251. [CrossRef] [PubMed]
7. Fang, S.Q.; Yang, Y.F.; Qiang, Y.D.; Wang, G.X. Distribution and environmental risk assessment of fertilizer application on farmland in the water source of the middle route of the south-to-northwater transfer project. *J. Agroenviron. Sci.* **2018**, *1*, 15–18.
8. Li, H.; Huang, M.S.; Ma, M.H.; Wei, J.B.; Seema, C. Evaluating sources and processing of nonpoint source nitrate in a small suburban watershed in china. *J. Hydrol.* **2017**, *559*, 661–668.
9. Leo, N.; Zhang, W.H.; Founemakan, S. Fertilizer application and Non-Point Source Pollution problems between Uganda and China-Review. *Adv. Soc. Sci. Res. J.* **2016**, *3*, 221–227.
10. Zhao, D.Z.; Zhao, L.; Zhang, F.S.; Zhang, X.Y. Temporal occurrence and spatial distribution of red tide events in china's coastal waters. *Hum. Ecol. Risk Assess. Int. J.* **2004**, *10*, 945–957. [CrossRef]
11. Fellmann, T.; Witzke, P.; Weiss, F.; Van Doorslaer, B.; Drabik, D.; Huck, I.; Salputra, G.; Jansson, T.; Leip, A. Major challenges of integrating agriculture into climate change mitigation policy frameworks. *Mitig. Adapt. Strateg. Glob. Chang.* **2018**, *23*, 451–468. [CrossRef]
12. Wang, R.; Wang, W.; Hu, X.T.; Yang, X.; Li, H. Impact of fertilizer proportion and fertilizer-water ratio on clogging of filter by fertilizer pump in microirrigation. *Trans. Chin. Soc. Agric. Eng.* **2017**, *23*, 324–329.
13. Ragab, R.; Battilani, A.; Matovic, G.; Stikic, R.; Psarras, G.; Chartzoulakis, K. Saltmed model as an integrated management tool for water, crop, soil and N-fertilizer water management strategies and productivity: Field and simulation study. *Irrig. Drain.* **2015**, *64*, 13–28. [CrossRef]
14. Zhang, H.X.; Dao, C.; Wang, F. Yield and quality response of cucumber to irrigation and nitrogen fertilization under subsurface drip irrigation in solar greenhouse. *Agric. Sci. China* **2011**, *10*, 921–930. [CrossRef]
15. Li, J.; Pan, T.; Wang, L.; Du, Q.; Liu, Y. Effects of water-fertilizer coupling on tomato photosynthesis, yield and water use efficiency. *Trans. Chin. Soc. Agric. Eng.* **2014**, *30*, 82–90.
16. Li, X.; Liu, L.; Yang, H.; Li, Y. Relationships between carbon fluxes and environmental factors in a drip-irrigated, film-mulched cotton field in arid region. *PLoS ONE* **2018**, *13*, e0192467. [CrossRef]
17. Jiao, W.R. Effects of fertilizer application rate of drip irrigation fertilization in various growing stages on growth and water use efficiency of potato in yulin city. *J. Drain. Irrig. Mech. Eng.* **2018**, *36*, 257–266.
18. Wang, X.W.; Huo, Z.; Guan, H.D.; Guo, P.; Qu, Z.Y. Drip irrigation enhances shallow groundwater contribution to crop water consumption in an arid area. *Hydrol. Process.* **2018**, *32*, 118–123. [CrossRef]
19. Khan, M.A.; Kim, K.W.; Wang, M.; Lim, B.K.; Lee, W.H.; Lee, J.Y. Nutrient-impregnated charcoal: An environmentally friendly slow-release fertilizer. *Environmentalist* **2008**, *28*, 231–235. [CrossRef]
20. Jiao, X.; Liang, W.; Chen, J.Y.; Wen, D. Effects of urease/nitrification inhibitors on soil available n and microbial biomass n and on n uptake of wheat. *Chin. J. Appl. Ecol.* **2004**, *15*, 1903–1906.
21. Kyung, J.M.; Daegi, K.; Jongkeun, L.; Kwanyong, L.; Ki, Y.P. Characteristics of vegetable crop cultivation and nutrient releasing with struvite as a slow-release fertilizer. *Environ. Sci. Pollut. Res. Ther.* **2019**, *21*, 1–13.
22. Windia, H.; Chandra, W.P.; Suryo, P. Slow Release NPK Fertilizer Preparation from Natural Resources. *Mater. Sci. Forum* **2019**, *948*, 43–48.

23. Zhang, S.; Hussain, H.A.; Wang, L.; Hussain, S.; Li, B.; Zhou, H.; Luo, H.; Zhang, X.; Ma, Z.; Long, L.; et al. Responses of Soil Respiration and Organic Carbon to Straw Mulching and Ridge Tillage in Maize Field of a Triple Cropping System in the Hilly Region of Southwest China. *Sustainability* **2019**, *11*, 3068. [CrossRef]
24. Gu, X.B.; Li, Y.N.; Du, Y.D. Effects of ridge-furrow film mulching and nitrogen fertilization on growth, seed yield and water productivity of winter oilseed rape (brassica napus, l.) in northwestern china. *Agric. Water Manag.* **2018**, *200*, 60–70. [CrossRef]
25. Mo, F.; Wang, J.Y.; Li, F.M.; Nguluu, S.N.; Ren, H.X.; Zhou, H. Yield-phenology relations and water use efficiency of maize (zea mays l.) in ridge-furrow mulching system in semiarid east african plateau. *Sci. Rep.* **2017**, *7*, 125–127. [CrossRef]
26. Liu, T.; Chen, J.; Wang, Z.; Wu, X.; Wu, X.; Ding, R. Ridge and furrow planting pattern optimizes canopy structure of summer maize and obtains higher grain yield. *Field Crops Res.* **2018**, *219*, 242–249. [CrossRef]
27. Mo, F.; Wang, J.Y.; Zhou, H.; Luo, C.L.; Zhang, X.F.; Li, X.Y. Ridge-furrow plastic-mulching with balanced fertilization in rainfed maize (zea mays l.): An adaptive management in east african plateau. *Agric. For. Mereorol.* **2017**, *236*, 100–112. [CrossRef]
28. Gan, Y.T. Ridge-furrow mulching systems—An innovative technique for boosting crop productivity in semiarid rain-fed environments. *Adv. Agron.* **2013**, *118*, 1189–1192.
29. Boldura, O.M.; Popescu, S.; Sumalan, R. A Molecular Approach for Identification of Drought Resistant Rapeseed Genotypes Based on Gene Expression. *Int. Symp. Prospects Millenn. Agric.* **2015**, *32*, 1251–1258. [CrossRef]
30. Wu, X.J.; Jiang, H.D.; Zhou, Q. Effects of acid rain and waterlogging after anthesis on key enzyme activities in relation to nitrogen metabolism and protein components in wheat. *J. Nanjing Agric. Univ.* **2016**, *47*, 337–352.
31. Liu, X.F.; Zhu, X.F.; Pan, Y.Z.; Bai, J.J.; Li, S.S. Performance of different drought indices for agriculture drought in the north china plain. *J. Arid Land* **2018**, *4*, 1–10. [CrossRef]
32. Chen, Z.D.; Xu, C.C.; Ji, L.; Fand, F.P. Spatial and temporal changes in carbon footprint for oilseed rape production in the middle and lower reaches of Yangtze River during 2004–2015. *Chin. J. EcoAgric.* **2019**, *27*, 1105–1114.
33. Kévin, B.; Isabelle, L.V.; Romain, J.; Christian, K. Weed control method drives conservation tillage efficiency on farmland breeding birds. *Agric. Ecosyst. Environ.* **2018**, *256*, 74–81.
34. Xie, L.; Liu, M.; Ni, B.; Wang, Y.F. New environment-friendly use of wheat straw in slow-release fertilizer formulations with the function of superabsorbent. *Ind. Eng. Chem. Res.* **2012**, *51*, 3855–3862. [CrossRef]
35. Feng, J.; Shi, C.; Linna, C.; Meng, S.N.; Duan, M.C.; Zhang, S.; Xu, Q.W.; Wu, H.Y.; Ou, G.; Xiang, X.H.; et al. Effects of reducing fertilizer application rate under different mulching types on yield and water-fertilizer utilization efficiency of rapeseed. *Trans. CSAE* **2019**, *35*, 85–94, (In Chinese with English abstract).
36. Liu, B.; Wei, Q.Q.; Lu, J.W. Effects of waterlogging at the seedling stage and nitrogen application on seed yields and nitrogen use efficiency of direct-sown winter rapeseed (Brassica napus L.). *Plant. Nutr. Fertil. Sci.* **2017**, *23*, 144–153, (In Chinese with English abstract).
37. Mo, F.; Wang, J.Y.; Xiong, Y.C.; Nguluu, S.N.; Li, F.M. Ridge-furrow mulching system in semiarid kenya: A promising solution to improve soil water availability and maize productivity. *Eur. J. Agron.* **2016**, *80*, 124–136. [CrossRef]
38. Lian, Y.H.; Wang, T.L.; Zhang, X.D. Suitable ratio of nitrogen and phosphorus application under ridge and furrow rainfall harvesting system improving water use efficiency and yield of foxtail millet in semi-arid area. *Trans. CSAE* **2016**, *32*, 106–115, (In Chinese with English abstract).