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Article

Improvement of Climate Resource Utilization in the Southwestern Hilly Region through the Construction of a New Multi-Maturing Cropping System

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Abstract: The construction of an appropriate cropping pattern is crucial for the improvement of regional agricultural economic efficiency and sustainable development. Despite previous efforts, there remains a gap in optimizing cropping patterns that fully leverage climate resources to enhance production efficiency. This study addresses this gap by systematically comparing the differences in climate resource allocation, production efficiency and crop response among models by constructing four new triple-maturing cropping models at typical ecological sites in the hilly areas of southwest China. To solve the above problems, we constructed eight cropping patterns and classified them to three as follows: the Traditional Double Cropping System, the Traditional Triple Cropping System, the Novel Triple Cropping System. The results showed that the new multi-maturing planting pattern was significantly better than the traditional two-maturing netting pattern and the traditional three-maturing planting pattern in terms of light, temperature and water productivity. Compared with the traditional two-maturity net cropping model and the traditional three-maturity cropping model, the new cropping model increased light energy productivity by 97.88% and 50.00%, respectively; light energy use by an average of 0.48% and 0.31%; cumulative temperature productivity by an average of 84.70% and 49.14%; and rainfall productivity by an average of 101.04% and 49.61%. An assessment of the light, temperature and water meteorological resource use efficiency of the different treatments showed that the resource use efficiency of the new multi-maturing planting pattern was on average 111.58% and 74.78% higher than that of the traditional two-maturing net planting pattern and the traditional three-maturing planting pattern, with the T6 pattern having the highest resource use efficiency. The new multi-ripening cropping pattern has demonstrated production stability in response to changes in light, temperature and water resources, better adapting to weekly climate changes, stabilizing yields and improving efficiency. In summary, the results of this study can provide a theoretical basis for optimizing cropping patterns and promoting the use of climate resources in agriculture and sustainable development. Future research should focus on further refining these models, exploring their adaptability to various climatic conditions, and evaluating their long-term economic and environmental impacts.

Keywords: polyculture; climate resource utilization; sustainable; yield

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1. Introduction

The intensification of climate change has posed a major challenge to global crop production [1] How to adapt crop production to the stress of meteorological factors such as changes in light environment, persistent warming, extreme rainfall and drought has become a pressing issue [2]. Crop growth and development are influenced by a combination of environmental, cultivation management, and gene regulation [3,4]. According to local agricultural resources and production conditions, an appropriate cropping system is essential to promote high crop yield and efficiency [5–8]. Sichuan is located in the southwestern hilly region is one of the main producing areas of corn in China, which is rich in light and heat resources, maize cultivation is more than enough for two crops and less than enough for three crops, and matched intercropping planting of maize and low crops is one of the main forms of efficient use of resources [9,10]. However, the hilly areas of southwestern China are typical rain-fed drought areas with uneven distribution of precipitation time and staggered occurrence of a spring drought, summer drought, and summer flooding [11], which reduces crop yields as well as the utilization efficiency of resources such as light, temperature, and water. Therefore, constructing and selecting cropping patterns with efficient resource utilization is important to ensure regional food security [12].

Several studies have shown that continuous monocropping reduces crop resource utilization [13,14]. In contrast, multiple cropping provides efficient and intensive use of natural resources such as light, temperature, water and nutrients in time and space [15]. In intensive cropping systems, short-term rotations and monocultures are prone to negative impacts on crop growth and development, and increasing rotation diversity is an effective way to overcome their negative impacts [16,17]. Crop yields are directly affected by photosynthesis, and light energy is the energy basis for crop yields; crop light energy utilization is closely related to crop yields and the amount of solar radiation available during the reproductive period [18]. In the study of light energy utilization by different planting patterns, the light energy utilization of multi-maturing planting patterns was significantly higher than that of two-maturing monoculture, and reasonable inter-set composite planting could improve the light and heat utilization [19]. At the same time, the multi-ripening intercropping pattern can spatially increase the photosynthetic area by improving light distribution to increase light interception and significantly increase the material yield by improving light transmission [20,21]. Intercropping cropping patterns could increase the water utilization of the crop [22]. Suitable temperature conditions are one of the key factors determining the productivity of crops in a region [23], and agronomists have found that improving the efficiency of crop utilization of thermal resources such as cumulative temperature, daily high temperature and minimum temperature is an effective way to increase food production in comprehensive analysis and research of thermal resources [24]. The empirical literature on the impacts of climate resources on agriculture has grown significantly in recent decades [25]; however, most of the studies have focused on existing well-established cropping systems [26,27], and there have been fewer studies on constructing new cropping systems.

The objective of this study is to construct eight composite planting patterns with the goal of developing winter planting potential, making full use of summer and autumn light and heat resources, escaping spring drought, inverted spring cold and summer flooding, and meeting production demands in response to the uneven distribution of light and heat resources, inverted spring cold, and seasonal drought that exist in the hilly mountainous areas of Sichuan.

2. Materials and Methods

2.1. Site Description

This experiment was conducted from November 2016 to November 2018 at the Modernised Agricultural Demonstration Base (116.41° E, 39.92° N in Renshou County, Sichuan Province, China. The test site has a subtropical monsoon climate with low sunshine and uneven year-to-year distribution of precipitation within the year. The total insolation radiation from 2016 to 2017 was 2716 $MJ \cdot m^2$, the annual effective cumulative temperature was 3267 °C, and the precipitation was 590 mm. The total insolation radiation from 2017 to 2018 was 2730 $MJ \cdot m^2$, the annual effective cumulative temperature was 3385 °C, and the precipitation was 1194 mm (Figure 1). The soil type was red clay loam with 20.52 g·kg^{-1} of organic matter, 1.06 g·kg^{-1} of total nitrogen, 0.47 g·kg^{-1} of total phosphorus, 142.63 mg·kg^{-1} of quick-release potassium, and a pH value of 7.26 in the plough layer (0–30 cm) [28].

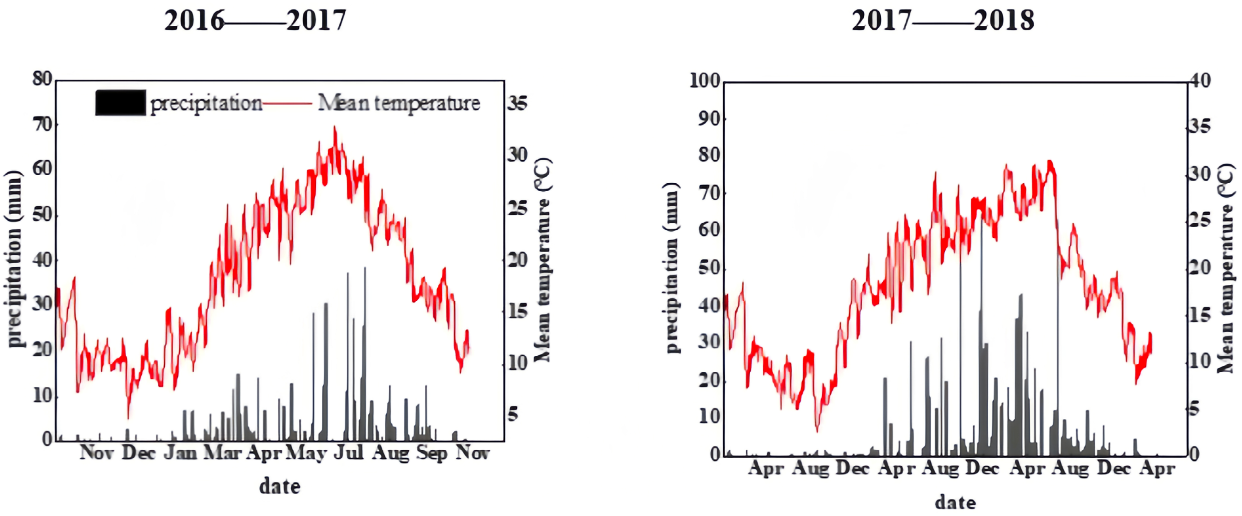

Figure 1. The 2016–2018 meteorological data map of the test site.

2.2. Experimental Design

Field experiments were conducted using a complete randomized block design with 8 treatments, 3 replications and a total of 24 plots, each with an area of 46.2 m^2 (6.6 m × 7 m). The experimental treatments included a two-maturity net cropping pattern, an existing three-maturity cropping pattern, and a new three-maturity cropping pattern (Table 1), including two-maturity net cropping patterns: oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), and potato-spring corn/summer soybean (T8). The wheat variety "Shu Mai 969", the forage oilseed rape variety "Deselect Oil 569", the potato variety "Fei Uri it", the corn variety "Rongyu 1210", the soybean variety "Nandou 25", and the peanut variety "Tianfu 22" were used. "Rongyu 1210", the soybean variety "Nandou 25", and the peanut variety "Tianfu 22" were used (specific cultivation measures and sowing time are shown in Table 1 of the Annex).

Table 1. Field Experiment Design of Different Cropping Modes.

Treatment	Cropping Patterns
T1	Rape—Summer soybean
T2	Rape—Summer Maize
T3	Wheat—Summer Maize
T4	Wheat/Spring Maize/Summer soybean
T5	Forage rape—Spring Maize/Summer soybean
T6	Forage rape—Spring Maize||peanut
T7	Potato—Spring Maize||peanut
T8	Potato—Spring Maize/Summer soybean

2.3. Crop Indicators

2.3.1. Yield

Oilseed rape was measured at maturity in a representative sample of 0.36 m^2 replicated three times from each plot, and the yield was calculated at 11% moisture.

Peanut yield was measured at maturity in a representative sample of 6.67 m^2 replicated three times from each plot, and the yield was calculated at 10% moisture.

Soybean and maize were harvested and replicated three times at maturity. After harvest, they were threshed and weighed, and plot yields were converted to seed yields per unit area (standard moisture calculated as 14% for maize and 13% for soybean).

Wheat was collected at maturity in a representative sample of 1 m^2 replicated three times from each plot, harvested and threshed manually, and the yield was determined at 13% moisture.

Forage oilseed rape was harvested at harvest time by selecting complete planting rows of plants in in a representative sample of 1 m^2 replicated three times, mowing the above-ground portion, and harvesting for yield (biomass is yield).

Potato yields were measured at maturity in a representative sample from each plot, and the number and weight of large potatoes (>150 g), medium potatoes (75–150 g), and small potatoes (<75 g) were determined.

2.3.2. Biomass

When foraging oilseed rape and oilseed rape were, respectively, 6 representative and uniformly long plants from each plot were taken during the harvesting period, and after determining the biomass yield, they were decomposed into 3 parts, stems, leaves and angiosperms, and dried at 80 °C to a constant weight and then weighed.

Eight representative potato plants were taken from each plot at maturity, divided into three parts, stems, leaves and tubers, dried at 80 °C to a constant weight and weighed to determine the biomass.

To determine the maturity of each plot, wheat was taken as a representative of the consistent growth of 12 plants, decomposed into stems, leaves, spikes, 3 parts, and dried at 80 °C to a constant weight and weighed to determine the biological yield.

To determine the maturity of each plot, corn was taken as a representative of the consistent growth of 6 plants, decomposed into stems, leaves, bracts, kernels, rachis, 5 parts, and dried at 80 °C to a constant weight and weighed to determine the biological yield.

To determine the maturity of each plot, peanut and soybean were taken as representatives of the same growth of 12 plants, decomposed into stems, leaves, hulls, seeds, 4 parts, and dried at 80 °C to a constant weight and weighed to determine the biological yield.

2.3.3. Resource Utilization Indicators

Meteorological Data

Meteorological data were obtained from Renshou meteorological stations and consisted mainly of indicators such as solar radiation, daily temperature, hours of sunshine and rainfall. Daily meteorological data are used to calculate total radiation, cumulative effective temperature and rainfall for the year and for different growing seasons.

$$rain\ fall = \sum rain\ fall \times Growth\ duration \tag{1}$$

$$effective\ accumulated\ temperature = \sum (T - T_0) \times Growth\ duration \tag{2}$$

where T and T_0 (Greater than 10 °C) are the mean daily temperature and biological zero temperature, respectively.

Since solar radiation cannot be recorded directly at weather stations, total radiation is converted from sunshine hours to daily radiation using the empirical formula, the Eisquellen equation [29,30].

$$R1 = RA\left(aA + bA \cdot \frac{n}{N}\right) \tag{3}$$

where $R1$ is the actual solar radiation received $[J \cdot (m^2 \cdot d)^{-1}]$, RA is the theoretical value of solar radiation reaching the ground assuming no atmosphere, which has a certain functional relationship with different days of the year and latitude, n/N is the ratio of the actual number of hours of sunshine (n) to the maximum number of hours of sunshine on a clear day (N), and aA and bA are empirical constants depending on the geographic location and the seasons, and in the present study in the spring–summer season aA = 0.23 and bA = 0.47, and in autumn and winter, the values aA = 0.16 and bA = 0.55 were taken [31].

Light energy utilization

$$LEDR = \sum R1 \times \frac{Growth\ duration}{Annual\ effective\ radiation} \tag{4}$$

$$LPE = \frac{Economic\ output\ per\ unit\ area}{Solar\ radiation\ per\ unit\ area} \tag{5}$$

$$ATLEUR = \frac{Biomass\ productivity}{Annual\ solar\ radiation\ per\ unit\ area} \tag{6}$$

Accumulative temperature utilization

$$AEATDR = \frac{Effective\ accumulated\ temperature\ during\ crop\ growth\ period}{Annual\ effective\ accumulated\ temperature} \times 100\% \tag{7}$$

$$ATPE = \frac{grain\ yield}{Effective\ accumulated\ temperature\ during\ growth\ period} \tag{8}$$

Precipitation utilization

$$APDR = \frac{Precipitation\ during\ crop\ growth}{annual\ precipitation} \times 100\% \tag{9}$$

$$PPE = \frac{grain\ yield}{Precipitation\ during\ growth\ period} \times 100\% \tag{10}$$

Evaluation model of meteorological resource utilization efficiency

$$Cj = \frac{Aj}{n} \sum_{i=1}^{n} \frac{bi}{Bi} \tag{11}$$

where Cj is the evaluation coefficient of climate utilization efficiency, bi is the occupancy of climate resources of a certain plant, Bi is the total amount of climate resources within a year, bi/Bi is the occupancy rate of climate resources, and Aj is the output of climate resources of a certain plant per unit area, which is expressed as biological yield or economic yield [32].

2.4. Data Statistics and Analysis

Data were collated using Excel (office2019). Analysis of variance (ANOVA) and multiple comparisons were carried out using the GLM procedure in the SPSS 19.0 (SPSS Ins., Chicago, IL, USA). The means of indexes such as economic yields, biological yields, light, temperature, and water, and material production efficiency were compared with a least significant difference (LSD) test at the $p < 0.05$ level. Graphs related to economic yield, biological yield, allocation of climate resources such as light, temperature and water, and production efficiency of different treatments between seasons and years were plotted using a three-line table to evaluate the efficiency of integrated use of climate resources.

3. Results

3.1. The Optical Resource Allocation Rate, Productivity and the Utilization Rate

3.1.1. The Optical Resource Allocation Ratio (Annex)

The results of this study showed that the 2-year light resource allocation pattern was consistent (Table 2). The annual light resource allocation rate of the planting patterns showed that T4 > T5 > T8 > T1 > T2 = T3 > T7 > T6, and the annual light energy allocation rate (LEDR) of T4 pattern (wheat/spring corn/summer soybean) reached 100%. The overall light resource allocation for each planting pattern was shown as follows: T4 > T5 > T8 >

T1 > T2 = T3 > T7 > T6. In the first season, the allocation of light resources was shown as T1 = T2 = T3 = T4 > T7 = T8 > T6 = T5. The photosynthetically active radiation of different crops was ranked as follows: oilseed rape>wheat>potato>forage oilseed rape. The distribution of light resources in the second season was as follows: T4 = T5 = T6 > T7 = T8 > T1 > T2 = T3. The photosynthetically active radiation of different crops was ranked as follows: spring maize>summer soybean>summer maize. The allocation of light resources in the third season showed that T6 > T7 > T8 = T4 = T5 and the allocation of light resources in peanuts was higher than that in soybean.

Table 2. Light Resource Allocation Rates of Different Cropping Modes (Unit: $MJ\cdot m^{-2}$).

Year	Treat Ment	1st Mature	2nd Mature	3rd Mature	Symbiotic Stage		Planting Mode	Whole Year	Rate (%)
					1–2 Mature	2–3 Mature			
2017	T1	1276	1244	-	-	-	2519	2716	92.75
	T2	1276	1230	-	-	-	2506	2716	92.25
	T3	1276	1230	-	-	-	2506	2716	92.25
	T4	1276	1322	1244	482	643	2716	2716	100.00
	T5	782	1322	1244	-	643	2704	2716	99.54
	T6	782	1322	1432	-	1322	2214	2716	81.50
	T7	883	1325	1413	-	1325	2296	2716	84.52
	T8	883	1325	1244	-	843	2609	2716	96.03
2018	T1	1352	1181	-	-	-	2533	2731	92.77
	T2	1352	1163	-	-	-	2515	2731	92.09
	T3	1352	1163	-	-	-	2515	2731	92.09
	T4	1352	1230	1181	481	552	2731	2731	100.00
	T5	864	1230	1181	-	552	2724	2731	99.74
	T6	864	1230	1328	-	1230	2192	2731	80.27
	T7	987	1201	1328	-	1201	2315	2731	84.76
	T8	987	1201	1181	-	753	2616	2731	95.81

Note: 1st mature indicated the first season's crops, 2nd mature indicated the second season's crops, 3rd mature indicated third season's crops. Planting mode represents the amount of light resources allocated during the existence of the crop; whole year represents the amount of light resources allocated in the whole year. oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), potato-spring corn/summer soybean (T8).

3.1.2. Dry Matter Production Efficiency of Light Resources

There were significant differences in the dry matter production efficiency of light resources (LPE) among different cropping patterns within the year and between seasons (Table 3), as shown in T6 > T5 > T7 > T8 > T3 > T4 > T2 > T1. In the first season, the overall productivity of the new multiple cropping pattern (T5 to T8) was significantly better than that of the existing multiple cropping pattern (T1 to T3). The productivity of T5 treatment forage oilseed rape was the highest at 1.57 $g\cdot MJ^{-1}$, while T1 and T2 treatment oilseed rape had the lowest productivity at 0.17 $g\cdot MJ^{-1}$. In the second season, the T2 and T3 treatments outperformed the new multiple maturity pattern and the T1 treatment significantly. In the third season, the T6 and T7 treatments in the new cropping pattern were more productive than the traditional three-maturity cropping pattern. Overall, the new multi-maturing planting pattern is superior to the existing planting pattern, and the annual light energy production efficiency of the new pattern (T5 to T8) has been increased by an average of 0.31 $g\cdot MJ^{-1}$, or 97.88%, compared with the traditional two-maturing net cropping pattern, and by an average of 0.21 $g\cdot MJ^{-1}$, or 50%, compared with the traditional three-maturing planting pattern.

Table 3. Production Efficiency of Light Competent Substances in Different Cropping Modes (Unit: $g\cdot MJ^{-1}$).

Item	Year	T1	T2	T3	T4	T5	T6	T7	T8
1st mature	2017	0.17 d	0.17 d	0.36 ± 0.02 c	0.23 ± 0.02 c	1.51 ± 0.11 a	1.51 ± 0.11 a	0.53 ± 0.03 b	0.53 ± 0.03 b
	2018	0.17 f	0.18 ± 0.01 f	0.33 ± 0.01 d	0.23 ± 0.01 e	1.63 ± 0.03 a	1.56 ± 0.02 b	0.50 ± 0.01 c	0.47 c
	average	0.17 e	0.17 de	0.35 ± 0.01 c	0.23 d	1.57 ± 0.05 a	1.54 ± 0.06 a	0.51 ± 0.01 b	0.50 ± 0.01 b
2nd mature	2017	0.16 ± 0.01 d	0.63 ± 0.01 a	0.65 ± 0.02 a	0.55 ± 0.01 b	0.50 ± 0.03 c	0.50 ± 0.03 bc	0.51 ± 0.03 bc	0.53 ± 0.01 bc
	2018	0.16 c	0.61 ± 0.01 ab	0.58 ± 0.03 b	0.54 ± 0.02 b	0.54 ± 0.02 b	0.54 ± 0.04 b	0.54 ± 0.03 b	0.52 b
	average	0.16 c	0.62 ± 0.02 a	0.62 ± 0.01 a	0.54 ± 0.02 b	0.52 ± 0.02 b	0.52 ± 0.02 b	0.52 ± 0.03 b	0.53 ± 0.01 b
3rd mature	2017	-	-	-	0.13 ± 0.01 c	0.14 ± 0.01 a	0.14 a	0.15 b	0.13 ± 0.01 b
	2018	-	-	-	0.12 ± 0.01 b	0.13 ± 0.01 b	0.16 a	0.16 ± 0.01 a	0.11 ± 0.01 b
	average	-	-	-	0.13 bc	0.13 b	0.15 a	0.15 a	0.12 c
Planting mode	2017	0.16 f	0.39 e	0.50 ± 0.01 d	0.44 ± 0.01 e	0.74 ± 0.04 b	0.92 ± 0.03 a	0.59 ± 0.03 c	0.51 ± 0.02 d
	2018	0.16 g	0.38 ± 0.02 f	0.45 d	0.41 ± 0.01 e	0.81 ± 0.01 b	1.02 ± 0.03 a	0.58 ± 0.02 c	0.47 d
	average	0.16 g	0.39 ± 0.01 f	0.48 d	0.42 ± 0.01 e	0.78 ± 0.02 b	0.97 ± 0.03 a	0.59 ± 0.02 c	0.49 ± 0.01 d
Whole year	2017	0.15 e	0.36 d	0.46 ± 0.01 bc	0.44 ± 0.01 c	0.74 ± 0.04 a	0.75 ± 0.03 a	0.50 ± 0.02 b	0.49 ± 0.02 b
	2018	0.15 f	0.35 ± 0.02 e	0.41 d	0.41 ± 0.01 d	0.81 ± 0.01 a	0.82 ± 0.02 a	0.49 ± 0.02 b	0.45 c
	average	0.15 f	0.36 ± 0.01 e	0.44 cd	0.42 ± 0.01 d	0.77 ± 0.02 a	0.78 ± 0.02 a	0.50 ± 0.02 b	0.47 ± 0.01 bc

Note: 1st mature indicated the first season's crops, 2nd mature indicated the second season's crops, 3rd mature indicated third season's crops. Planting mode represents the amount of light resources allocated during the existence of the crop; whole year represents the amount of light resources allocated in the whole year. oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), potato-spring corn/summer soybean (T8). The different lowercase letters indicate significant differences among different treatments ($p < 0.05$).

Annual economic yield light energy utilization (ATLEUR) varied significantly between years and seasons for different cropping patterns (Table 4). The treatments performed as T6 > T5 > T7 > T8 > T4 > T3 > T2 > T1, with the new model improving by an average of 0.48% and 0.31% over the traditional two-maturity net cropping model and the traditional three-maturity planting model in both years. In the first season, the two-year light energy use rate of the new models (T5, T6, T7, T8) averaged 1.62%, which was 1.07% and 1.18% higher than that of the traditional two-maturity net cropping model (T1, T2, T3,) and the traditional three-maturity cropping model (T4). In the second season, the new model's two-year light energy use rate averaged 1.00%, which was 0.09% higher than the traditional two-maturity net cropping model and 0.05% lower than the traditional three-maturity cropping model. In the third season, the light energy usage rate of the new model averaged 0.34%, which is 0.04% higher than the traditional three-year cropping model.

Table 4. The Light Energy Utilization Rate of Different Cropping Modes.

Year	Treat Ment	Economic Utilization (%)					Group Utilization (%)				
		1st Mature	2nd Mature	3rd Mature	Planting Mode	Whole Year	1st Mature	2nd Mature	3rd Mature	Planting Mode	Whole Year
2017	T1	0.49 d	0.38 ± 0.02 d	-	0.43 ± 0.01 e	0.40 ± 0.01 e	1.51 ± 0.02 b	1.52 ± 0.01 c	-	1.52 ± 0.01 e	1.41 ± 0.01 e
	T2	0.49 d	1.20 ± 0.01 a	-	0.84 ± 0.01 d	0.77 ± 0.01 d	1.51 ± 0.02 b	2.15 ± 0.02 a	-	1.82 ± 0.02 cd	1.68 ± 0.02 c
	T3	0.69 ± 0.04 c	1.24 ± 0.05 a	-	0.96 ± 0.02 c	0.89 ± 0.02 c	1.41 ± 0.06 b	2.30 ± 0.09 a	-	1.85 ± 0.01 c	1.71 ± 0.01 c
	T4	0.44 ± 0.01 d	1.05 ± 0.03 b	0.31 ± 0.01 c	0.86 ± 0.01 d	0.86 ± 0.01 c	0.83 ± 0.04 d	1.74 ± 0.05 b	1.02 ± 0.03 a	1.71 ± 0.03 d	1.71 ± 0.03 c
	T5	2.20 ± 0.17 a	0.95 ± 0.05 c	0.32 ± 0.01 c	1.25 ± 0.06 b	1.24 ± 0.06 a	2.20 ± 0.17 a	1.72 ± 0.09 b	1.06 ± 0.01 a	1.96 ± 0.08 b	1.95 ± 0.08 a
	T6	2.20 ± 0.17 a	0.97 ± 0.07 bc	0.36 ± 0.01 b	1.59 ± 0.04 a	1.29 ± 0.04 a	2.20 ± 0.17 a	1.76 ± 0.12 b	0.61 ± 0.09 b	2.23 ± 0.05 a	1.82 ± 0.04 b
	T7	1.00 ± 0.06 b	0.98 ± 0.05 bc	0.38 ± 0.01 a	1.19 ± 0.05 b	1.00 ± 0.04 b	1.15 ± 0.06 c	1.74 ± 0.10 b	0.60 ± 0.02 b	1.82 ± 0.07 cd	1.54 ± 0.06 d
	T8	1.00 ± 0.06 b	1.03 ± 0.03 bc	0.31 ± 0.01 c	1.01 ± 0.04 c	0.97 ± 0.04 b	1.15 ± 0.06 c	1.86 ± 0.05 b	0.97 ± 0.01 a	1.79 ± 0.05 cd	1.72 ± 0.05 bc
2018	T1	0.48 ± 0.01 ef	0.37 ± 0.01 c	-	0.43 f	0.40 f	1.58 ± 0.03 c	1.48 ± 0.05 c	-	1.54 ± 0.01 f	1.42 ± 0.01 e
	T2	0.50 ± 0.02 e	1.17 ± 0.08 a	-	0.81 ± 0.04 e	0.75 ± 0.03 e	1.61 ± 0.05 c	2.30 ± 0.14 a	-	1.93 ± 0.06 c	1.78 ± 0.06 b
	T3	0.63 ± 0.02 d	1.12 ± 0.01 ab	-	0.86 e	0.79 de	1.45 ± 0.04 d	2.21 ± 0.06 a	-	1.80 ± 0.05 d	1.66 ± 0.05 cd
	T4	0.44 ± 0.02 f	1.04 ± 0.06 b	0.30 ± 0.01 b	0.81 ± 0.01 e	0.81 ± 0.01 d	0.90 ± 0.01 f	1.95 ± 0.09 b	0.99 ± 0.03 a	1.75 ± 0.03 de	1.75 ± 0.03 bc
	T5	2.38 ± 0.05 a	1.03 ± 0.03 b	0.30 ± 0.02 b	1.35 ± 0.01 b	1.35 ± 0.01 a	2.38 ± 0.05 a	1.95 ± 0.06 b	1.01 ± 0.04 a	2.19 ± 0.02 b	2.07 ± 0.02 a
	T6	2.28 ± 0.03 b	1.04 ± 0.08 b	0.40 ± 0.01 a	1.73 ± 0.05 a	1.39 ± 0.04 a	2.28 ± 0.03 b	1.95 ± 0.09 b	0.82 ± 0.05 b	2.60 ± 0.07 a	2.00 ± 0.06 a
	T7	0.95 ± 0.01 c	1.03 ± 0.06 b	0.41 ± 0.01 a	1.17 ± 0.04 c	0.99 ± 0.03 b	1.09 ± 0.01 e	1.95 ± 0.06 b	0.91 ± 0.03 a	2.01 ± 0.04 bc	1.69 ± 0.03 bcd
	T8	0.91 ± 0.01 c	1.00 b	0.27 ± 0.01 b	0.92 ± 0.01 d	0.88 ± 0.01 c	1.04 ± 0.01 e	1.89 ± 0.04 b	0.94 ± 0.03 a	1.69 ± 0.02 e	1.62 ± 0.02 d

Note: 1st mature indicated the first season's crops, 2nd mature indicated the second season's crops, 3rd mature indicated third season's crops. Planting mode represents the amount of light resources allocated during the existence of the crop; whole year represents the amount of light resources allocated in the whole year. oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), potato-spring corn/summer soybean (T8). The different lowercase letters indicate significant differences among different treatments ($p < 0.05$).

3.2. Allocation of Cumulative Temperature Resources and Productivity

3.2.1. The Allocation Rate of Cumulus Resources

Differences in cumulative temperature allocation (AEATDR) between cropping patterns existed between seasons and weeks, but the pattern was consistent across the two-year trial (Table 5). The two-year cumulative temperature distribution of the new multi-maturing planting pattern (T5, T6, T7, T8) averaged 2817.25 °C, while the traditional two-maturing net cropping pattern (T1, T2, T3) averaged 2934 °C. The traditional three-maturing planting pattern (T4) had an average of 3316 °C. The new pattern had a 3.98% and 15.04% lower temperature distribution than the traditional two-maturing net cropping pattern and the traditional three-maturing planting pattern, respectively. The cumulative temperature distribution rate and amount are highest in the traditional triple cropping pattern as they cover the entire year. In the first season, the two-year Cumulative Temperature Allocation (CTA) of the novel model (T5, T6, T7, T8) averaged 395.5 °C, and the two-year CTA of the two traditional models (T1, T2, T3, T4) averaged 864.5 °C, which is 118.58% higher than that of the novel model. In the second season, the cumulative temperature allocation over two years averaged 1851 °C for the new model, 2070.2 °C for the traditional two-maturing net cropping model, and 1771 °C for the traditional three-maturing planting model. The cumulative temperature allocation of the new model was 10.59% lower than that of the traditional two-maturing net cropping model and 4.52% higher than that of the traditional three-maturing planting model. In the third season, the two-year cumulative temperature distribution averaged 2077 °C for the new model and 2162.5 °C for the traditional three-ripening planting model, which is 3.95% higher than that of the new model.

Table 5. The Distribution Rate of Accumulated Temperature Resources in Different Cropping Modes (Unit: °C).

Year	Treat Ment	1st Mature	2nd Mature	3rd Mature	Symbiotic Stage		Planting Mode	Whole Year	Rate %
					1–2 Mature	2–3 Mature			
2017	T1	753	2200	-	-	-	2953	3247	90.94
	T2	753	2049	-	-	-	2802	3247	86.30
	T3	753	2049	-	-	-	2802	3247	86.30
	T4	753	1773	2200	471	1008	3247	3247	100.00
	T5	271	1773	2200	-	1008	3237	3247	99.70
	T6	271	1773	1967	-	1773	2239	3247	68.95
	T7	355	1951	2117	-	1951	2472	3247	76.15
	T8	355	1951	2200	-	1379	3128	3247	96.33
2018	T1	976	2125	-	-	-	3101	3385	91.61
	T2	976	1999	-	-	-	2975	3385	87.88
	T3	976	1999	-	-	-	2975	3385	87.88
	T4	976	1769	2125	534	951	3385	3385	100.00
	T5	435	1769	2125	-	951	3379	3385	99.80
	T6	435	1769	1941	-	1769	2376	3385	70.19
	T7	521	1911	1941	-	1911	2462	3385	72.74
	T8	521	1911	2125		1313	3245	3385	95.87

Note: 1st mature indicated the first season's crops, 2nd mature indicated the second season's crops, 3rd mature indicated third season's crops. Planting model represents the amount of light resources allocated during the existence of the crop; whole year represents the amount of light resources allocated in the whole year. oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), potato-spring corn/summer soybean (T8).

3.2.2. Dry Matter Production Efficiency of Thermal Resources

There were significant inter-season differences in dry matter cumulative temperature production efficiency (ATPE) between cropping patterns (Table 6). The annual cumulative temperature productivity is shown as T6 > T5 > T7 > T8 > T3 > T4 > T2 > T1, The annual cumulative temperature productivity of the new multi-maturing planting pattern (T5, T6, T7, T8) averaged 5.19 $\mathrm{kg{\cdot}hm^{-2}{\cdot}{}^{\circ}C^{-1}}$, the traditional two-maturing net cropping pattern (T1, T2, T3) averaged 2.81 $\mathrm{kg{\cdot}hm^{-2}{\cdot}{}^{\circ}C^{-1}}$, and the traditional three-maturing planting pattern

(T4) averaged 3.48 kg·hm^{-2}·°C^{-1}, and the new pattern was 84.70% and 49.14% higher than that of the traditional two-maturing net cropping pattern and the new pattern was 84.70% and 49.14% higher than the traditional two-maturing net cropping pattern and the traditional three-maturing cropping pattern.

Table 6. Accumulated Temperature and Dry Matter Production Efficiency of Different Cropping Modes (Unit: kg·hm^{-2}·°C^{-1}).

Item	Year	T1	T2	T3	T4	T5	T6	T7	T8
1st mature	2017	2.89 ± 0.02 c	2.89 ± 0.02 c	6.16 ± 0.36 c	3.93 ± 0.12 c	43.48 ± 3.30 a	43.48 ± 3.30 a	13.11 ± 0.64 b	13.11 ± 0.64 b
	2018	2.31 ± 0.03 f	2.44 ± 0.10 f	4.62 ± 0.12 d	3.20 ± 0.13 e	32.29 ± 0.65 a	31.01 ± 0.39 b	9.39 ± 0.25 c	8.98 ± 0.09 c
	average	2.60 ± 0.02 d	2.67 ± 0.05 d	5.39 ± 0.13 c	3.57 ± 0.07 d	37.89 ± 1.62 a	37.24 ± 1.66 a	11.25 ± 0.32 b	11.04 ± 0.36 b
2nd mature	2017	0.90 ± 0.04 d	3.75 ± 0.04 abc	3.89 ± 0.14 ab	4.07 ± 0.11 a	3.69 ± 0.04 bc	3.75 ± 0.26 abc	3.47 ± 0.19 c	3.63 ± 0.10 bc
	2018	0.86 ± 0.02 c	3.55 ± 0.25 ab	3.39 ± 0.03 ab	3.75 ± 0.21 a	3.74 ± 0.12 a	3.79 ± 0.28 a	3.36 ± 0.19 ab	3.26 ± 0.01 b
	average	0.88 ± 0.03 d	3.65 ± 0.14 abc	3.64 ± 0.06 abc	3.91 ± 0.12 a	3.72 ± 0.15 ab	3.77 ± 0.15 a	3.42 ± 0.19 c	3.45 ± 0.05 bc
3rd mature	2017	-	-	-	0.75 ± 0.03 b	0.77 ± 0.03 b	1.03 ± 0.02 a	0.99 ± 0.02 a	0.73 ± 0.03 b
	2018	-	-	-	0.69 ± 0.03 b	0.70 ± 0.04 b	1.08 ± 0.01 a	1.09 ± 0.04 a	0.63 ± 0.03 b
	average	-	-	-	0.72 ± 0.02 b	0.74 ± 0.03 b	1.05 ± 0.02 a	1.04 ± 0.03 a	0.68 ± 0.02 b
Planting mode	2017	1.41 ± 0.03 f	3.52 ± 0.03 e	4.50 ± 0.09 d	3.64 ± 0.06 e	6.19 ± 0.34 b	9.15 ± 0.31 a	5.47 ± 0.24 c	4.27 ± 0.15 d
	2018	1.32 ± 0.01 f	3.18 ± 0.16 e	3.79 ± 0.02 d	3.32 ± 0.06 e	6.56 ± 0.07 b	9.38 ± 0.24 a	5.46 ± 0.21 c	3.78 ± 0.02 d
	average	1.36 ± 0.02 f	3.35 ± 0.09 e	4.15 ± 0.04 d	3.48 ± 0.06 e	6.38 ± 0.19 b	9.26 ± 0.28 a	5.47 ± 0.20 c	4.03 ± 0.08 d
Whole year	2017	1.28 ± 0.03 e	3.04 ± 0.03 d	3.89 ± 0.08 bc	3.64 ± 0.06 c	6.17 ± 0.34 a	6.31 ± 0.21 a	4.17 ± 0.18 b	4.11 ± 0.14 b
	2018	1.21 ± 0.01 f	2.80 ± 0.14 e	3.33 ± 0.02 d	3.32 ± 0.06 d	6.55 ± 0.07 a	6.58 ± 0.17 a	3.97 ± 0.15 b	3.62 ± 0.02 c
	average	1.24 ± 0.02 f	2.92 ± 0.08 e	3.60 ± 0.04 cd	3.48 ± 0.06 d	6.36 ± 0.19 a	6.45 ± 0.19 a	4.07 ± 0.15 b	3.86 ± 0.08 bc

Note: 1st mature indicated the first season's crops, 2nd mature indicated the second season's crops, 3rd mature indicated third season's crops. Planting mode represents the amount of light resources allocated during the existence of the crop; whole year represents the amount of light resources allocated in the whole year. oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), potato-spring corn/summer soybean (T8). The different lowercase letters indicate significant differences among different treatments ($p < 0.05$).

During the first season, the new model demonstrated significantly higher cumulative temperature productivity compared to the two traditional models. The average cumulative temperature productivity for the new model was 24.36 kg·hm^{-2}·°C^{-1} while for the traditional two-maturing net cropping model and traditional three-maturing planting model, it was 3.55 kg·hm^{-2}·°C^{-1} and 3.57 kg·hm^{-2}·°C^{-1}, respectively. The new three-maturity planting patterns outperformed the two-maturity net cropping pattern and existing three-maturity cropping pattern by 586.20% and 582.35%, respectively. In the second season, the average cumulative productivity of the new model was 3.59 kg·hm^{-2}·°C^{-1}, while that of the traditional two-maturing net cropping model was 2.72 kg·hm^{-2}·°C^{-1}, and that of the traditional three-maturing planting model was 3.91 kg·hm^{-2}·°C^{-1}, which was 31.99% higher than that of the traditional two-maturing net cropping model, and 8.14% lower than that of the traditional three-maturing planting model. In the third season, the average cumulative productivity of the new model was 0.88 kg·hm^{-2}·°C^{-1}, while that of the traditional three-maturing planting model was 0.72 kg·hm^{-2}·°C^{-1}, and the new model was 22.22% higher than the traditional three-maturing planting model.

3.3. Precipitation Resource Allocation and Productivity

3.3.1. The Precipitation Resource Allocation Rate

The precipitation resource allocation rates (APDR) varied between seasons and years for different cropping patterns, with a consistent pattern for both years (Table 7). The annual rainfall resource allocation of the new three-maturing planting pattern (T5, T6, T7, T8) was 789 mm, the annual rainfall resource allocation of the traditional two-maturing planting pattern (T1, T2, T3) was 824 mm, and the annual rainfall resource allocation of the traditional three-maturing planting pattern (T4) was 892 mm, and the new pattern was lower than that of the traditional two-maturing net cropping pattern and the traditional three-maturing planting pattern by 6.43% and 11.55%. In the first season, the new model's precipitation resource allocation was 53.36% lower than that of the two traditional models. In the second season, the average rainfall resource allocation was 558 mm for the new model, 676 mm for the traditional two-maturing net cropping model, and 499 mm for the traditional three-maturing planting model. The new model was 17.46% lower than the traditional two-maturing net cropping model, and 11.82% higher than the traditional three-maturing planting model, and the rainfall resource allocation showed a tendency to increase with the delayed sowing period. In the third season, the precipitation resource allocation of the new model was 663.25 mm, while that of the traditional three-maturing planting model was 698 mm, representing a 4.98% increase compared to the new model. The allocation of precipitation resources was 87.42% for the new model, 92.18% for the traditional two-maturing net cropping model, and 100% for the traditional three-maturing planting model, which utilized the entire year.

Table 7. Distribution of Precipitation Resources for Different Cropping Modes (Unit: mm).

Year	Treat Ment	1st Mature	2nd Mature	3rd Mature	Symbiotic Stage		Planting Mode	Whole Year	Rate %
					1–2 Mature	2–3 Mature			
2017	T1	134	434	-	-	-	568	590	96.19
	T2	134	376	-	-	-	510	590	86.41
	T3	134	376	-	-	-	510	590	86.41
	T4	134	233	434	82	128	590	590	100.00
	T5	52	233	434	-	128	590	590	100.00
	T6	52	233	286	-	233	338	590	57.19
	T7	73	315	407	-	315	479	590	81.21
	T8	73	315	434	-	236	586	590	99.27
2018	T1	162	962	-	-	-	1124	1194	94.12
	T2	162	954	-	-	-	1116	1194	93.46
	T3	162	954	-	-	-	1116	1194	93.46
	T4	162	765	962	113	582	1194	1194	100.00
	T5	48	765	962	-	582	1193	1194	99.95
	T6	48	765	894	-	765	943	1194	78.94
	T7	68	919	927	-	919	994	1194	83.26
	T8	68	919	962		760	1189	1194	99.56

Note: 1st mature indicated the first season's crops, 2nd mature indicated the second season's crops, 3rd mature indicated third season's crops. Planting mode represents the amount of light resources allocated during the existence of the crop; whole year represents the amount of light resources allocated in the whole year. oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), potato-spring corn/summer soybean (T8).

3.3.2. Dry Matter Production Efficiency of Precipitation Resources

There were significant differences in annual and intra-seasonal precipitation dry matter production efficiencies (PPE) among planting patterns (Table 8). The annual dry matter production efficiency as a whole showed that T6 > T5 > T7 > T8 > T3 > T4 > T2 > T1, and the new multi-ripening planting pattern (T5, T6, T7, T8) was better than the two traditional patterns (T1, T2, T3, T4). The annual dry matter production efficiency averaged 1.93 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the new model, 0.96 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the traditional two-maturing net cropping model, and 1.29 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the traditional three-maturing planting model, which was 101.04% and 49.61% higher than that of the traditional two-maturing net cropping model and the traditional three-maturing planting model, respectively. In the first season, dry matter production efficiency averaged 16.19 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the new model, 2.06 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the traditional two-maturing planting model, and 2.07 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the traditional three-maturing planting model, which was 685.92% and 682.13% higher than that of the traditional two-maturing net cropping model and the traditional three-maturing planting model, respectively. The T5 and T6 treatments of the forage oilseed rape system were the most productive, with 17 fold the productivity of the T1 and T2 treatments and 8 fold that of the T3 treatment. The dry matter production efficiency in the second season was 1.65 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the new model, 1.04 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the traditional two-ripe net-crop model, and 1.99 kg$\cdot$m$^{-3}\cdot$mm^{-1} for the traditional three-ripe planting model. The new model showed a 58.65% increase in efficiency compared to the traditional two-ripe net-crop model, and a 17.09% decrease compared to the traditional three-ripe planting model. In the second season crop, maize exhibits a greater advantage in dry matter production efficiency compared to soya bean. This advantage tends to decline with the delay in the sowing period. During the third season, the dry matter production efficiency was 0.34 $kg{\cdot}m^{-3}{\cdot}mm^{-1}$ for the new model and 0.27 $kg{\cdot}m^{-3}{\cdot}mm^{-1}$ for the traditional three-maturing planting model, representing a 25.93% decrease compared to the new model.

Table 8. Dry Matter Production Efficiency of Precipitation under Different Cropping Modes (Unit: $kg{\cdot}m^{-3}{\cdot}mm^{-1}$).

Item	Year	T1	T2	T3	T4	T5	T6	T7	T8
1st mature	2017	1.63 ± 0.01 c	1.63 ± 0.01 c	3.47 ± 0.20 c	2.21 ± 0.07 c	22.74 ± 1.72 a	22.74 ± 1.72 a	6.39 ± 0.31 b	6.39 ± 0.31 b
	2018	1.40 ± 0.02 f	1.48 ± 0.06 ef	2.79 ± 0.07 d	1.93 ± 0.08 e	29.10 ± 0.59 a	27.95 ± 0.35 b	7.25 ± 0.19 c	6.92 ± 0.07 c
	average	1.51 ± 0.01 d	1.55 ± 0.03 d	3.13 ± 0.07 c	2.07 ± 0.04 d	25.92 ± 0.86 a	25.34 ± 0.88 a	6.82 ± 0.16 b	6.66 ± 0.19 b
2nd mature	2017	0.45 ± 0.02 d	2.04 ± 0.02 c	2.12 ± 0.08 c	3.10 ± 0.08 a	2.81 ± 0.15 b	2.86 ± 0.20 b	2.15 ± 0.12 c	2.25 ± 0.06 c
	2018	0.19 ± 0.01 c	0.74 ± 0.05 b	0.71 ± 0.01 b	0.87 ± 0.05 a	0.87 ± 0.03 a	0.88 ± 0.06 a	0.70 ± 0.04 b	0.68 b
	average	0.32 ± 0.01 b	1.39 ± 0.03 c	1.42 ± 0.04 c	1.99 ± 0.05 a	1.84 ± 0.09 b	1.87 ± 0.09 ab	1.42 ± 0.08 c	1.46 ± 0.03 c
3rd mature	2017	-	-	-	0.38 ± 0.02 c	0.39 ± 0.02 c	0.71 ± 0.02 a	0.52 ± 0.01 b	0.37 ± 0.02 c
	2018	-	-	-	0.15 ± 0.01 b	0.16 ± 0.01 b	0.23 a	0.23 ± 0.01 a	0.14 ± 0.01 b
	average	-	-	-	0.27 ± 0.01 c	0.27 ± 0.01 c	0.47 ± 0.01 a	0.37 ± 0.01 b	0.26 ± 0.01 c
Plantingmode	2017	0.73 ± 0.02 f	1.93 ± 0.02 e	2.47 ± 0.05 d	2.00 ± 0.03 e	3.40 ± 0.19 b	6.06 ± 0.21 a	2.82 ± 0.12 c	2.28 ± 0.08 d
	2018	0.36 g	0.85 ± 0.04 f	1.01 ± 0.01 de	0.94 ± 0.02 e	1.86 ± 0.02 b	2.36 ± 0.06 a	1.35 ± 0.05 c	1.03 ± 0.01 d
	average	0.55 ± 0.01 f	1.39 ± 0.03 e	1.74 ± 0.02 d	1.47 ± 0.02 e	2.63 ± 0.10 b	4.21 ± 0.13 a	2.09 ± 0.08 c	1.66 ± 0.04 d
Whole year	2017	0.70 ± 0.02 e	1.67 ± 0.02 d	2.14 ± 0.04 bc	2.00 ± 0.03 c	3.40 ± 0.19 a	3.47 ± 0.12 a	2.29 ± 0.10 b	2.26 ± 0.08 b
	2018	0.34 f	0.79 ± 0.04 e	0.95 ± 0.01 d	0.94 ± 0.02 d	1.86 ± 0.02 a	1.87 ± 0.05 a	1.13 ± 0.04 b	1.03 ± 0.01 c
	average	0.46 ± 0.01 f	1.08 ± 0.03 e	1.34 ± 0.01 cd	1.29 ± 0.02 d	2.37 ± 0.07 a	2.40 ± 0.07 a	1.51 ± 0.06 b	1.44 ± 0.03 bc

Note: 1st mature indicated the first season's crops, 2nd mature indicated the second season's crops, 3rd mature indicated third season's crops. Planting mode represents the amount of light resources allocated during the existence of the crop; whole year represents the amount of light resources allocated in the whole year. oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), potato-spring corn/summer soybean (T8). The different lowercase letters indicate significant differences among different treatments ($p < 0.05$).

3.4. Evaluation of the Efficiency of Utilizing Meteorological Resources for Light, Temperature, and Water

The concept of Climate Resource Occupancy (C-value) is used to indicate the amount of climate resources allocated and occupied by the cropping pattern. A higher C-value is positively correlated with more efficient resource use and greater resource output. It is important to note that the C-value should not be used as a subjective evaluation of the cropping pattern's efficiency. There was a significant difference in the C-values of the different models (Table 9). The combined mean value of the new multi-maturing cropping pattern (T5, T6, T7, T8) was 2.01, that of the traditional two-maturing net cropping pattern (T1, T2, T3) was 0.95, and that of the traditional three-maturing cropping pattern (T4) was 1.15, and the new pattern was higher than that of the traditional two-maturing cropping pattern and that of the traditional three-maturing cropping pattern by an average of 111.58% and 74.78%, respectively. T6 treatment has the highest C-value of 2.90 and optimal resource use efficiency.

Table 9. The Comprehensive Quantitative Assessment of Occupancy Rate of Climate Resources and the Utilization Rate of Climate Resources in Different Cropping Modes.

Treat Ment	Light Occupancy (%)	Accumulated T Occupancy (%)	Rain Occupancy (%)	Economic Output ($kg{\cdot}m^{-2}$)	Economic C Value
T1	92.76	91.28	94.80	0.41	0.44
T2	92.17	87.11	91.13	0.97	1.07
T3	92.17	87.11	91.13	1.20	1.33
T4	100.00	100.00	100.00	1.15	1.15
T5	99.64	99.75	99.97	2.11	2.12
T6	80.88	69.58	71.75	2.14	2.90
T7	84.64	74.41	82.58	1.35	1.68
T8	95.92	96.10	99.47	1.28	1.32

Note: oilseed rape-summer soybean (T1), oilseed rape-summer corn (T2), and wheat-summer corn (T3); existing three-maturity planting patterns: wheat/spring corn/summer soybean (T4); and new three-maturity planting patterns: forage oilseed rape-spring corn/summer soybean (T5), forage oilseed rape-spring corn||peanut (T6), potato-spring corn||peanut (T7), potato-spring corn/summer soybean (T8).

4. Discussion

4.1. Quantitative Evaluation of the Allocation and Production of Meteorological Resources and Their Combined Effects

Meteorological resources are fundamental to the physical production of crops, which is closely related to the climatic conditions of the region in which they are located [33,34]. Previous research has demonstrated that the flowering time of japonica rice is significantly influenced by light and temperature, whereas precipitation has a minor effect [35]. Increased temperature significantly affects the growth and quality of rice varieties in India and the Himalayan region [36]. Sustained high temperatures reduce rice quality and grain weight [37]. The experiment analyzed the allocation of climate resources, production efficiency and comprehensive effects. The results showed that the allocation ratio of the three-maturing set-crop planting pattern of T4, T5 and T8 treatments was superior in the allocation of light, temperature and water climate resources. This system had clear advantages compared to intercropping and monocropping systems due to its short symbiosis period and long effective fertility period. Trends in dry matter productivity and light energy utilization of climate resources and trends in annual material productivity converge across cropping patterns. Overall the productivity of climate resources in the T5 to T8 multi-crop models was better than that of the two-maturity net-crop model, indicating that the intercropping system can utilize climate resources such as light, temperature and water more efficiently relative to the monocrop system [38–40]. As forage oilseed rape has higher material-energy accumulation characteristics and its low allocation and high yield result in efficient use of resources, the T5 and T6 treatments prevailed in terms of climate resource productivity and light energy utilization; The high biological yield characteristics of the intercropped soybean system resulted in optimal climate resource productivity and light energy utilization for the T5 treatment in terms of biological yield, and the high economic yield characteristics of the intercropped peanut system resulted in optimal climate resource productivity and light energy utilization for the T6 treatment in terms of economic yield. Previous studies have shown that intercropping systems can effectively utilize soil water during the growing season to achieve efficient use of soil water in space and time [41], and that the biological yield advantage of intercropping systems can significantly improve resource use efficiency [42–45].

In the comprehensive evaluation of climate resource use efficiency, the intercropping system was rated higher than the monocropping model in terms of combined C-value for both economic and biological yields because of its higher resource yield [25,35]. Among the different cropping patterns, the T5 and T6 treatments had the highest annual economic yield C-value and biological yield C-value. Additionally, the planting crop for the T5 and T6 treatments, forage oilseed rape, had low resource allocation and high resource output characteristics, resulting in significantly higher C-values compared to the other patterns in the first season. It is important to note that this evaluation is based solely on objective data and not subjective opinions. The T6 treatments had higher C-values than the T5 treatments and the highest C-values among all cropping patterns. This was due to intercropping being comparable to monoculture in terms of material output while occupying fewer resources. Overall, intercropping was found to be more effective than monoculture in terms of integrated climate resource utilization. Among the eight models tested, the T6 treatment was found to be the most effective in terms of integrated resource utilization.

4.2. Allocation of Climate Resources and Crop Synergistic Response Mechanisms

Previous studies have shown that the response of different crops to effective cumulative temperature over the reproductive period is consistent. Estimating the contribution of plant traits to light partitioning in simultaneous maize/soybean intercropping showed that yield is significantly and positively correlated with effective cumulative temperature [21]. Improving the efficiency of water resource usage in crops can enhance nutrient utilization and, consequently, crop yields [46]. Additionally, efficient agricultural production can be promoted by maximizing light radiation utilization and temperature productivity [47].

Improving crop utilization of water resources can increase the stability of agricultural production [48]. The present study showed that intra- and inter-seasonal allocation of climatic resources significantly affected the yields of different cropping patterns (Table 5). Within the first season, economic and biological yields increased in the T1 to T4 treatments as the allocation of climatic resources increased, but economic yields in the T3 treatment may have declined due to precipitation limitations. In contrast, the crops in the T5 to T8 treatments avoided the negative effects of precipitation on economic yields by shortening the fertility period, reducing resource allocation, maintaining inter-annual equilibrium, and increasing production potential. The T5 and T6 treatments made better use of light and temperature resources, especially the significant increase in cumulative temperature, which favored the production of forage oilseed rape, highlighting the potential of these two treatments as winter forage crops. These crops are capable of mitigating the negative effects of summer rainfall on yields, utilizing light and temperature resources more efficiently, particularly cumulus, and are superior to winter cropping patterns for grain and oil production. Within the second season, precipitation distribution was the main production limiting factor. During the 2017 spring drought, maize in the later sown T5 to T8 treatments was less affected by the drought, had better dry matter accumulation and performed better in the intercropping system. The T4 treatment had the highest maize yield in the intercropping system, which complemented wheat as a resource and improved water use efficiency. However, treatments T5 to T8 were more affected by precipitation during the summer 2018 flooding scenario, resulting in lower economic yields. The overall decline in net-crop maize yields over the two-year period suggests that summer-sown maize is more susceptible to precipitation factors. Biological yields increased in the intercropping system, suggesting that the increase in precipitation mainly affected late-season yields. Intercropping systems with later sowing dates are relatively unstable and susceptible to climatic factors, while net cropping systems are less stable overall.

Different crop combinations also affect the yield stability and yield potential of cropping patterns. The multi-maturing cropping pattern from T5 to T8 has successfully prevented summer flooding. Additionally, the intercropping system is more efficient in water use, reduces the impact of spring drought on production, and provides better yield stability. Furthermore, during winter production, treatments T5 to T8 demonstrate superior resource allocation adjustment and mitigation of precipitation's impact on late-season yields, making them more efficient compared to winter cropping patterns for grain and oil. In summary, the T6 treatment outperformed the two-maturity net cropping model in terms of yield stability and yield potential, indicating the superiority of the new model. However, this study is not yet comprehensive and there is a need to investigate specific factors affecting yield in different climates or explore other crop combinations in future studies.

5. Conclusions

The light, temperature and water productivity of the new multi-maturing cropping pattern are significantly better than that of the traditional two-maturing net cropping pattern and the traditional three-maturing cropping pattern. The new three-maturity planting patterns have significantly increased LPE by 97.88% and 50%, ATLEUR by 0.48% and 0.31%, ATPE by 84.70% and 49.14%, and PPE by 101.04% and 49.61, compared to the two-maturity net cropping pattern and existing three-maturity cropping patterns. It was discovered that the resource output efficiency of new three-maturity planting patterns was higher than that of the two-maturity net cropping pattern and existing three-maturity cropping patterns by an average of 111.58% and 74.78%. The T6 treatment had the highest resource output efficiency, making it the optimal choice among all the models. Assessing the long-term sustainability and environmental impact of these cropping patterns is crucial. Future studies could examine soil health, biodiversity, and greenhouse gas emissions associated with these practices, ensuring they contribute to sustainable agricultural development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14061154/s1. Table S1. Introduction of the Growth Period of Different Cropping Modes. Table S2. Field Density and Fertilizer Application Amount of Different Cropping Modes. Table S3. Energy Conversion Coefficients of Different Cropping Modes. Table S4. Conversion Rates of Solar Energy Values for Major Energy Types in Agroecosystems. Table S5. Resource Allocation for Different Cropping Modes. Table S6. Annual Variation of Climatic Resource Allocation and Crop Response in Different Cropping Modes. Figure S1. Relationship between resource utilisation and economic yield in different cropping patterns.

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