RESEARCH ARTICLE

Effects of Mixed Sowing of Chinese Milk Vetch (*Astragalus sinicus L.*) and Rape on Rice Yield and Soil Physical and Chemical Properties

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Abstract: In order to explore the effects of Chinese milk vetch and rape mixed sowing on rice yield and soil fertility, and select the best planting mode, five different ratios of Chinese milk vetch and rape mixed sowing were designed to study the effects of different ratios on rice yield, soil physicochemical properties and soil fertility in 0-10 cm, 10- 20 cm and 20-30 cm layers. Grey correlation analysis of soil nutrients and yield was carried out by using the grey system theory. The influence of different soil layers on soil chemical properties was greater than physical properties. The effect on shallow soil is greater than that on deep soil. Mixed sowing of Chinese milk vetch and rape improved soil comprehensive fertility in all soil layers, and rice yield was the highest in the 2M2R treatment. pH value had the greatest effect on actual rice yield, followed by available potassium. Therefore, mixed sowing of Chinese milk vetch and rape could significantly increase the yield of early rice and soil nutrient content, and the pattern of "1/2 Chinese milk vetch +1/2 rape-early rice-late rice" had the best effect.

Keywords: Mixed sowing of Chinese milk vetch and rape; Rice yield; Comprehensive fertility; Grey correlation method

1. Introduction

The paddy field triple cropping system of planting green fertilizer in winter in double cropping rice field is a traditional planting mode in south China. As early as more than 3,000 years ago, China used green fertilizer to control weeds and cultivate land and fertilizer [1], and China has the largest planting area of green fertilizer in the world. Chinese milk vetch is a biennial legume crop having symbiotic nitrogen fixing bacteria with its root can fix nitrogen in the air, and average nitrogen fixation is 75-120 kg•hm^{-2} in the peak flowering stage. However, due to the shortage of Chinese milk vetch seed resources, high price, and the low C/N of Chinese milk vetch, it is not beneficial to the accumulation of nitrogen and organic matter in soil, which restricts its promotion and application [2]. Rape is the traditional cruciferous green fertilizer

in China, which has the advantages of wide range of adaptation, easy seed acquisition, low cost, high fertilizer efficiency, conducive to the accumulation of organic matter, and can activate phosphorus and potassium in the soil. Root exudates can stimulate nitrogen-fixing bacteria. Therefore, mixed sowing of Chinese vetch and rape can make full use of light and heat resources in over ground and water and nutrient resources in underground part [3]. Huang showed that, compared with the winter fallow treatment, the long-term return of Chinese milk vetch and rape to the field as green fertilizer could increase rice yield, reduce yield variation coefficient and increase the sustainability index of rice yield [4]. Gao [5] showed that returning green fertilizer to the field can promote rice yield, improve soil organic matter content and maintain soil nitrogen supply, which is a tillage system to maintain high and stable yield and sustainable development of rice. Deng [6] showed that winter rapeseed had obvious effects on improving soil physical and chemical properties, reducing soil bulk density, and increasing soil available potassium and organic matter contents, and the subsequent rice production increased significantly. There are many studies on the effects of single sowing of green fertilizer on rice yield and soil physicochemical properties, but there are few studies and comprehensive analysis on the effects of different mixed sowing ratios of Chinese milk vetch and rape on subsequent crops and soil. Therefore, in this paper, the actual rice yield and the comprehensive fertility index (IFI) of different soil layers under the mixed sowing of Chinese milk vetch and rape were studied, and the main soil chemical properties affecting the rice yield were analyzed by using the grey relational system theory, providing a scientific theoretical basis for the mixed sowing of green fertilizer technology in double cropping rice field.

2. Materials and Methods

2.1 Experimental Site Overview

The experiment was conducted from September 2017 to present in the rice experimental field (28° 46'N, 115° 55'E) in the Science park of Jiangxi Agricultural University. The experimental site belongs to the subtropical monsoon humid climate, with the annual total solar radiation of 4.79×1013 J•hm^{-2}, the annual sunshine duration of 1852 h, the annual effective accumulated temperature ≥ 0 °C of 6450 °C, the annual precipitation of 1665.7 mm, and the annual average temperature between 17.1 °C and 17.8 °C. The soil used in the experiment is red clay developed in the Quaternary, which is a typical subtropical red soil distribution area. At the beginning of the experiment, the content of organic matter was 34.93 g•kg^{-1}, total nitrogen was 2.00 mg•kg^{-1}, available phosphorus was 15.58

mg•kg^{-1}, available potassium was 41.73 mg•kg^{-1} and pH was 4.98.

2.2 Experimental Design

The experiment consisted of five treatments: (1) M (CK$_1$), single seeding of Chinese milk vetch - early rice-late rice; (2) treatment 3M1R, 3/4 Chinese milk vetch+1/4 rape-early rice-late rice; (3) treatment 2M2R, 1/2 Chinese milk vetch + 1/2 rape-early rice-late rice; (4) treatment 1M3R, 1/4 Chinese milk vetch + 3/4 rape-early rice-late rice; (5) Treatment R (CK$_2$), single sowing rape - early rice-late rice. The sowing amount was 22.5 kg•hm^{-2} for Chinese milk vetch and 7.5 kg•hm^{-2} for rape. Each treatment was repeated for 3 times, with a total of 15 plots with an area of 16.5 m^2 (5.5 m×3 m). The plots were separated by cement ridges 30 cm high. Before the experiment, soil fertility in each plot was uniform. Both sides are provided with a protection line, the width of the protection line is 30 cm.

2.3 Sample Collection and Determination

2.3.1 Rice Yield Measurement

At the late rice maturity stage, 50 stump were surveyed in each plot as the basis for effective panicle calculation, and 3 stump of representative rice plants were randomly selected in each plot by average method, and then used as seed test materials after natural air drying. The mass of 1000 grains was measured with 1/1000 analytical balance; each single cell as the actual yield.

2.3.2 Soil Nutrient Determination

One day after rice harvesting, each plot was divided into 0-10 cm, 10-20 cm and 20-30 cm layers according to the "5-point sampling method", and the tillage layer soil was evenly mixed, air-dried naturally, impurities removed and sieving, and soil nutrients were measured: soil pH was measured by pH meter; The content of organic matter was determined by external heating method of potassium dichromate and concentrated sulfuric acid; The total nitrogen content was determined by semi micro open nitrogen determination method; The content of available phosphorus was determined by NaHCO$_3$ extraction and molybdenum-antimony resistance colorimetry; The content of available potassium was extracted by NH$_4$OAc and flame photometry [7].

2.4 Data Calculatio

Soil Integrated Fertility Index (IFI): Nemerow index method [8] was used to evaluate the soil fertility quality un-

der each treatment. In this paper, soil pH, organic matter, total nitrogen, available phosphorus and available potassium were selected as fertility indexes to calculate fertility coefficient, and the modified Nemerow formula was used to calculate soil comprehensive fertility index.

(1) Calculation of fertility index IFI_i:

$$IFI_i \begin{cases} X/Xa & X \leq Xa \\ 1 + (X - Xa)/(Xc - Xa) & Xa < X \leq Xc \\ 2 + (X - Xc)/(Xp - Xc) & Xc < X \leq Xp \\ 3 & X > Xp \end{cases}$$

Where, IFI_i: fertility coefficient, X: measured value of this attribute; Xa and Xp grading standards lower and upper limit, Xc: between the upper and lower limits of grading standards (Table 1).

Table 1. Standard values of soil attribute classification

classification	pH	Organic matte (g·kg⁻¹)	Total nitrogen (g·kg⁻¹)	Available phosphorus (mg·kg⁻¹)	Available potassium (mg·kg⁻¹)
Xa	4.5	20	1	10	100
Xc	6.5	30	1.5	20	150
Xp	8.5	40	2	40	200

(2) Calculation of comprehensive soil fertility index IFI:

$$IFI = \frac{\sqrt{(IFI_{i\,average})^2 + (IFI_{i\,min})^2}}{2} + \frac{n-1}{n}$$

Where, $IFI_{i\,average}$ and $IFI_{i\,minimum}$ are the mean and minimum values of soil fertility of each attribute; n is the number of evaluation indicators.

Grey correlation degree calculation of soil nutrients. Different soil nutrient indexes were represented by X, different plots were represented by K, and the actual rice yield was taken as the reference series X_0. Based on the grey relational system theory, the range normalization method is used to standardize the data [9,10]. The specific calculation formula is as follows:

Correlation formula:

$$\varepsilon_{i(k)} = \frac{minmin|xo(k)-xi(k)| + \rho maxmax|xo(k)-xi(k)|}{|xo(k)-xi(k)| - \rho maxmax|xo(k)-xi(k)|}$$

Equal weight correlation: $R_i = \frac{1}{N}\sum_{K=1}^{N} \varepsilon_{i(k)}$

Type: $minmin|xo(k)-xi(k)|$ for the secondary minimum differential, $maxmax|xo(k)-xi(k)|$ for maximum differential secondary, is distinguish coefficient, the value range is 0 to 1, the N number of samples.

2.5 Data Analysis

Excel2019 was used for statistical processing, SPSS20.0 was used for one-way analysis of variance, and Origin 2018 was used for icon making.

3. Results

3.1 Effects of Different Mixing Ratios of Chinese Milk Vetch and Rape on Rice Yield

As can be seen from Table 2, the effects of different treatments on effective panicle number, 1000-grain weight and actual yield of rice under different proportions of Chinese milk vetch and rape were significant. There was no significant difference in grain number per panicle and seed setting rate among all treatments. In terms of effective panicle number, 1000-grain weight and actual yield, treatment 2M2R had the best performance, and the effective panicle number of treatment 2M2R was significantly different from that of two monocultures ($P<0.05$), which was 15.18-16.18% higher than that of two monocultures. The 1000-grain weight of treatment 2M2R was significantly higher than that of treatment R by 8.40% ($P<0.05$). Treatment 2M2R (9073.11 kg•hm⁻²) was significantly higher than that of treatment R (7594.76 kg•hm⁻²) by 19.47% ($P<0.05$). Therefore, mixed sowing of Chinese milk vetch and rape could significantly increase rice yield compared with monoculture treatment.

Table 2. Effects of mixed sowing Chinese milk vetch and rape on rice yield and its components

Planting season	Treatment	Effective panicle number/ (×10⁴·hm⁻²)	Grain number per spike	Seed setting rate/%	1000 grain weight/g	Actural production/ (kg·hm⁻²)
	M(CK₁)	212.31±8.96b	206.43±13.20a	71.85%±2.37a	23.49±0.57ab	7941.89±541.39ab
	3M1R	232.93±8.08ab	203.12±8.98a	74.34%±1.89a	24.24±0.50ab	8376.47±366.71ab
late rice	2M2R	244.54±9.49a	209.65±12.61a	76.24%±2.72a	25.04±0.47a	9073.11±375.37a
	1M3R	225.35±7.93ab	208.14±7.38a	74.29%±2.01a	23.34±0.46b	8209.09±249.75ab
	R(CK₂)	210.49±6.86b	214.39±7.55a	73.87%±2.78a	23.10±0.37b	7594.76±173.14b

Note: Data are mean of 3 replicates ± standard error; Different letters in the same column indicate a significant difference of 5%.

3.2 Effects of Different Mixing Ratios of Chinese Milk Vetch and Rape on Soil Physical Properties

As shown in Figure 1, at the late rice maturity stage in 2020, the water content and bulk density of each treatment in different soil layers were significantly different, but the difference between each treatment in the same soil layer was not significant. With the deepening of soil layer, soil moisture content decreased and bulk density increased. In 0-30 cm tilled soil, soil physical properties changed faster with the deepening of soil layer. There were significant differences in 0-10 cm soil layer. There was no significant difference in bulk density between the treatments in 10-20 cm and 20-30 cm soil layers, but there was a significant difference between control R and other treatments in the depth of 10-20 cm soil layer ($P<0.05$).

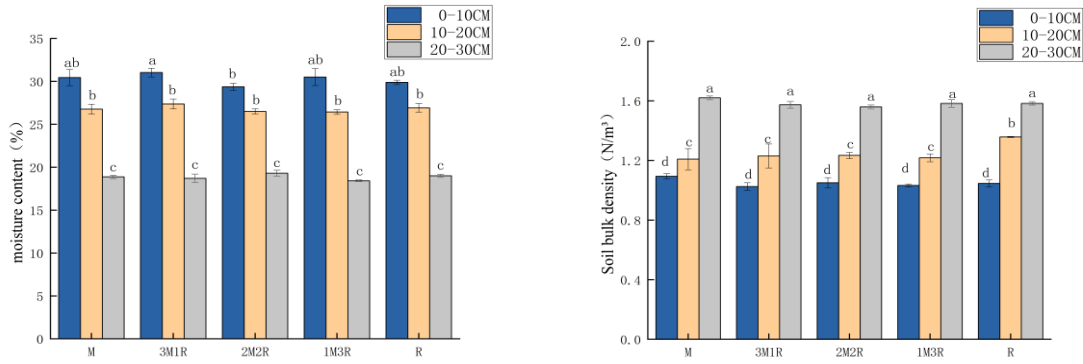## 3.3 Effects of Different Mixing Ratios of Chinese Milk Vetch and Rape on Soil Chemical Properties

Figure 1. Effects of mixed sowing of Chinese milk vetch and rape on water content and bulk density in different soil layers

Table 3. Effects of mixed sowing of Chinese milk vetch and rape on soil nutrients and fertility

Depth	Treatment	pH	Organic matter (g·kg⁻¹)	Total nitrogen (g·kg⁻¹)	Available phosphorus (mg·kg⁻¹)	Available potassium (mg·kg⁻¹)
0-10 cm	M(CK₁)	4.55±0.03c	31.98±0.33a	2.02±0.02a	16.26±1.32abcd	61.00±10.58abc
	3M1R	4.54±0.07c	33.29±0.15a	2.13±0.02a	18.72±1.94ab	69.67±5.24a
	2M2R	4.56±0.04c	33.04±0.38a	2.16±0.01a	19.54±1.13a	73.33±2.40ab
	1M3R	4.52±0.03c	31.58±0.83a	2.04±0.05a	17.33±2.97abc	64.00±3.61abc
	R(CK₂)	4.51±0.04c	31.71±0.36a	2.05±0.01a	16.88±0.93abc	62.67±1.20ab
10-20 cm	M(CK₁)	4.69±0.05b	21.98±1.30b	1.45±0.09b	14.13±3.12abcde	47.33±1.20b
	3M1R	4.73±0.06b	24.35±1.24b	1.61±0.11b	12.07±3.07abcde	46.67±3.71b
	2M2R	4.73±0.03b	22.61±1.47b	1.61±0.23b	13.08±3.20abcde	50.00±10.00b
	1M3R	4.73±0.04b	23.74±0.28b	1.58±0.04b	11.90±0.99bcde	51.00±7.55b
	R(CK₂)	4.77±0.05b	22.42±2.20b	1.47±0.13b	13.47±1.11abcd	58.67±7.80bc
20-30 cm	M(CK₁)	5.59±0.04a	13.60±1.36c	0.95±0.08c	7.72±0.22e	49.67±4.33b
	3M1R	5.55±0.02a	16.49±1.06c	0.91±0.10c	9.30±1.65de	46.00±4.36b
	2M2R	5.57±0.02a	16.02±1.54c	0.82±0.11c	9.74±2.44de	51.00±1.73b
	1M3R	5.52±0.02a	16.63±0.76c	0.90±0.02c	11.85±2.32bcde	47.00±5.29b
	R(CK₂)	5.55±0.02a	13.99±0.96c	0.77±0.04c	10.40±1.48cde	46.67±2.40b

3.4 Effects of Mixed Sowing of Different Proportions of Chinese Milk Vetch and Rape on Soil Chemical Properties

Figure 2 shows the comprehensive soil fertility index (IFI) at the late rice maturity stage in 2020. As shown in Figure 2, there were significant differences in soil fertility among different soil layers under different treatments (*P*<0.05), but no significant differences among different treatments in the same soil layer (*P*>0.05). In 0-10 cm layer, 2M2R was the highest and M was the lowest. In 10-20 cm layer, treatment 3M1R was the highest and treatment M was the lowest. At 20-30 cm, treatment 1M3R was the highest, and treatment M and R were the lowest. In general, mixed sowing of Chinese milk vetch and rape had a great effect on the comprehensive index of shallow soil fertility, and the IFI index of mixed sowing was higher than that of single sowing.
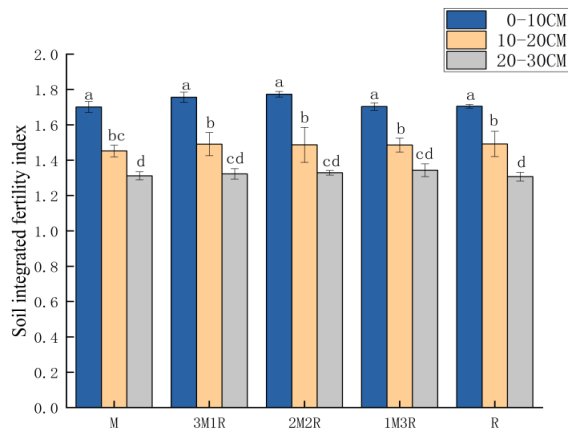

Figure 2. Comprehensive soil fertility index under different treatments

3.5 Grey Correlation Analysis of Rice Yield and Soil Fertility under Different Mixed-planting Ratios

According to the requirements of grey system theory, the grey correlation degree between soil nutrient indexes and actual rice yield was analyzed, and ρ was 0.5. The higher the score of the equal-weight correlation coefficient, the greater the correlation between the index and the actual rice yield. It can be seen from Figure 3 that the correlation degree of all indexes on yield is as follows: pH (0.7332) > available potassium (0.6957) > organic matter (0.6785) > total nitrogen (0.6562) > available phosphorus (0.6561). Gray correlation analysis of soil nutrients and rice yield can explore the relationship between rice yield and soil nutrients, and help clarify the nutrient factors affecting rice yield. In this test field, pH is the biggest fac-

tor affecting rice yield, followed by available potassium. Increasing soil pH and applying potassium fertilizer can greatly improve rice yield.
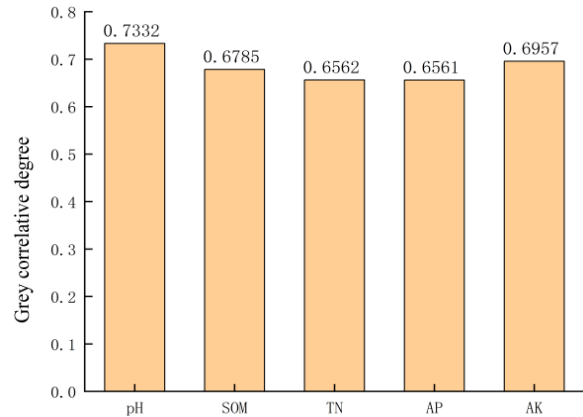

Figure 3. Equal-weight correlation degree and ranking of soil nutrient indexes

4. Discussion

4.1 Effects of Different Mixing Ratio on Rice Yield

By turning green fertilizer into soil, organic fertilizer is formed and released into paddy soil, which not only improves the utilization rate of fertilizer, but also ensures the need for fertilizer at all stages of rice growth and improves rice yield [11]. Increased application of organic materials can significantly improve crop yield [12]. Zeng [13] showed that the effective panicle number, solid grain number and 1000-grain weight of rice under milk vetch mulching were increased, and the number of grains per panicle and seed setting rate of rice under rape straw returning were increased [14]. The results of this study showed that the effective panicle number of 2M2R was 15.18-16.18% higher that of monoculture, and the actual rice yield was 14.24-19.47% higher than that of monoculture. Green fertilizer returning could increase rice yield by improving the effective panicle number, which was consistent with the research results of Li Ping [15].

4.2 Effects of Different Mixing Ratio on Soil Physical and Chemical Properties

Winter planting of green manure in double cropping rice fields not only improves surface water content, enhances soil permeability, and achieves the effect of conserving soil moisture, but also reduces soil bulk density and optimizes soil structure by turning and returning green manure to the field [16]. The results of this study showed that the effect of Chinese milk vetch monoculture and mixed sowing of Chinese milk vetch and rape on soil bulk

density reduction was better than that of rape monoculture. Returning green manure to the field as organic matter can increase rich nutrients for the soil and transform insoluble nutrients in the soil [17]. Huang [18] showed that the mixed sowing of Chinese milk vetch and rape could increase the contents of soil organic matter, insoluble nutrient transformation, available phosphorus and available potassium. The results of this study showed that under the green fertilizer and double cropping rice planting mode, the mixed sowing treatments of Chinese milk vetch and rape improved the soil nutrients in different layers, and each treatment had a great impact on the soil nutrients in 0-10 cm layer, in which the available phosphorus and available potassium were the most obvious. The available phosphorus content in treatment 2M2R was the highest, and the available potassium content in treatment 3M1R was the highest. In 0-30 cm soil layer, there were significant differences in comprehensive soil fertility of each layer, indicating that soil depth was closely related to soil fertility.

Mixed green manure increased the soil comprehensive fertility index (IFI) the most, which might be because Chinese milk vetch was a leguminous crop and atmospheric nitrogen during its growth. Rape has the function of activating insoluble nutrients, and the biomass of mixed sowing treatment is larger, green manure rot explains the release of a large amount of nitrogen, phosphorus, potassium, so improve the comprehensive soil fertility. There was no obvious difference among all treatments, which may be due to the lack of test years. The specific content of soil nutrients increased by mixed sowing of different proportions of Chinese vetch rape needs to be verified by long-term positioning test. Soil fertility reflects the degree of soil fertility, which is the basis of productivity [19,20]. The results of this study showed that different soil nutrients had different effects on rice yield, and the most important factor affecting rice yield was pH, followed by available potassium. Therefore, selecting a suitable mixture ratio of Chinese milk vetch and rape can increase rice yield.

5. Conclusions

In conclusion, the mixed planting pattern of Chinese milk veg and rape can better improve shallow soil fertility and increase rice yield and components. In this experiment, 11.25 kg•hm^{-2} Chinese milk vetch +3.75 kg•hm^{-2} rape-early-rice-late rice had the best effect, which was a new green fertilizer planting mode and crop rotation mode in south China, and had a very good application prospect.

Conflict of Interest

The authors declare no conflict of interest.

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