

# Soil Fertility Comparison between Rotations of Tobacco-Rice (TR) and Rape-Rice (RR)

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## Abstract

Tobacco-planting plays an important role in ensuring the high-quality tobacco raw materials supply and the local social and economic development in Chenzhou City. In recent years whether tobacco-planting is better for the maintenance and improvement of soil fertility than other crop-planting has been highly concerned. In this study, 16 soil fertility indicators and soil integrated index (*IFI*) were compared by 21 pairs of fields in Chenzhou city under the rotations of tobacco-rice (TF) and rice-rice (RR), and results showed that, comparing the mean values of soil fertility indicators, the contents of OM, TN, AN, AK, S and *IFI* were extremely significantly higher in TR than those in RR ( $p < 0.01$ ), the contents of Cu, Ca, Mg and Fe were significantly higher in TR than those in RR ( $p < 0.05$ ), but Mn content was significantly lower in TR than those in RR ( $p < 0.05$ ). Meanwhile the contents of TP, TK and AP were insignificantly higher in TR than those in RR, and the contents of B, Mo and Zn were insignificantly lower in TR than those in RR. The above significant differences in soil fertility indicators were mainly due to relatively higher fertilizer inputs and less nutrient removal during tobacco-growing season than during rape-growing season, the net increase of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O are 8.61, 5.25 and 24.89 kg per 667 m<sup>2</sup> respectively in tobacco-growing season, while the net decrease of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O are 8.88, 4.70 and 4.62 kg per 667 m<sup>2</sup> respectively in rape-growing season. C.V. of soil fertility indicators and *IFI* were meanly lower in TR (52.25% and 15.95%, respectively) than those in RR (63.07% and 22.12%, respectively). Comparatively, tobacco-planting can improve soil fertility better than rape-planting when rotated with late rice in Chenzhou city. For tobacco-planting, Mg fertilizer should be applied for 23.8% TR fields, while more N, K, Ca, Mg, S and B fertilizers should be ap-

plied for 42.86%, 23.81%, 14.29%, 47.62%, 80.95% and 47.62% RR fields, respectively.

## Keywords

Comparison, Soil Fertility Indicator, Soil Integrated Index, Tobacco-Rice Rotation (TR), Rape-Rice Rotation (RR), Chenzhou

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## 1. Introduction

Chenzhou city is located in the southeast of Hunan Province, between 112°13' - 114°14' east longitude and 24°53' - 26°50' north latitude with a total area of is  $1.94 \times 10^4$  km<sup>2</sup>, which is belonged to the sub-tropical monsoon humid climate zone with annual sunshine duration of 1663 h, temperature of 17.4°C, precipitation of 1452 mm and frost-free period of 280 d. With a long history of tobacco-planting as early as 1593 [1], Chenzhou is the most important and typical tobacco-planting region with burnt-pure sweet aroma in China [2], which plays an important role in ensuring the high-quality tobacco raw materials supply and the local social and economic development. The current area of the cultivated land in Chenzhou city is  $22.0 \times 10^4$  hm<sup>2</sup> with the paddy field of  $16.8 \times 10^4$  hm<sup>2</sup>, and some paddy fields there are under the rotations of tobacco-rice (about  $2.67 \times 10^4$  hm<sup>2</sup>) and rape-rice. In recent years, rotation is more beneficial to soil fertility maintenance and improvement has been highly concerned by the local agricultural decision-makers and farmers.

There are reports in China on the comparison of soil properties of tobacco fields under the different situations, which included soil nutrients [3] [4] [5] [6], enzyme activities, bacterial community structures and diversities [7] [8] [9]. However, fewer studies were conducted on the comparison of soil nutrients or fertilities between tobacco fields and other crop fields, for example, Long *et al.* [10] found that soil aggregates under maize continuous-cropping had higher organic carbon content, carbon sequestration capacity and contribution rates to soil organic carbon than tobacco continuous-cropping in northwestern Hunan. Zhang [11] showed no significant difference in soil organic matter, total nitrogen, total phosphorus, total potassium, alkali-hydrolyzable nitrogen, available sulfur and CEC between tobacco-rice rotation and rice-rice rotation in Jianghua, Changning, Xintian and Changsha of Hunan, but available phosphorus and potassium in the former were significantly higher than those in the latter. Wang *et al.* [12] disclosed that rice-rice rotation and tobacco-rice rotation were better for soil fertility improvement than the planting modes of single rice, Chinese medicinal materials, rice-rape and rice-wheat in Xuanzhou district of South Anhui.

Although some literatures were published about tobacco soil in Chenzhou city [13] [14] [15] [16], which play an important guiding role in improving soil fer-

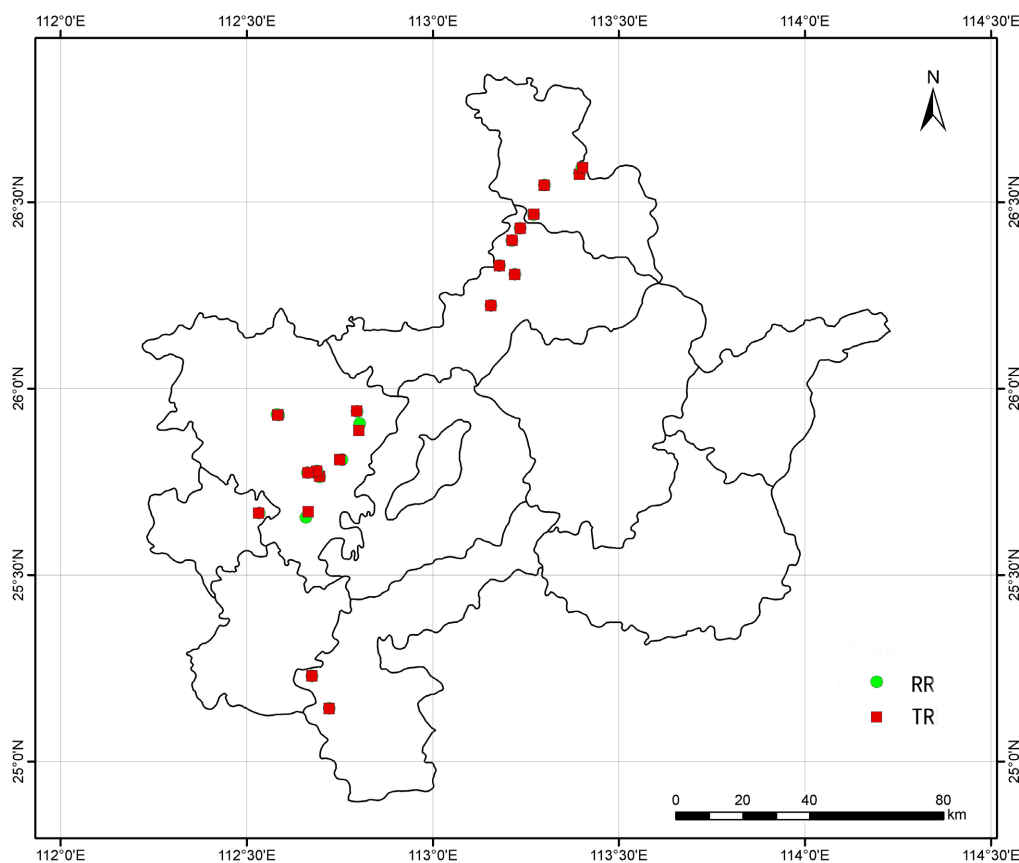
tility and quality of tobacco fields, so far there is no report on comparison of soil fertility indicators and integrated fertility indexes (*IFI*) under the rotations of tobacco-rice (TR) and rape-rice (RR). Therefore, this study was conducted to clarify the difference between TR and RR in maintaining or improving soil quality in order to provide further scientific guidance for fertilization and soil improvement.

## 2. Methods and Materials

### 2.1. Soil Sampling and Determination

In the December of 2020 after the later rice was harvested, 21 pairs of tight adjacent TR and RR fields were selected in Chenzhou city according to the spatial distribution tobacco fields (see **Figure 1**). Soil samples of the plough layers (0 - 20 cm) in the selected TR and RR fields were collected randomly at 8 sites and mixed fully (1.5 - 2 kg in total).

16 soil fertility indicators were selected in this study, and their determination methods are as follows: organic matter (OM) by potassium dichromate oxidation, total nitrogen (TN) by Kelvin method, available nitrogen (AN) by alkali-hydrolyzed diffusion, total and available phosphorus (TP and AP) by molybdenum antimony colorimetry, total and available potassium (TK and AK) by



**Figure 1.** Sites of selected TR and RR fields in Chenzhou city.

photometry, available calcium (Ca), magnesium (Mg), sulfur (S), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) by atomic absorption spectrophotometry, effective boron (B) by curcumin colorimetry, effective molybdenum (Mo) by polarization spectrometer. All the detailed determination methods for soil fertility indicators could be found in related literatures [17] [18].

## 2.2. Soil Fertility Indicator Grading and Quantitative Assessment

There are many reports available in China on the grading standards of soil fertility indicators for tobacco-planting fields. In this study, for easily and rapidly assess tobacco-planting suitability of the fertility indicators, all fertility indicators were simply divided into 3 grades (low, suitable, high) as in **Table 1** based on the related literatures in Hunan Province and its neighboring areas [19] [20] [21] [22] [23].

There are various methods for the assessment of soil *IFI* [24], usually soil *IFI* is calculated according to the following formula  $IFI = \sum(W_i \times N_i)$ , where  $W_i$  is for the weight of indicator  $i$ , according to a current concept of “storing nutrients in soil” and in order to simply calculate soil *IF*, in this study the contributions of all fertility indicators to soil *IFI* were thought as equal so the weight value of each fertility indicator was meanly defined as  $1/16 = 0.0625$ ;  $N_i$  is the membership of indicator  $i$  which was simply calculated as the measured value ( $X_i$ ) of an indicator divided by the measured maximum value of that indicator ( $X_{max}$ ). Thus, soil *IFI* is also ranged from 0 to 1, the higher *IFI* value, the higher soil fertility.

**Table 1.** Grading standards of soil fertility indicators for tobacco-planting fields.

Fertility indicator	Grade		
	Low	Suitable	high
OM	<15	15 - 30	≥30
AN	<100	100 - 180	≥180
AP	<15	15 - 30	≥30
AK	<150	150 - 220	≥220
Ca	<6	6 - 10	≥10
Mg	<1.0	1.0 - 1.6	≥1.6
S	<16	16 - 30	≥30
B	<0.3	0.3 - 0.6	≥0.6
Cu	<0.5	0.5 - 1.0	≥1.0
Fe	<4.5	4.5 - 10	≥10
Mn	<10	10 - 20	≥20
Mo	<0.15	0.15 - 0.2	≥0.2
Zn	<1.0	1.0 - 2.0	≥2.0

Note: in the first column, SOM, TN, TP and TK, g/kg; AN, AP, AK, S, B, Fe, Mn, Cu, Zn and Mo, mg/kg; Ca, cmol(1/2Ca<sup>2+</sup>)/kg; Mg, cmol(1/2Mg<sup>2+</sup>)/kg. The same below.

### 2.3. Data Processing and Statistics

Microsoft Excel 2016 and IBM Statistics SPSS 22.0 software were used for statistical analysis of the data, and T-test method of paired sample was used for the multiple comparisons [25].

## 3. Results

### 3.1. Suitability Assessment of TR and RR Fields for Tobacco-Planting

**Table 2** lists the field numbers of TR and RR in the lower grades of soil fertility indicators for the suggestion of reasonable fertilization and soil improvement for tobacco planting, it can be seen that no field was lower in OM, Cu, Fe and Zn in TR and RR. For TR, only 1 field was lower in AN, AP and Mn, 2 fields were lower in AK, Ca, S, B and Mo, while 5 fields were lower in Mg. However, For RR, 1 field was lower in AP and Mo, 3 fields were lower in Ca, 5 fields were lower in AK, 9 fields were lower in AN, 10 fields were lower in Mg and B, 17 fields were lower in S. These above differences in field numbers show that TR are better than RR in soil fertility indicators, thus, it is better for the megafinance and improvement of soil fertility. For the reasonable application of fertilizers for tobacco-planting, Mg fertilizer should be applied for 23.8% TR fields, while more N, K, Ca, Mg, S and B fertilizers should be applied for 42.86%, 23.81%, 14.29%, 47.62%, 80.95% and 47.62% RR fields, respectively.

### 3.2. Statistics and Comparison of Soil Fertility Indicators between TR and RR

**Table 3** shows the general statistical results of soil fertility indicators of TR and

**Table 2.** Field numbers with low grades of soil fertility indicators.

Fertility indicator	TR		RR	
	Field no.	%	Field no.	%
OM	0	0	0	0
AN	1	4.76	9	42.86
AP	1	4.76	1	4.76
AK	2	9.52	5	23.81
Ca	2	9.52	3	14.29
Mg	5	23.81	10	47.62
S	2	9.52	17	80.95
B	2	9.52	10	47.62
Cu	0	0	0	0
Fe	0	0	0	0
Mn	1	4.76	0	0
Mo	2	9.52	1	4.76
Zn	0	0	0	0

**Table 3.** Statistical descriptions of soil fertility indicators.

Fertility indicator	Min.		Max.		Mean $\pm$ S.D.		C.V. (%)		Difference (%)	P
	TR	RR	TR	RR	TR	RR	TR	RR		
OM	20.30	17.30	56.10	51.20	39.59 $\pm$ 9.55	27.80 $\pm$ 8.59	24.13	30.90	42.39	0
TN	1.20	0.89	2.96	2.81	2.09 $\pm$ 0.48	1.50 $\pm$ 0.44	22.92	29.25	39.20	0
TP	0.59	0.47	1.52	1.57	1.01 $\pm$ 0.26	0.89 $\pm$ 0.30	26.03	33.86	13.68	0.095
TK	6.83	6.15	20.98	22.38	12.44 $\pm$ 3.78	12.02 $\pm$ 3.97	30.39	33.04	3.46	0.669
AN	92.00	74.00	202.00	173.00	143.19 $\pm$ 27.98	109.19 $\pm$ 27.83	19.54	25.48	31.14	0.001
AP	14.60	13.50	72.20	82.50	42.60 $\pm$ 15.90	37.85 $\pm$ 17.57	37.32	46.41	12.57	0.230
AK	106.0	75.0	418.00	455.0	279.4 $\pm$ 84.9	206.7 $\pm$ 30.8	30.37	43.44	35.18	0.009
Ca	4.39	3.47	48.73	50.06	24.72 $\pm$ 17.31	14.08 $\pm$ 11.56	70.02	82.07	75.54	0.038
Mg	0.54	0.63	2.72	2.63	1.71 $\pm$ 0.67	1.24 $\pm$ 0.55	38.94	44.21	38.18	0.013
S	14.12	0.78	50.32	49.01	30.35 $\pm$ 11.18	10.44 $\pm$ 11.58	36.83	110.92	190.61	0
B	0.25	0.17	0.68	3.58	0.48 $\pm$ 0.12	0.51 $\pm$ 0.72	25.07	142.82	-4.60	0.926
Cu	1.92	1.26	8.15	7.70	4.60 $\pm$ 1.72	3.24 $\pm$ 1.61	37.32	49.70	41.96	0.018
Fe	45.76	20.60	171.60	246.25	97.25 $\pm$ 42.54	68.98 $\pm$ 53.28	43.75	77.25	40.99	0.049
Mn	8.50	13.70	19.53	19.35	16.21 $\pm$ 2.97	17.72 $\pm$ 1.59	18.35	8.96	-8.50	0.017
Mo	0.08	0.08	7.56	9.58	1.20 $\pm$ 2.16	1.36 $\pm$ 2.09	179.73	153.96	-11.60	0.811
Zn	1.35	1.56	21.46	13.34	4.55 $\pm$ 4.63	4.85 $\pm$ 2.91	101.64	59.99	-6.08	0.822

Note: data in Difference column were calculated as:  $(TR - RR) \times 100/RR$ .

RR. Comparing the mean values of soil fertility indicators, it can be seen that the contents of OM, TN, AN, AK and S were extremely significantly higher in TR than those in RR, the contents of Cu, Ca, Mg and Fe were significantly higher in TR than those in RR. Meanwhile, the contents of TP, TK and AP were insignificantly higher in TR than those in RR. Only Mn content was significantly lower in TR than those in RR, meanwhile the contents of B, Mo and Zn were insignificantly lower in TR than those in RR. It also can be found from **Table 3** that C.V. of soil fertility indicators were ranged from 18.35% to 179.73% for TR and 8.96% to 153.96% for RR, but the mean value of C.V. was 46.40% for TR, which was lower than that of RR (60.76%).

### 3.3. Statistics and Comparison of IFI in Chenzhou TR and RR

**Table 4** exhibits the statistic information of soil *IFI* of TR and RR, it can be seen that soil *IFI* was ranged from 0.336 - 0.723 with a mean of 0.528 for TR, which is significantly higher than that of RR (ranged from 0.287 - 0.653 with a mean of 0.412,  $p < 0.001$ ). For the 21 RR fields, there were 10, 10 and 1 fields with soil *IFI* in the range of 0.2 - 0.4, 0.4 - 0.6 and 0.6 - 0.8 respectively, while for the 21 TR fields, there were 1, 16 and 4 fields with soil *IFI* in the range of 0.2 - 0.4, 0.4 - 0.6 and 0.6 - 0.8 respectively. It also can be found from **Table 4** that C.V. of soil *IFI* were 15.95% for TR, which is lower than RR (22.12%).

**Table 4.** Statistic descriptions of soil *IFI* of TR and RR.

Rotation mode	Min.	Max.	Mean $\pm$ S.D.	C.V. (%)
TR	0.336	0.723	0.528 $\pm$ 0.084A	15.95
RR	0.287	0.653	0.412 $\pm$ 0.091B	22.12

Note: values in the same column followed by different uppercase letters are significantly different at the 0.001 level.

#### 4. Discussion

Soil fertility assessment is one of the basic studies in soil science, and it is also important for the maintenance and improvement of soil fertility, new literatures are continuously published even in recent years [26] [27] [28] [29]. Meanwhile, soil fertility evaluation of tobacco-planting fields also has been reported more so far [19] [20] [21] [22] [23], but fewer studies compared the differences in soil fertility between TR and RR, our study gives the preliminary information on this issue, and proved that TR is better for the megafinance and improvement of soil fertility than RR, which is similar as the results obtained by Wang *et al.* [6].

For the differences in the contents of OM and effective nutrients between TR and RR, according to our survey in Chenzhou city, the straws of flue-cured tobacco, rape and rice are all returned to the fields. Here, the nutrient contents input from fertilizers into soil and removal out from soil by rice yield are not considered in this study (generally 15 kg compound fertilizer (N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O = 15:15:15) + 5 kg urea (46.2% N), rice yield is about 700 kg). The fertilizers applied in tobacco season included 15 kg cake fertilizer, 50 kg base fertilizer, 8 kg seedling raising fertilizer, 50 kg topdressing fertilizer and 15 kg potassium sulfate, the total inputs of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O are about 1.15, 9.23 and 27.61 kg 667 m<sup>2</sup>, respectively; while the total N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O removed out by tobacco leaves (the yield is about 150 kg 667 m<sup>2</sup>) are about 2.54, 3.98 and 2.72 kg 667 m<sup>2</sup>, respectively; Thus, the net increase of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O are about 8.61, 5.25 and 24.89 kg 667 m<sup>2</sup>, respectively. In addition, the organic matter input was 8 kg 667 m<sup>2</sup> by applying cake fertilizer. The fertilizers applied in rape season were 30 kg compound fertilizer and 10 kg urea, the total inputs of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O are about 9.12, 4.50 and 4.50 kg 667 m<sup>2</sup>, respectively; while the total N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O removed out by rapeseed (the yield is about 400 kg 667 m<sup>2</sup>) are about 18.00, 9.20 and 9.12 kg 667 m<sup>2</sup>, respectively; Thus, the net decrease of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O are about 8.88, 4.70 and 4.62 kg 667 m<sup>2</sup>, respectively. Therefore, it could be thought that soil fertility is improved in tobacco season but is deteriorated in rape season. These above data could explain why soil OM, AN and AK of TR were significantly higher than those of RR (for AP, TR was also higher than RR, although no significant level is obtained).

Ca and Mg was significantly higher in TR than in RR, which could be related with that phosphorus in tobacco compound fertilizers applied in Chenzhou comes from calcium magnesium phosphate, and sometimes the applied dolomite powders rich in Ca and Mg to improve the acid tobacco fields (pH < 5.5).

the significant higher of S in TR than in RR could be attributed to the application of potassium sulphate, which is the most important and necessary top-dressing (usually 225 kg hm<sup>2</sup>) in China for the growth of high-quality tobacco [30]. However, it should be noticed that the application of potassium sulphate should be strictly monitored and controlled because excessive S would worsen the quality of tobacco leaves [31] [32]. It needs further to explore the significant higher of Cu and Fe in TR than RR, one reason may be the application of the pesticides containing Cu or Fe. No significant difference in B, Mo and Zn between TR and RR may be related with little concern were paid on these trace nutrients, thus, the corresponding fertilizers are seldomly used, meanwhile there are few literatures on the application of these fertilizers for tobacco-planting in China [33] [34] [35] [36].

Soil fertility affects or determines the growth, yield and quality of tobacco, it also determines the economic benefits of local tobacco-planting farmers, comparatively, the net income of tobacco-planting (about 1000 - 2000 yuan) is higher than that of rape-planting (about 200 yuan), so more and great concerns have been paid to soil improvement, almost all the tobacco-planting regions in China have formulated the technical regulation of tobacco planting, which can homogenize soil fertility of tobacco fields, so the mean values of C.V. of soil fertility indicators and *IFI* were lower in TR (46.40% and 15.95%, respectively) than those in RR (60.76% and 22.12%, respectively, see **Table 2** and **Table 3**).

It should be pointed that there are certain relationships between soil fertility with the growth, yield and quality of tobacco, however, it is not studied in this study but would be conducted in our further research.

## 5. Conclusion

This study compared soil fertility indicators and integrated fertility index (*IFI*) under the rotations of tobacco-rice (TR) and rape-rice (RR) in Chenzhou city, comparatively, TR was significantly higher than RR in soil OM, TN, AN, AK, Ca, Mg, S, Cu, Fe and *IFI*, but Mn was significantly lower in TR than RR, while there was no significant difference in the contents of soil TP, TK, AP, B, Mo and Zn. The above significant differences could be attributed due to the higher fertilizer inputs and less nutrient removal during tobacco-growing season than during rape-growing season, which proves that tobacco-planting can improve soil fertility better than rape-planting when rotated with late rice in Chenzhou city.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.



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