Remote Sensing Study on Improving Rice Yield by Cotton-Rice Rotation

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Abstract. From 2001 to 2002, an observation experiment based on satellite remote sensing was conducted in Xinghua City to study the difference between continuous rice monoculture and cotton-rice rotation rice in the rice ratio vegetation indexes or rice yields. This paper introduces the analysis method of rice yield difference developed for this experiment, and demonstrates it with the rice vegetation index. The results show that the average rice vegetation index or yield of cotton-rice and rice modes is different. We have found enough experiment data to come to conclusion that rice yield under cotton-rice mode is higher than that under continuous rice monoculture.

1. Introduction
Now the question is whether the cotton-rice rotation, when subject to significance testing, produces a higher rice yield than the rice-rice monoculture. A solution to test the significance of crop yield increase is to carry out small crop culture experiments. In another aspect, even if the yield response in rice rotation was confirmed in small crop culture trials, large geographical scope trials of the yield response in rice rotation have received little attention [1-3]. In this paper, a remote sensing observation experiment is proposed to test the significance of rice yield response to large geographical scope cotton-rice rotation. This method uses the rice vegetation index and the rice sampling in remote sensing images to test the significant difference of rice yield response to cotton and rice rotation. The combination of these two different technologies forms a novel remote sensing observation experiment for better study of large-scale crop rotations.

2. Material and methods
The following work was conducted in Xinghua of China between 2001 and 2002. The crop vegetation index analysis on remote sensing images is a major tool for studying crop yield [4]. On the LANDSAT 7 images (their date for 2001/7/26 and 2002/7/29), 40 samples were collected for computing the rice vegetation indexes under the cotton-rice mode with a total area of 1.71 hectares, and another 40 samples for computing the rice vegetation indexes under the rice-rice mode with a total area of 3.72 hectares, as shown in table 1. The rice vegetation index is computed using the equation

\[ RVI = B_4 / B_3 \]  

where B3 is near-infrared-channel radiance and B4 is red-channel radiance in table 1.

Suppose \( y_{11}, y_{12}, \ldots, y_{1n1} \) be for the rice vegetation index values of \( n_1 \) samples from rice and rice culture mode and \( y_{21}, y_{22}, \ldots, y_{2n2} \) be for the rice vegetation index values of \( n_2 \) samples from cotton and
rice culture mode. We suppose that these vegetation indexes are randomly sampled from the normal distribution populations.

Table 1. Data from continuous rice monoculture area and cotton-rice rotation area.

| SN | Digital-Number-Band of Rice and Rice | 0° | Digital-Number-Band of Cotton and Rice | RVI |
|----|-------------------------------------|----|---------------------------------------|-----|
| 1  | 61.00                               | 104.25 | 1.7090 | 1.7090 | 99.89 | 108.11 | 1.8051 |
| 2  | 61.50                               | 105.25 | 1.7144 | 1.7144 | 98.89 | 107.89 | 1.8321 |
| 3  | 61.67                               | 104.67 | 1.6973 | 1.6973 | 98.67 | 108.78 | 1.8541 |
| 4  | 63.75                               | 103.75 | 1.6275 | 1.6275 | 99.22 | 108.78 | 1.8369 |
| 5  | 62.75                               | 104.50 | 1.6653 | 1.6653 | 98.78 | 110.67 | 1.8513 |
| 6  | 62.50                               | 104.17 | 1.6667 | 1.6667 | 99.11 | 106.22 | 1.7970 |
| 7  | 65.25                               | 104.00 | 1.5939 | 1.5939 | 61.00 | 106.78 | 1.7505 |
| 8  | 64.50                               | 106.75 | 1.6550 | 1.6550 | 60.67 | 104.67 | 1.7252 |
| 9  | 64.00                               | 103.25 | 1.6133 | 1.6133 | 60.56 | 106.89 | 1.7650 |
| 10 | 64.25                               | 106.25 | 1.6537 | 1.6537 | 60.33 | 105.08 | 1.7418 |
| 11 | 62.75                               | 106.75 | 1.7012 | 1.7012 | 61.81 | 107.56 | 1.7402 |
| 12 | 65.00                               | 102.75 | 1.5808 | 1.5808 | 62.20 | 106.40 | 1.7106 |
| 13 | 64.67                               | 104.50 | 1.6159 | 1.6159 | 62.56 | 108.11 | 1.7281 |
| 14 | 63.00                               | 106.75 | 1.6944 | 1.6944 | 63.67 | 106.83 | 1.6779 |
| 15 | 61.25                               | 108.75 | 1.7755 | 1.7755 | 62.56 | 108.22 | 1.7299 |
| 16 | 62.50                               | 105.50 | 1.6880 | 1.6880 | 64.89 | 108.22 | 1.6677 |
| 17 | 63.00                               | 103.00 | 1.6349 | 1.6349 | 62.81 | 108.69 | 1.7305 |
| 18 | 61.25                               | 108.50 | 1.7714 | 1.7714 | 65.42 | 105.75 | 1.6165 |
| 19 | 64.25                               | 104.50 | 1.6265 | 1.6265 | 64.25 | 105.67 | 1.6447 |
| 20 | 64.50                               | 101.75 | 1.5775 | 1.5775 | 64.33 | 104.75 | 1.6283 |
| 21 | 64.00                               | 104.60 | 1.6250 | 1.6250 | 65.00 | 106.33 | 1.6358 |
| 22 | 65.00                               | 103.75 | 1.5962 | 1.5962 | 65.00 | 108.33 | 1.6859 |
| 23 | 65.00                               | 104.00 | 1.6000 | 1.6000 | 62.56 | 107.44 | 1.7174 |
| 24 | 65.00                               | 104.50 | 1.6077 | 1.6077 | 64.56 | 106.56 | 1.6506 |
| 25 | 66.75                               | 106.00 | 1.5880 | 1.5880 | 65.56 | 108.56 | 1.6599 |
| 26 | 64.25                               | 100.50 | 1.5642 | 1.5642 | 64.67 | 109.89 | 1.6992 |
| 27 | 62.00                               | 108.25 | 1.7460 | 1.7460 | 65.00 | 107.33 | 1.6512 |
| 28 | 66.00                               | 104.50 | 1.5833 | 1.5833 | 66.08 | 104.25 | 1.5776 |
| 29 | 65.50                               | 105.75 | 1.6145 | 1.6145 | 62.92 | 106.17 | 1.6874 |
| 30 | 62.83                               | 105.00 | 1.6712 | 1.6712 | 64.08 | 109.08 | 1.7022 |
| 31 | 62.67                               | 104.17 | 1.6622 | 1.6622 | 62.33 | 105.22 | 1.6881 |
| 32 | 61.25                               | 106.00 | 1.7306 | 1.7306 | 66.56 | 105.56 | 1.5893 |
| 33 | 61.00                               | 100.50 | 1.6475 | 1.6475 | 62.00 | 110.17 | 1.7769 |
| 34 | 60.25                               | 105.25 | 1.7460 | 1.7460 | 63.67 | 108.67 | 1.7068 |
| 35 | 59.75                               | 105.50 | 1.7657 | 1.7657 | 63.83 | 106.50 | 1.6685 |
| 36 | 60.75                               | 106.50 | 1.7531 | 1.7531 | 62.00 | 109.33 | 1.7634 |
| 37 | 59.83                               | 107.00 | 1.7884 | 1.7884 | 60.50 | 104.58 | 1.7286 |
| 38 | 60.75                               | 106.00 | 1.7449 | 1.7449 | 61.33 | 108.44 | 1.7681 |
| 39 | 62.25                               | 99.25  | 1.9944 | 1.9944 | 60.89 | 110.11 | 1.8083 |
| 40 | 63.00                               | 99.00  | 1.5714 | 1.5714 | 61.33 | 107.11 | 1.7465 |

*Sample Number.

*Ratio Vegetation Index.

Thus, the average rice vegetation indexes

\[
y_i = \frac{1}{n_1} \sum_{j=1}^{n_1} y_{ij}, \quad \bar{y}_x = \frac{1}{n_2} \sum_{j=1}^{n_2} y_{xj} \tag{2-3}
\]

and the RVI variance

\[
S_i^2 = \frac{1}{(n_1 - 1)} \sum_{j=1}^{n_1} (y_{ij} - \bar{y}_i)^2, \quad S_x^2 = \frac{1}{(n_2 - 1)} \sum_{j=1}^{n_2} (y_{xj} - \bar{y}_x)^2 \tag{4-5}
\]

are four statistics [5].

The hypothesis testing is that the average rice vegetation index for rice-rice and cotton-rice modes is equal. This testing can be expressed as follows

\[
H_0: \mu_1 = \mu_2; \quad H_1: \mu_1 \neq \mu_2. \tag{6}
\]

Suppose that the variance of rice vegetation index is the same under the two cultivation modes. Then, in complete random sampling, the effective statistic \( t_0 \) for comparing the average values of two ratio vegetation indices is
\[ t_0 = \frac{\bar{y}_1 - \bar{y}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \]
\[ S_p = \sqrt{\frac{(m_1 - 1)S_1^2 + (m_2 - 1)S_2^2}{m_1 + m_2 - 2}} \]  
(7-8)

where \( S_p \) is a common variance estimate or \( \sigma^2 = \sigma_i^2 = \sigma^2 \); \( S_1 \) and \( S_2 \) are the individual variance estimates for rice vegetation indexes. To decide whether to reject \( H_0 \), we would compare \( t_0 \) to the \( t \) distribution with \( m_1 + m_2 - 2 \) freedom degrees. Thus, if \( |t_0| > t_{\alpha/2., m_1 + m_2 - 2} \), we would reject \( H_0 \) and come to conclusion that the average rice vegetation indexes for rice-rice and cotton-rice modes are different. In fact, we are usually more concerned in the \( \mu_1 - \mu_2 \) confidence interval. Assume that we want to compute a \( 100(1-\alpha)\% \) true \( \mu_1 - \mu_2 \) confidence interval. This \( \mu_1 - \mu_2 \) confidence interval can be derived from the equations (9-11). The statistical quantity

\[ \frac{\bar{y}_1 - \bar{y}_2 - (\mu_1 - \mu_2)}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \]
(9)

obeys \( t_{m_1 + m_2 - 2} \) distribution. Thus,

\[ P \left\{ -t_{\alpha/2., m_1 + m_2 - 2} \leq \frac{\bar{y}_1 - \bar{y}_2 - (\mu_1 - \mu_2)}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \leq t_{\alpha/2., m_1 + m_2 - 2} \right\} = 1 - \alpha \]  
(10)

We have

\[ \mu_1 - \mu_2 \in \left[ \bar{y}_1 - \bar{y}_2 - t_{\alpha/2., m_1 + m_2 - 2}S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}; \bar{y}_1 - \bar{y}_2 + t_{\alpha/2., m_1 + m_2 - 2}S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \right] \]  
(11)

is a \( 100(1-\alpha)\% \) confidence interval of \( \mu_1 - \mu_2 \).

3. Results
Considering the vegetation indexes in table 1, we find table 2.

| Rice and rice monoculture | Cotton and rice rotation |
|---------------------------|--------------------------|
| \( \bar{y}_1 = 1.6615 \) | \( \bar{y}_2 = 1.7180 \) |
| \( S_1 = 0.0444 \)     | \( S_1 = 0.0049 \)      |
| \( S_2 = 0.0660 \)     | \( S_2 = 0.0701 \)      |
| \( n_1 = 40 \)         | \( n_2 = 40 \)          |

Table 2 gives the statistical analysis data of the rice vegetation indexes of rice-rice and cotton-rice modes. Because the rice vegetation index standard deviations are quite analogous, it is reasonable to draw the conclusion that the two standard deviations are equal. Further, we can make use of equation (11) to test equation (6). Therefore, the actual 99.5\% confidence interval for \( \mu_1 - \mu_2 \) is estimated as below:

\[-0.0565 - 0.0402 \leq \mu_1 - \mu_2 \leq -0.0565 + 0.0402 \]

\[-0.0967 \leq \mu_1 - \mu_2 \leq -0.0163 \]

The estimated 99.5\% confidence interval for \( \mu_1 - \mu_2 \) is between - 0.0967 and - 0.0163. That is to say, this confidence interval is \( \mu_1 - \mu_2 = -0.0565 \pm 0.0402 \), or the difference-in-mean of rice vegetation indexes is -0.05. Since this confidence interval does not include \( \mu_1 - \mu_2 = 0 \), it does not support the \( \mu_1 = \mu_2 \) hypothesis under the 0.5\% significance testing level. The average rice vegetation index for cotton-
rice rotation is likely to exceed that of rice-rice mode, that is, the yield of the former is likely to exceed that of the latter. On the other hand, if we choose \( \alpha=0.005 \) and have \( t_0=-3.7528 \), because of \( t_0 < -t_{0.0025,78} = -2.6403 \), we accept \( H_1 \).

4. Conclusion
As an exception, the paper concludes that after cotton, rice production has increased (3.40%), which may be due to increased soil nitrogen content in previous cotton crops or changes in soil microbial populations that favor subsequent rice crops. We found that in the remote sensing observation experiment, the rice population of cotton-rice rotation was associated with a significant increase in the rice vegetation index needed to increase rice yield. This conclusion not only extends the results of leguminous crops supplying \( N \) to non-legume crops in small rotation experiments, but also confirms that large geographical scope rotation of cotton and rice tends to make the non-legume cotton produce the effect similar to legume crop yield gain [6].

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