Linking large-scale bean-rice rotation with increased rice yield in remote sensing experiment

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Abstract. In this study, the two different treatments are continuous rice and rice in rotation with bean, and the response is the normalized difference vegetation index (NDVI) of rice or the rice yield. This study is to determine whether the rice in rotation with bean results in a significant effect—increasing the rice yield. In this completely randomized experiment, we randomly assigned 40 samples to the continuous rice and 40 samples to the rice in rotation with bean. Then the rice NDVIS of all 80 samples were computed. Because the statistical significance of the rice NDVI of the rotation treatment was observed in the experiment, we can be confident in the conclusion that it was the difference in treatments that resulted in the difference in the rice yield. That is, we can be confident that a cause-and-effect relationship between the rice in rotation with bean and the rice yield increase has been found.

1. Introduction
The most noticeable benefit of rice in rotation with bean is the increase in its yield in comparison to continuous rice (CR). This yield increase is often due to the rotational benefits of rice [1]. In recent years, large-area bean-rice rotation (BRR) has obtained much notice due to its environment and economic benefits. That is, such rotation offers significant economic and ecological benefits. But, it has been found that the traditional method of testing the significance of rotational benefits of rice is too weak to be used over large-area rotation. One method for implementing such significance testing of rotational benefits is to carry out a small-area experiment of crop rotation by using the Monte-Carlo sampling. Thus, there has been a lot of investigation conducted on such experiment of crop rotation [2]. On the other hand, even though such rotational benefits of rice were shown and explained [3], little interest has been paid to how to solve the problem of rotational benefits of rice in the large-area BRR by using observational studies based on remote sensing technology. In such large-area BRR, it is imperative to know whether the BRR cause the desired rotational benefits of rice.

In this paper, we focus on a satellite remote sensing experiment (SRSE). The SRSE is used for testing significance of the rotational benefits of rice of large-area bean-rice rotation. Then, this paper illustrates how to test the significance of the rotational benefits of rice by using both normalized difference vegetation index (NDVI) and random sampling in SRSE. Such combination of NDVI and random sampling techniques formed an effective SRSE for research on large-area bean-rice rotation.

2. Material and methods
Our study work was carried out in Rudong County during 2009-2010. The County is located on Jiangsu Province of China. It is located between latitudes 32°00’-33°29’ N and longitudes 120°20’-
120°49’ E. Its major economic crops included rice and bean. The BRR is the important eco-agricultural mode. This mode has obvious economic and ecological profits. The NDVIs of BRR were evaluated by interpreting vegetation of the rice in monoculture and the rice in rotation with bean on satellite remote sensing images. Further, the SPOT 4 (August 26, 2009) and SPOT 5 (August 13, 2010) images were used to compute the NDVIs of the rice in monoculture and the rice in rotation with bean.

The NDVI values of rice are significantly correlated with the rice yield [4]. It is interested that the NDVIs of the rice in monoculture and the rice in rotation with bean are compared for their yield assessment by using the SPOT 4 and SPOT 5 images. The SPOT 5 image has been used to collect randomly 40 samples for computing the NDVIs of the rice in rotation with bean and another 40 samples for computing the NDVIs of the rice in monoculture. These NDVIs are shown in Tables 1. Further, these NDVIs are computed by using the following equation

\[
NDVI = (B_3 - B_4)/(B_3 + B_1)
\]

(1)

where \(B_3\) is the infrared reflectance value and \(B_1\) is the radiometrically normalized red value in Table 1. Table 1 also gives the data of NDVIs of the rice in monoculture and the rice in rotation with bean. These data could be obtained from the eighty random samples of Table 1. Let \(y_{11}, y_{12}, \ldots, y_{1n1}\) represent the \(n_1\) NDVI samples of the CR and \(y_{21}, y_{22}, \ldots, y_{2n2}\) represent the \(n_2\) NDVI samples of the BRR. We suppose that these samples are collected by using two populations of independent normal distribution at random. Thus, the means of these collected samples

\[
\bar{y}_1 = \frac{1}{n_1} \sum_{j=1}^{n_1} y_{1j}, \quad \bar{y}_2 = \frac{1}{n_2} \sum_{j=1}^{n_2} y_{2j}
\]

(2)

and the variances of these collected samples

\[
S_1^2 = \frac{1}{(n_1-1)} \sum_{j=1}^{n_1} (y_{1j} - \bar{y}_1)^2, \quad S_2^2 = \frac{1}{(n_2-1)} \sum_{j=1}^{n_2} (y_{2j} - \bar{y}_2)^2
\]

(3)

are four important statistics used in analyzing the dispersion and tendency of these samples or data. That is, they measure the dispersion value and the centre tendency value of these data [5].

A statistic hypothesis may be used to determine whether the mean NDVIs of the rice in monoculture and the rice in rotation with bean are equal. The hypothesis may be described as

\[H_0 : \mu_1 = \mu_2, \quad H_1 : \mu_1 \neq \mu_2 \]

Further, we could suppose that the variances of NDVIs of the rice in monoculture and the rice in rotation with bean were identical. Thus, the student test statistics \(t_0\) can be used to compare mean NDVIs of the rice in monoculture and the rice in rotation with bean. This test statistics is

\[
t_0 = \frac{\bar{y}_1 - \bar{y}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}
\]

(4)

where \(S_p^2\) is the estimation value of \(\sigma_1^2 = \sigma_2^2 = \sigma^2\) (common-variance) and computed by

\[
S_p^2 = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1 + n_2 - 2}
\]

(5)

and \(S_1^2\) and \(S_2^2\) are individual sample variances of NDVIs of the rice in monoculture and the rice in rotation with bean. To determine whether to reject \(H_0\), we would compare \(t_0\) to the distribution of student test statistics \(t\) with \(n_1 + n_2 - 2\). If \(|t_0| > t_{\alpha/2, n_1 + n_2 - 2}\), \(H_0\) would be rejected. Thus, we decide that the mean NDVIs of the rice in monoculture and the rice in rotation with bean differ.

In the SRSE, the difference-in-mean NDVIs \(\mu_1 - \mu_2\) would usually be more usual. Thus, we would compute its confidence interval (CD). Further, we would find a 100(1 - \(\alpha\)) percent. This percent is the
CD on the true difference-in-mean NDVIs $\mu_1 - \mu_2$ and can be used to analyze the rotational benefits of bean in SRSE. We find that $L \leq \mu_1 - \mu_2 \leq U$ is a 100$(1 - \alpha)$ percent CD on the difference-in-mean NDVIs $\mu_1 - \mu_2$ for BRR and CR, where $L = \bar{y}_1 - \bar{y}_2 - t_{\alpha/2, m + n - 2} S_\alpha \sqrt{\frac{1}{m} + \frac{1}{n}}$, $U = \bar{y}_1 - \bar{y}_2 + t_{\alpha/2, m + n - 2} S_\alpha \sqrt{\frac{1}{m} + \frac{1}{n}}$.

| Sample Number | Digital Number for Band with Rice-Rice | NDVI | Digital Number for Band with Bean-Rice | NDVI |
|---------------|----------------------------------------|------|----------------------------------------|------|
| 1             | 128 47 67 86                           | 1.91 | 132 46 68 88                           | 1.94 |
| 2             | 129 46 68 89                           | 1.90 | 129 47 67 87                           | 1.93 |
| 3             | 127 46 65 86                           | 1.95 | 125 47 67 82                           | 1.87 |
| 4             | 126 47 66 81                           | 1.91 | 124 46 66 84                           | 1.88 |
| 5             | 130 47 67 84                           | 1.94 | 132 45 66 84                           | 2.00 |
| 6             | 132 48 67 88                           | 1.97 | 136 45 66 85                           | 2.06 |
| 7             | 133 49 68 88                           | 1.96 | 134 47 67 87                           | 2.00 |
| 8             | 127 50 68 89                           | 1.87 | 130 48 66 88                           | 1.97 |
| 9             | 129 46 67 81                           | 1.93 | 130 47 66 88                           | 1.97 |
| 10            | 127 46 66 84                           | 1.92 | 131 47 68 85                           | 1.93 |
| 11            | 130 46 66 86                           | 1.97 | 134 48 67 86                           | 2.00 |
| 12            | 133 48 66 87                           | 2.02 | 134 48 68 88                           | 1.97 |
| 13            | 134 46 67 83                           | 2.00 | 132 48 67 83                           | 1.97 |
| 14            | 129 49 67 82                           | 1.93 | 131 47 67 87                           | 1.96 |
| 15            | 118 52 70 84                           | 1.69 | 129 47 65 84                           | 1.98 |
| 16            | 122 52 69 79                           | 1.77 | 131 45 66 82                           | 1.98 |
| 17            | 121 52 72 83                           | 1.68 | 133 46 66 84                           | 2.02 |
| 18            | 124 50 70 81                           | 1.77 | 132 49 67 86                           | 1.97 |
| 19            | 125 50 69 80                           | 1.81 | 134 48 67 83                           | 2.00 |
| 20            | 122 49 69 78                           | 1.77 | 132 49 67 82                           | 1.97 |
| 21            | 123 49 69 78                           | 1.78 | 135 46 65 79                           | 2.08 |
| 22            | 124 52 68 81                           | 1.82 | 133 49 65 83                           | 2.05 |
| 23            | 123 49 68 81                           | 1.81 | 127 49 67 79                           | 1.90 |
| 24            | 127 49 69 78                           | 1.84 | 133 48 67 88                           | 1.99 |
| 25            | 125 50 69 82                           | 1.81 | 132 48 67 85                           | 1.97 |
| 26            | 114 52 69 78                           | 1.65 | 129 50 69 84                           | 1.87 |
| 27            | 107 53 71 78                           | 1.51 | 132 49 67 86                           | 1.97 |
| 28            | 129 45 65 86                           | 1.98 | 126 48 67 80                           | 1.88 |
| 29            | 126 46 66 90                           | 1.91 | 121 50 68 82                           | 1.78 |
| 30            | 133 46 66 86                           | 2.02 | 124 49 68 84                           | 1.82 |
| 31            | 133 48 67 85                           | 1.99 | 113 52 70 78                           | 1.61 |
| 32            | 128 48 68 85                           | 1.88 | 119 52 70 82                           | 1.70 |
| 33            | 126 48 67 82                           | 1.88 | 119 51 70 80                           | 1.70 |
| 34            | 133 47 67 84                           | 1.99 | 121 53 72 76                           | 1.68 |
| 35            | 133 48 68 91                           | 1.96 | 120 55 72 81                           | 1.67 |
| 36            | 124 48 69 81                           | 1.80 | 129 56 73 85                           | 1.77 |
| 37            | 128 50 70 89                           | 1.83 | 126 53 71 82                           | 1.77 |
| 38            | 128 53 70 91                           | 1.83 | 123 49 68 79                           | 1.81 |
| 39            | 124 52 71 83                           | 1.75 | 132 49 68 84                           | 1.94 |
| 40            | 118 50 70 79                           | 1.69 | 133 50 69 83                           | 1.93 |

3. Results
Consider the bean NDVIs of BRR and CR by Table 1. For these NDVIs, we find that there are $n_1=40$, $\bar{y}_1=1.86$, $S^1_1=0.013$ and $S_1=0.115$ for the CR and there are $n_2=40$, $\bar{y}_2=1.91$, $S^1_2=0.014$ and $S_2=0.117$ for the BRR. Furthermore, if we choose $\alpha = 0.1$, then we would reject $H_0$ if $t_o > t_{0.05, 78} = 1.66$, or if
The real 99.5% CD estimation for the difference-in-mean NDVIs for BRR and CR is found as follows:

\[-0.05 - 0.0429 \leq \mu_1 - \mu_2 \leq 0.05 + 0.0429, \quad -0.0898 \leq \mu_1 - \mu_2 \leq -0.0040.\]

Therefore, this 99.5% CD estimation value ranges from -0.0898 to -0.0040. Thus, this CD estimation value is \(\mu_1 - \mu_2 = -0.05 \pm 0.0429\), that is, the difference-in-mean NDVIs is -0.05. Note that the result does not support the \(\mu_1 - \mu_2 = 0\) at the 10% of significance level. This is because \(\mu_1 - \mu_2 = 0\) is not included in this confidence interval. Thus, the mean NDVI of the rice in monoculture exceeds likely the mean NDVI of the rice in rotation with bean. Thus, the yield of the rice in rotation with bean is much higher than the yield of the bean in monoculture.

**4. Conclusion**

Past researches have shown the efficiency of the rice in rotation with other crop in increasing the rice yield. For instance, Angus et al. [6] report that the wheat in rotation with rice improved the rice yield. But, these researches have been only small-area rice rotation experiments. That is, they have not concerned large-area rice rotation by using observational studies based on remote sensing technology. However, our study analyzed the rotational benefits of rice in large-area BRR by analyzing the difference-in-mean NDVIs of the rice in monoculture and the rice in rotation with bean. In our observational studies of BRR, we found that the rice in rotation with bean was associated with obvious increases in the rice yield or in the NDVI. This conclusion develops the result of rotational benefits of the small-area rice in rotation with bean, affirming that a larger-area BRR inclines to create the similar rotational benefits. Otherwise, the rotational benefits of the rice in rotation with bean were not related to the varieties of bean and the bean area. Thus, our work shows that the experiences obtained from SRSE may satisfy the large-area crop rotation experiment needs. Most importantly, to our knowledge, our present paper is the first report to analyze the rotational benefits of crop by using the NDVIs of remote sensing image. This paper outcome gives strong evidence that the rotational benefits of the rice in rotation with bean occurs to be effective in larger-area BRR, and suggest that this approach based on observation experiment will be more usual for the large-area rotation examination.

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