Evaluation of rotational effect of bean in large-scale rice-bean rotation using satellite remote sensing experiment

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Abstract. A large-scale rice-bean rotation experiment was examined to analyze the rotational effect of bean by using the normalized difference vegetation index (NDVI) of bean on satellite remote sensing image. The experiment was undertaken at Rudong County of China from 2009 to 2010. The difference between the bean NDVIs of bean-bean monoculture and rice-bean rotation was used to evaluate the rotational effect of bean. The results show that the NDVI of rice-bean rotation is obviously larger than one of bean-bean monoculture in such large-scale experiment. Thus, we have also found the compelling evidence that the bean yield of rice-bean rotation is greater than the bean yield of bean-bean monoculture.

1. Introduction
The most noticeable benefit of bean in rotation with rice is the increase in its yield in comparison to continuous bean (CB). This yield increase is often due to the rotational benefits of bean [1]. In recent years, large-area rice-bean rotation (RBR) 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 bean 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 bean were shown and explained [3], little interest has been paid to how to solve the problem of rotational benefits of bean in the large-area RBR by using observational studies based on remote sensing technology. In such large-area RBR, it is imperative to know whether the RBR cause the desired rotational benefits of bean.

In this paper, we focus on a satellite remote sensing experiment (SRSE). The SRSE is used for testing significance of the rotational benefits of bean of large-area rice-bean rotation. Then, this paper illustrates how to test the significance of the rotational benefits of bean 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 rice-bean 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 bean and rice. The RBR is the important eco-agricultural mode. This mode has obvious economic and ecological profits. The NDVIs of RBR were evaluated by interpreting vegetation of the bean in monoculture and the bean in rotation with rice 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 bean in monoculture and the bean in rotation with rice.

The NDVI values of bean are significantly correlated with the bean yield [4]. It is interested that the NDVIs of the bean in monoculture and the bean in rotation with rice 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 bean in rotation with rice over an area of 1211 ha and another 40 samples for computing the NDVIs of the bean in monoculture over an area of 1470 ha. These NDVIs are shown in Tables 1. Further, these NDVIs are computed by using the following equation

$$NDVI = (B_i - B_r)/(B_i + B_r)$$  \quad (1)$$

where $B_3$ is the infrared reflectance value and $B_1$ is the radio metrically normalized red value in Table 1. Table 1 also gives the data of NDVIs of the bean in monoculture and the bean in rotation with rice. 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 BBM and $y_{21}, y_{22}, \ldots, y_{2n2}$ represent the $n_2$ NDVI samples of the RBM. We suppose that these samples are collected by using two populations of independent normal distribution at random. Thus, the means of these collected samples

$$\bar{y}_1 = \frac{1}{n_1} \sum_{j=1}^{n_1} y_{1j}, \quad \bar{y}_2 = \frac{1}{n_2} \sum_{j=1}^{n_2} y_{2j}$$  \quad (2)$$

and the variances of these collected samples

$$s_1^2 = \frac{1}{(n_1-1)} \sum_{j=1}^{n_1} (y_{1j} - \bar{y}_1)^2, \quad s_2^2 = \frac{1}{(n_2-1)} \sum_{j=1}^{n_2} (y_{2j} - \bar{y}_2)^2$$  \quad (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 bean in monoculture and the bean in rotation with rice are equal. The hypothesis may be described as $H_0 : \mu_1 = \mu_2$, $H_1 : \mu_1 \neq \mu_2$. Further, we could suppose that the variances of NDVIs of the bean in monoculture and the bean in rotation with rice were identical. Thus, the student test statistics $t_0$ can be used to compare mean NDVIs of the bean in monoculture and the bean in rotation with rice. This test statistics is

$$t_0 = \frac{\bar{y}_1 - \bar{y}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$  \quad (4)$$

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

$$S_p^2 = \frac{(m_1-1)S_1^2 + (n_2-1)S_2^2}{m_1 + n_2 - 2}$$  \quad (5)$$

and $S_1^2$ and $S_2^2$ are individual sample variances of NDVIs of the bean in monoculture and the bean in rotation with rice. To determine whether to reject $H_0$, we would compare $t_0$ to the distribution of student test statistics $t$ with $m + n_2 - 2$. If $|t_0| > t_{0.05, m+n_2-2}$, $H_0$ would be rejected. Thus, we decide that the mean NDVIs of the bean in monoculture and the bean in rotation with rice 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 NDVI's $\mu_1 - \mu_2$ for RBM and CB, where $L = \overline{y}_1 - \overline{y}_2 - t_{a/2, n_1 + n_2} \cdot z_{SP} \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$, $U = \overline{y}_1 - \overline{y}_2 + t_{a/2, n_1 + n_2} \cdot z_{SP} \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$.

Table 1. NDVIS of RBM and CB beans.

| Sample Number | Digital Number for Band with Bean-Bean | NDVI  | Digital Number for Band with Rice-Bean | NDVI  |
|---------------|----------------------------------------|-------|----------------------------------------|-------|
|               | 1  | 2  | 3  | 4  |                               | 1  | 2  | 3  | 4  |
| 1             | 162 | 52 | 70 | 130 | 0.3805 | 162 | 48 | 70 | 137 | 0.3966 |
| 2             | 161 | 51 | 71 | 133 | 0.3879 | 162 | 49 | 69 | 136 | 0.4026 |
| 3             | 162 | 51 | 71 | 132 | 0.3906 | 161 | 50 | 70 | 134 | 0.3939 |
| 4             | 163 | 49 | 71 | 131 | 0.3932 | 156 | 52 | 72 | 137 | 0.3684 |
| 5             | 158 | 49 | 71 | 132 | 0.3799 | 158 | 50 | 71 | 138 | 0.3799 |
| 6             | 154 | 50 | 71 | 131 | 0.3689 | 167 | 50 | 71 | 139 | 0.4034 |
| 7             | 159 | 49 | 71 | 131 | 0.3826 | 163 | 50 | 70 | 138 | 0.3991 |
| 8             | 162 | 50 | 71 | 131 | 0.3906 | 159 | 49 | 69 | 136 | 0.3947 |
| 9             | 150 | 50 | 71 | 132 | 0.3333 | 166 | 51 | 71 | 140 | 0.4008 |
| 10            | 167 | 53 | 73 | 138 | 0.3917 | 165 | 50 | 71 | 140 | 0.3983 |
| 11            | 160 | 49 | 70 | 131 | 0.3913 | 160 | 50 | 72 | 138 | 0.3793 |
| 12            | 162 | 50 | 71 | 139 | 0.3906 | 166 | 51 | 72 | 138 | 0.3950 |
| 13            | 165 | 50 | 71 | 138 | 0.3983 | 161 | 50 | 70 | 136 | 0.3939 |
| 14            | 160 | 51 | 71 | 138 | 0.3853 | 158 | 50 | 72 | 132 | 0.3739 |
| 15            | 151 | 62 | 73 | 149 | 0.3482 | 158 | 52 | 71 | 136 | 0.3799 |
| 16            | 155 | 50 | 70 | 128 | 0.3778 | 162 | 54 | 74 | 134 | 0.3729 |
| 17            | 137 | 55 | 73 | 124 | 0.3048 | 159 | 53 | 73 | 132 | 0.3077 |
| 18            | 140 | 63 | 79 | 124 | 0.2785 | 161 | 55 | 74 | 136 | 0.3702 |
| 19            | 142 | 56 | 76 | 120 | 0.3028 | 154 | 54 | 74 | 135 | 0.3509 |
| 20            | 141 | 55 | 73 | 116 | 0.3178 | 153 | 57 | 77 | 136 | 0.3304 |
| 21            | 150 | 52 | 72 | 123 | 0.3514 | 154 | 55 | 74 | 132 | 0.3509 |
| 22            | 148 | 55 | 74 | 125 | 0.3333 | 147 | 55 | 75 | 129 | 0.3243 |
| 23            | 155 | 54 | 73 | 132 | 0.3596 | 160 | 52 | 72 | 125 | 0.3793 |
| 24            | 156 | 53 | 72 | 128 | 0.3684 | 157 | 53 | 72 | 123 | 0.3712 |
| 25            | 155 | 54 | 71 | 126 | 0.3717 | 155 | 57 | 77 | 140 | 0.3632 |
| 26            | 141 | 59 | 77 | 130 | 0.2936 | 156 | 57 | 77 | 140 | 0.3391 |
| 27            | 151 | 57 | 76 | 134 | 0.3304 | 153 | 56 | 76 | 136 | 0.3362 |
| 28            | 143 | 56 | 74 | 122 | 0.3180 | 155 | 56 | 75 | 137 | 0.3478 |
| 29            | 144 | 55 | 75 | 122 | 0.3151 | 149 | 57 | 77 | 132 | 0.3186 |
| 30            | 140 | 56 | 73 | 122 | 0.3146 | 149 | 57 | 76 | 135 | 0.3244 |
| 31            | 156 | 57 | 74 | 138 | 0.3565 | 161 | 54 | 74 | 139 | 0.3702 |
| 32            | 156 | 57 | 76 | 136 | 0.3448 | 160 | 51 | 74 | 138 | 0.3675 |
| 33            | 154 | 56 | 76 | 137 | 0.3391 | 160 | 51 | 70 | 135 | 0.3913 |
| 34            | 140 | 58 | 76 | 133 | 0.2963 | 163 | 52 | 73 | 139 | 0.3814 |
| 35            | 134 | 59 | 77 | 130 | 0.2701 | 160 | 49 | 71 | 139 | 0.3853 |
| 36            | 150 | 56 | 74 | 131 | 0.3393 | 161 | 49 | 71 | 138 | 0.3879 |
| 37            | 149 | 56 | 75 | 130 | 0.3304 | 161 | 50 | 72 | 141 | 0.3820 |
| 38            | 161 | 49 | 71 | 137 | 0.3879 | 164 | 50 | 71 | 140 | 0.3957 |
| 39            | 160 | 50 | 70 | 134 | 0.3913 | 161 | 50 | 72 | 142 | 0.3820 |
| 40            | 161 | 49 | 71 | 135 | 0.3879 | 164 | 50 | 72 | 144 | 0.3898 |

3. Results
Consider the bean NDVIs of RBM and CB by Table 1. For these NDVIs, we find that there are \( n_1=40 \), \( \bar{y}_1=0.3496 \), \( S_1^2=0.0132 \) and \( S_1^2=0.1148 \) for the RBM there are \( n_2=40 \), \( \bar{y}_2=0.3709 \), \( S_2^2=0.0136 \) and \( S_2^2=0.1165 \) for the CB. Furthermore, if we choose \( \alpha=0.005 \), then we would reject \( H_0 \) if \( t_0 > t_{0.0025,78} = 2.900 \), or if \( t_0 < -t_{0.0025,78} = -2.900 \). The real 99.5 % CD estimation for the difference-in-mean NDVIs for RBM and CB is found as follows:

\[
-0.0213 - 0.0203 \leq \mu_1 - \mu_2 \leq -0.0213 + 0.0203, \quad -0.0416 \leq \mu_1 - \mu_2 \leq -0.0010.
\]

Therefore, this 99.5 % CD estimation value ranges from \(-0.0416\) to \(-0.0010\). Thus, this CD estimation value is \(-0.0213 \pm 0.0203\). That is, the difference-in-mean NDVIs is 0.0213. Note that the result does not support the \( \mu_1 - \mu_2 = 0 \) at the 0.5 % of significance level. This is because \( \mu_1 - \mu_2 = 0 \) is not included in this confidence interval. Thus, the mean NDVI of the bean in monoculture exceeds likely the mean NDVI of the bean in rotation with rice. Thus, the yield of the bean in rotation with rice is much higher than the yield of the bean in monoculture.

4. Conclusion
Past researches have shown the efficiency of the bean in rotation with other crop in increasing the bean yield. For instance, Varvel and Wilhelm [6] report that the corn in rotation with bean improved the bean yield. But, these researches have been only small-area bean rotation experiments. That is, they have not concerned large-area bean rotation by using observational studies based on remote sensing technology. However, our study we analyzed the rotational benefits of bean in large-area RBR by analyzing the difference-in-mean NDVIs of the bean in monoculture and the bean in rotation with rice. In our observational studies of RBR, we found that the bean in rotation with rice was associated with obvious increases in the bean yield or in the NDVI. This conclusion develops the result of rotational benefits of the small-area bean in rotation with rice, affirming that a larger-area RBR inclines to create the similar rotational benefits. Otherwise, the rotational benefits of the bean in rotation with rice were not related to the varieties of rice and the rice 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 bean in rotation with rice occurs to be effective in larger-area RBR, and suggest that this approach based on observation experiment will be more usual for the large-area rotation examination.

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