

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

$$NDVI = (B_1 - B_3) / (B_1 + B_3) \quad (1)$$

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 rice in monoculture and the rice in rotation with bean. These data could be obtained from the eighty random samples of Table 1. Let $y_{11}, y_{12}, \dots, y_{1n_1}$ represent the n_1 NDVI samples of the CR and $y_{21}, y_{22}, \dots, y_{2n_2}$ 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

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

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 rice in monoculture and the rice in rotation with bean 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 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

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

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

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \quad (5)$$

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 $L = \bar{y}_1 - \bar{y}_2 - t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$, $U = \bar{y}_1 - \bar{y}_2 + t_{\alpha/2, n_1 + n_2 - 2} S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$.

Table 1. NDVIS of BRR and CR beans.

Sample Number	Digital Number for Band with Rice-Rice				NDVI	Digital Number for Band with Bean-Rice				NDVI
	1	2	3	4		1	2	3	4	
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 $n_1=40$, $\bar{y}_1=1.86$, $S_1^2=0.013$ and $S_1=0.115$ for the CR and there are $n_2=40$, $\bar{y}_2=1.91$, $S_2^2=0.014$ and $S_2=0.117$ for the BRR. Furthermore, if we choose $\alpha=0.1$, then we would reject H_0 if $t_0 > t_{0.05, 78} = 1.66$, or if

$t_0 < -t_{0.05, 78} = -1.66$. The real 99.5 % CD estimation for the difference-in- mean NDVIs for BRR and CR is found as follows:

$$-0.05 - 0.0429 \leq \mu_1 - \mu_2 \leq -0.05 + 0.0429, -0.0898 \leq \mu_1 - \mu_2 \leq -0.0040.$$

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 we 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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References

- [1] P Vereijken. A methodical way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. *Eur J Agron*, 1997, 7(1–3): 235–250
- [2] J E Olesen, M Askegaard, I A Rasmussen, Design of an organic farming crop-rotation experiment . *Acta Agriculturae Scandinavica, Section B-Plant Soil Science*, 2000, 50(1): 13–21.
- [3] S Dogliotti, W A H Rossing, M K van Ittersum. Systematic design and evaluation of crop rotations enhancing soil conservation, soil fertility and farm income: a case study for vegetable farms in South Uruguay. *Agric Syst*, 2004, 80(3): 277–302
- [4] S Moulin, A Bondeau, R Delecolle. Combining agricultural crop models and satellite observations: from field to regional scales[J]. *International Journal of Remote Sensing*, 1998, 19(6): 1021–1036.
- [5] D C Montgomery, D C Montgomery, Design and analysis of experiments. New York: Wiley, 2008.
- [6] J F Angus, J A Kirkegaard, J R Hunt, et al. Break crops and rotations for wheat[J]. *Crop and Pasture Science*, 2015, 66(6): 523–552.