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Examining cotton in rotation with rice and cotton in rotation with other crops using natural experiment

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Abstract. This paper is to show the ability of remote sensing image analysis combined with statistical analysis to characterize the environmental risk assessment of cotton in rotation with rice and cotton in rotation with other crops in two ways: (1) description of rotation period of cotton in rotation with rice and cotton in rotation with other crops by the observational study or natural experiment; (2) analysis of rotation period calculation of cotton in rotation with rice and cotton in rotation with other crops. Natural experimental results show that this new method is very promising for determining crop rotation period for estimating regional averages of environmental risk. When it is applied to determining crop rotation period, two requested remote sensing images of regional crop are required at least.

1. Introduction

Paddy-upland cotton rotation (PUCR) has received greater concentration in last several years owing to its significant ecological and economic benefits [1]. Such information of PUCR has many possible applications in agriculture sectors [2]. PUCR is usually managed with rural household sampling investigation. This information has also been examined as a potential environment protection data for controlling diffuse sources of fertilization and pesticide pollution in areas of PUCR. The major problem with this survey method, however, is that the assumption of randomness is not credible. Thus, this survey method has been found to be too weak under providing complete and real time information of PUCR in large area to be used practically in environmental risk assessment [3]. Although the effect of this sampling survey on controlling diffuse sources of fertilization and pesticide pollution in areas of PUCR was demonstrated over a few years ago, little concentration has been paid how to develop an appropriate environmental risk assessment model of PUCR based on natural experiment [4] [5]. However, the advantage of the natural experimental approach is that the assumption of randomness for the PUCR survey is more credible than for this survey used in almost all other studies.

This paper presents a rotation period of cotton in rotation with rice and cotton in rotation with other crops as an effective index of environmental risk assessment of PUCR using a natural experimental approach. On the basis of the natural experiment it then describes how to calculate these rotation periods using satellite remote sensing images.

2. Material and methods

Our natural experiment was carried out in Xinghua City during 2001-2002. Such natural experiment is sometimes referred to as observational study. The City, including 38 towns, is located on Jiangsu Province of China. It is located between latitudes 32°40’-33°13’ N and longitudes 119°43’-120°16’ E. Its average annual precipitation and temperature are 1100 mm 15°C respectively. Its major economic crops included rice, cotton, and other crops. The cotton in rotation with rice and cotton in rotation with other crops is important eco-agricultural mode. This mode has obvious economic and ecological profits. PUCR was evaluated by interpreting the areas of cotton in rotation with rice and cotton in rotation with other crops on satellite remote sensing images. Further, the TM 5 (26 July 2001) and TM 7 (29 July 2002) images were used to compute the areas.

We used a statistical model for computing the rotation periods of cotton in rotation with rice and cotton in rotation with other crops as follows

$$CRP_j = \frac{CA_j}{CRA_j} \tag{1}$$

$$COP_j = \frac{CA_j}{COA_j} \tag{2}$$

$$CRP_M = \sum_{j=1}^{M}\left(\frac{(CA_j)^2}{CRA_j \times \sum_{j=1}^{M} CA_j}\right) \tag{3}$$

$$COP_M = \sum_{j=1}^{M}\left(\frac{(CA_j)^2}{COA_j \times \sum_{j=1}^{M} CA_j}\right) \tag{4}$$

$$s_{CRP_M} = \sqrt{\frac{1}{M-1}\sum_{j=1}^{M}\left(CRP_j - CRP_M\right)^2} \tag{5}$$

$$s_{COP_M} = \sqrt{\frac{1}{M-1}\sum_{j=1}^{M}\left(COP_j - COP_M\right)^2} \tag{6}$$

$$CRP_M - t_{\alpha/2,M-1} s_{CRP_M} / \sqrt{M} \le \mu_{CRP_M} \le CRP_M + t_{\alpha/2,M-1} s_{CRP_M} / \sqrt{M} \tag{7}$$

$$COP_M - t_{\alpha/2,M-1} s_{COP_M} / \sqrt{M} \le \mu_{COP_M} \le COP_M + t_{\alpha/2,M-1} s_{COP_M} / \sqrt{M} \tag{8}$$

where:

CRP_j = rotation period of cotton in rotation with rice for town j ,

COP_j = rotation period of cotton in rotation with other crops for town j ,

CRP_M = an estimate of rotation period mean of cotton in rotation with rice for all M towns,

COP_M = an estimate of rotation period mean of cotton in rotation with other crops for all M towns,

s_{CRP_M} = standard deviation of CRP_M ,

s_{COP_M} = standard deviation of COP_M ,

μ_{CRP_M} = the true value of rotation period mean of cotton in rotation with rice for all M towns,

μ_{COP_M} = the true value of rotation period mean of cotton rotated with other crops for all M towns,

$t_{\alpha/2,M-1}$ =, the upper 100 $\alpha/2$ percentage point of the t distribution with $M-1$ degrees of freedom

M = total number of towns.

Table 1. Periods of cotton rotated with rice and cotton rotated with other crops (area: ha, period: year)

Number	Town Name	CA[a]	CRA[b]	COA[c]	CRP[d]	COP[e]
1	An Feng	76.53	39.12	28.41	1.96	2.69
2	Bian Cheng	363.25	185.13	119.58	1.96	3.04
3	Chang Rong	105.89	37.92	39.23	2.79	2.70
4	Da Duo	124.03	71.55	41.88	1.73	2.96
5	Da Ying	367.09	186.9	87.00	1.96	4.22
6	Da Zou	276.22	168.49	105.52	1.64	2.62
7	Dai Nan	150.56	51.10	69.92	2.95	2.15
8	Dai Yao	293.42	119.88	92.13	2.45	3.18
9	Dang Zhu	465.88	143.97	200.14	3.24	2.33
10	Di Duo	337.14	187.20	122.35	1.80	2.76
11	Diao Yu	287.15	120.02	85.17	2.39	3.37
12	Dong Bao	19.66	9.40	5.67	2.09	3.47
13	Dong Tan	428.51	196.89	139.32	2.18	3.08
14	Duo Tian	6.90	2.87	3.41	2.40	2.02
15	Gu Zhuang	316.40	160.08	110.25	1.98	2.87
16	Hai He	233.56	131.92	77.50	1.77	3.01
17	Hai Nan	172.93	63.91	49.43	2.71	3.50
18	He Ta	248.87	117.65	71.14	2.12	3.50
19	Hong Xing	853.46	479.02	214.74	1.78	3.97
20	Lao Wei	691.01	418.52	132.59	1.65	5.21
21	Li Jian	622.23	260.45	265.34	2.39	2.35
22	Lin Hu	74.68	38.68	27.10	1.93	2.76
23	Lin Tan	247.25	82.30	101.68	3.00	2.43
24	Liu Lu	701.98	439.08	153.11	1.60	4.58
25	Mao Shan	317.49	178.96	78.24	1.77	4.06
26	She Chen	228.67	87.17	80.45	2.62	2.84
27	Shen Lun	471.15	286.40	112.24	1.65	4.20
28	Tan Liu	383.84	185.80	110.52	2.07	3.47
29	Tao Zhuang	490.43	179.79	191.21	2.73	2.56
30	Xi Bao	340.89	147.88	139.56	2.31	2.44
31	Xia Wei	96.09	44.23	39.99	2.17	2.40
32	Xin Duo	515.44	312.75	109.13	1.65	4.72
33	Xu Yang	128.14	43.94	40.51	2.92	3.16
34	Yong Feng	77.00	25.26	28.17	3.05	2.73
35	Zhang Guo	473.74	255.65	157.30	1.85	3.01
36	Zhao Yang	497.24	259.20	155.86	1.92	3.19
37	Zhong Bao	112.71	52.89	59.71	2.13	1.89
38	Zhu Hong	183.06	100.77	60.06	1.82	3.05

[a]CA= cotton area in 2001
[b]CRA= area of cotton in 2001 in rotation with rice in 2002
[c]COA= area of cotton in 2001 in rotation with other crops in 2002
[d]CRP= rotation period of cotton rotated with rice
[e]COP= rotation period of cotton in rotation with other crops

3. Results

The relevant results from the classification of TM images acquired on 26 July 2001 and 29 July 2002 and the calculation of equations (1) and (2) are given in Table 1. The second column (Town Name) indicates the names of 38 Xinghua towns. The third column (CA) simply lists the cotton areas of 38 Xinghua towns through classification of TM image acquired on 26 July 2001. The fourth column (CRA) then gives the areas of cotton land in 2001 in rotation for rice land in 2002 for 38 Xinghua towns through classification of TM images acquired on 26 July 2001 and 29 July 2002 respectively. The fifth column (COA) gives the areas of cotton land in 2001 in rotation for other crop land in 2002 for 38 Xinghua towns through classification of TM images acquired on 26 July 2001 and 29 July 2002 respectively. The sixth column (CRP) calculates the rotation periods of cotton in rotation with rice for

38 Xinghua towns by equation (1). The rotation periods of cotton in rotation with other crops for 38 Xinghua towns, derived from equation (2), are listed in the last column (COP). On the basis of Table 1, we may find the seven estimates of rotation period using Equations (3)-(8) as follows:

$$CRP_M = 2.09 \text{ (year)}$$

$$COP_M = 3.38 \text{ (year)}$$

$$s_{CRP_M} = 0.47$$

$$s_{COP_M} = 0.81$$

$$1.94 \text{ (year)} \le \mu_{CRP_M} \le 2.24 \text{ (year)}$$

$$3.11 \text{ (year)} \le \mu_{COP_M} \le 3.65 \text{ (year)}$$

Thus, the remote sensing image analysis combined with the statistical analysis proved to be a useful procedure for the environmental risk assessment of cotton in rotation with rice and cotton in rotation with other crops.

4. Conclusion

Our outcomes provide strong evidence that there is a statistics relationship between the cotton rotated with rice and the cotton rotated with other crops and suggest strongly that the statistical model based on this relationship appears to be effectual in the environmental risk assessment. However, some problems related to this relationship are worth noting. Although the theory and practice of rotation period was supported in the natural experiment of Xinghua, this environmental risk assessment is abandoned when the erratic climate condition makes difficult to obtain cloud-free remote sensing images. Subsequent work should be designed how to develop the optimum sampling methods to reduce the number of required cloud-free remote sensing images.

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