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Could Rice Yield Change Be Caused by Weather?

—Empirical Analysis from Hainan, China

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Abstract

Data from 4 counties of Hainan Province of China from 1991-2012 was used to determine the weather impact on rice yields in both early and late rice seasons with multiple regression models. The results show there is normal weather environment for rice in the heading stage for early season rice in May and the milking stage for late season rice in November. For early season rice, more rain in April and June is better for rice to boot and milk, the average temperature has negative effect for the season rice yield ; for late season rice, the average temperature have positive effect for the difference between rice yield and the mean of total years but in seedling and booting stage; the rice yield difference between double season is compared and analyzed through the difference of meteorological factors, the results show that the precipitation gap in tillering stage has positive effect to rice yield increasing, but against in booting stage. The relative results should be use to forecast rice yield, and further provide the rice production guiding.

Keywords

Meteorological Factors, Rice Yield Change, Model, Hainan of China

1. Introduction

Scientists conducted research explaining relationship between climate and crop yield forecasting (Mikhail A. Semenov, et. al., 2012) [1]. Some scientists worked on the relationship between crop yield and climate (Nicholls N., 1997; David B Lobell and Gregory P Asner, 2003; Peng, S.,etc., 2004; Xu Shiwei, Yu Wen and etc., 2013; Xu S., Yu W., and etc., 2013) [2]-[6]; and also these articles referred above did not include more climate factors and disasters for regression estimation. In this article, precipitation, temperature, wind speed, sunshine will be included and also low temperature, extreme wind speed, floods, etc.. in addition, the monthly data help estimation the weather contribution in detail.

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After the research, not only the yield change contributions by meteorological factors, but also the coefficients help crop yield changing forecasting.

The article is organized in the following parts: first part is introduction; 2nd part is about data and its description; 3rd part is the method, multiple regression models; part 4 is estimation analysis based on model results; and the last part is about conclusion and discussion.

2. Data

This article uses time series data, including early and late season rice yield, and meteorological data. Meteorological data is from China Meteorological Data Sharing Service System (CMDSSS); and rice yield data in local regions for Hainan Province is from Hainan Statistical Yearbooks.

Hainan province is an island located at the extreme south of China. It is located in 180˚10' - 200˚10'N and 1080˚37' - 1110˚03'E covering land area of about 35.4 thousand square kilometres and has maritime area of about 2 million square kilometers. 4 counties or cities were selected from 18 of Hainan Province, they are Qiongshan (north of Hainan, 19˚32' - 20˚05'N, 110˚11' - 110˚41'E), Danzhou (northwestern Hainan, 19˚11' - 19˚52'N, 108˚56' - 109˚46'E), Qiongzhong (Center of Hainan, 18˚43'- 19˚25'N, 109˚31' - 110˚09'E) and Lingshui (southeastern Hainan, 18˚22' - 18˚47'N, 109˚45' - 110˚08'E).

Rice is one of the major main crops in the region and mostly cultivated twice a year. According to the rice growth seasons, early season rice are often transplanted in February and harvest in June or earlier July; late season rice often transplants in July or earlier August and harvest in November. According to the disaster dataset about Hainan from CMDSSS, for early season rice, drought and clod are main constraints; but floods, heavy rains, typhoon and disease are major disasters for late season rice. The main meteorological index are in the following **Table 1**.

Like southern China, Hainan often plant double rice annually. In the above **Figure 1**, the yields of early season rice have significant increasing trend generally, but late season rice yield show no obvious trend.

Table 1. The average value of meteorological factors from 1991 to 2012 for selected station in Hainan of China.

Weather (unit)	station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
precipitation	danxian	6	8	15	27	76	68	78	114	112	74	29	14
(0.1 mm)	lingshui	5	7	10	28	53	72	88	64	113	104	25	12
	qiongshan	6	12	16	27	60	83	76	89	94	91	18	13
	qiongzhong	11	15	17	37	83	60	73	103	131	142	64	29
	mean	7	10	14	30	68	71	79	92	113	103	34	17
temperature	danxian	177	196	224	257	272	283	281	273	262	246	219	187
(0.1˚C)	lingshui	207	219	240	265	280	286	284	281	273	261	242	217
	qiongshan	180	194	222	256	277	288	288	283	274	258	230	196
	qiongzhong	174	193	219	248	264	273	272	265	254	236	211	182
	mean	185	200	226	257	273	282	281	276	266	251	226	195
wind	danxian	20	20	20	19	18	19	20	18	18	21	20	20
(0.1 m/s)	lingshui	23	21	21	19	17	17	17	17	20	27	28	28
	qiongshan	26	26	29	29	25	24	24	21	22	27	27	27
	qiongzhong	11	13	16	15	13	14	15	13	11	10	10	9
	mean	20	20	21	21	18	18	19	17	18	21	21	21
sunshine	danxian	38	44	49	57	64	67	70	64	50	51	44	34
(0.1 h)	lingshui	52	51	51	63	70	67	70	67	55	57	53	48
	qiongshan	28	33	39	52	64	67	74	68	55	53	41	32
	qiongzhong	36	44	54	64	67	67	70	63	50	46	38	30
	mean	39	43	48	59	66	67	71	65	53	52	44	36

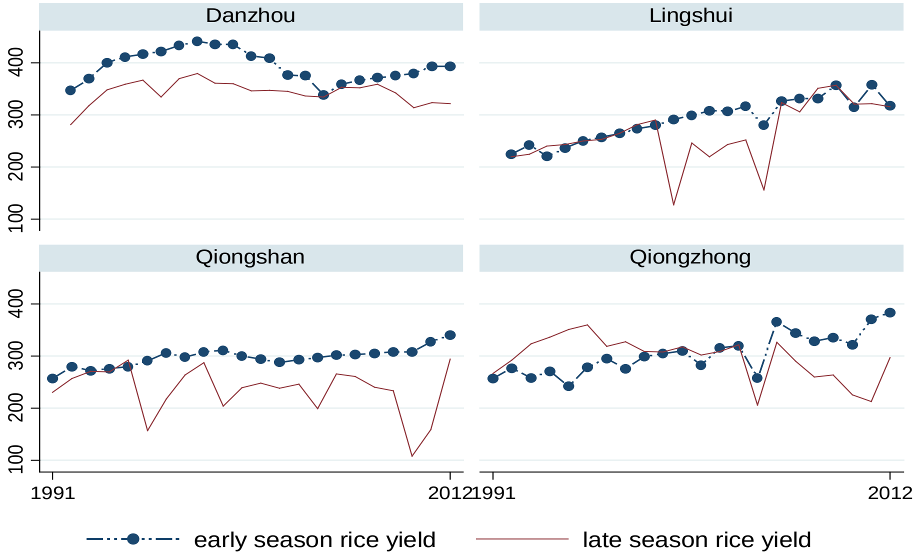

Figure 1. Season rice yield in Danzhou, Lingshui, Qiongshan and Qiongzhong of Hainan, China during 1991-2012.

3. Method

In order to estimate the relationship between rice yield and meteorological factors, the model considers precipitation, rain frequency per month, wind speed, the days of strong wind, average temperature, low temperature, sunshine and technological trend, which is denoted as T. In this article, the analysis will be going on by two methods.

3.1. Independent Season Rice Yield Model

The model in this article hypothesized that the climate or weather has the same effective to rice yield excluding regions.

Firstly, using the difference between season rice yield and average rice yield by the station group as dependent variable, this is estimated by empirical analysis with technology variable denoted as T and meteorological factor change (the difference between meteorological factor and its mean). The relative function is as in the following:

$$\begin{aligned}\Delta \text{yield} = \text{constant} + \text{T} + \sum(\alpha_i * \Delta \text{rain}_i + \beta_i * \Delta \text{sunshine}_i + \gamma_i * \Delta \text{temp}_i + \theta_i * \Delta \text{wind}_i \\ + a_i * \Delta \text{raintimes}_i + b_i * \Delta \text{lowtemp}_i + c_i * \Delta \text{windtimes}_i)\end{aligned} \quad (1)$$

And the relative variables are in the **Table 2**.

3.2. Comparative Season Rice Yield Model

Secondly, using the difference between early season and late season rice yield as dependent variable, as well as the independent variable by the difference between double season meteorological factors (the difference between meteorological factors during the same rice growing stage), the relative function is as in the following:

$$\begin{aligned}\text{d\_yield} = \text{constant} + \text{T} + \sum(\alpha_i * \text{d\_rain}_i + \beta_i * \text{d\_sunshine}_i + \gamma_i * \text{d\_temp}_i + \theta_i * \text{d\_wind}_i \\ + a_i * \text{d\_raintimes}_i + b_i * \text{d\_lowtemp}_i + c_i * \text{d\_windtimes}_i)\end{aligned} \quad (2)$$

Apart from **Table 2**, all variables in Function (2) is the difference in the same life cycles between early season and late season rice; for example, d_yield is the difference between double season yield; and the d_rain1 denotes the precipitation difference in seedling stage for double season rice; i, from 1 to 5, denotes rice lifecycle, including stage of sowing and seedling, stage of transplanting and green turning, tillering stage, booting stage, heading stage, stage of milking and ripening, separately.

Table 2. Variables and their description.

variable	denotation
Δyield	rice yield in early season or late season, unit: kg/mu, 1 mu = 1/15 ha or 0.06667 ha
T	T is technological variable for rice yield caused by seed, management and ect. Progress, 1991 is the based year
Δrain_i	Difference between current precipitation and average precipitation in the ith month, **for example,** there are 5 rainy days in January 1991, but there are 4 rainy days averagely in January from 1991 to 2012, then the Δrain_1 in 1991 is 1 (=5 - 4), unit: 0.1 mm
Δraintimes_i	Difference between current rainy days and average rainy days in the ith month
Δsunshine_i	Difference between current and average solar radiation duration in the ith month, unit: 0.1 hours/day
Δtemp_i	Difference between current and average temperature per day in the ith month, unit: 0.1 centigrade
Δlowtemp_i	Difference between current and average low temperature per day in the ith month, unit: 0.1 centigrade
Δwind_i	Difference between current and average wind speed per day in the ith month, unit: 0.1 m/s
Δwindtimes_i	Difference between current and average days when wind speed is over 20m/s in the ith month, unit: 0.1 m/s
i	January to December orderly with number 1, 2, …, 12 respectively; among the early season, i = 1 to 6; in late season for rice, the I is from 6 to 11
_Istation_1	Station = Danzhou
_Istation_2	Station = lingshui
_Istation_3	Station = qiongshan
_Istation_4	Station = qiongzhong

4. Results

The meteorological units in this research are: rain or precipitation 0.1 mm; wind speed 0.1 m/s; temperature 0.1˚C; Solar radiation 0.1 h. it is the same units in the **Table 4** as in the following.

From the results in the **Table 3**, F-Value show that the model could be appropriate; and the R-squared value instructs the independent variables could explain the dependent-yield more than 50%.

Early season rice: January is the sowing period, in the stage, rice begins emergence and seedling. Comparing with average yield, the yield changing is caused by average temperature and low temperature. Increasing low-temperature has positive effect for yield but average temperature has negative effect. It is the period for young plant to transplant to field, and it will turn green in February. the higher temperature is not good, and more wind will brings cool air benefits seedlings; In March, rice plant is in the tillering stage, rice likes more cloudy days to tiller, which means little higher temperature but less solar radiation; In April, after tillering, the booting rice require more water, in this stage, low temperature would hard the plant, higher average temperature is not suitable for the plant growth; In May, the normal climate environment is adapted for rice heading; in June, the rainy with higher average temperature is good for rice to filling milk.

Late season rice: in June or early July, after harvesting early season rice, young plant will soon be transplanted into the field. So the sowing and emergence and seedling should be prepared in June, when temperature is higher, more rain and more wind benefits for the yield increasing; in July, the plant is at its weak state, the rice is turning green, higher temperature and strong wind is not good for the plant development, but more sunshine is better; in August, rice is at its tillering stage, wind and rain is suitable for young plant but continuous rain and low temperature will be harmful to young tillering plant; during booting stage in September, more rainy and windy days are not good for rice but low temperature and sunshine increasing benefit for the plant, anyway average temperature decreasing is better; and in October, it is in the heading stage, cold, speed wind, sunny weather is not better but higher average temperature and more windy benefit heading for rice; the weather in November is appropriated for rice milking and ripening.

In the second step, the difference between early season and late season rice yield is estimated through T variable (technology and management) meteorological factors. From the results in **Table 4** (the authors use the

Table 3. Analysis of double season rice yield change contributed by being changed climate in growing stages from 1991 to 2012.

stage	Early season rice				Late season rice			
	month	**varialble**	**Coef.**	**t-Value**	**month**	**variable**	**Coef.**	***t*-Value**
	Jan	Δrain_01			**Jun**	Δrain_06	0.30	3.06
sowing		Δraintimes_01				Δraintimes_06		
emergence		Δtemp_01	-1.84	-2.86		Δtemp_06	2.89	2.65
seedling		Δlowtemp_01	1.96	3.24		Δlowtemp_06		
		Δwind_01				Δwind_06		
		Δwindtimes_01				Δwindtimes_06	21.07	1.89
		Δsunshine_01				Δsunshine_06		
	Feb	Δrain_02			**Jul**	Δrain_07		
transplanting		Δraintimes_02				Δraintimes_07		
Greenturn		Δtemp_02	−0.53	−3.06		Δtemp_07	−2.07	−1.77
		Δlowtemp_02				Δlowtemp_07		
		Δwind_02	1.31	2.81		Δwind_07	−2.98	−2.32
		Δwindtimes_02				Δwindtimes_07		
		Δsunshine_02				Δsunshine_07	0.67	1.61
	Mar	Δrain_03			**Aug**	Δrain_08		
tillering		Δraintimes_03				Δraintimes_08	−3.09	−2.52
		Δtemp_03	0.99	2.76		Δtemp_08	3.67	1.93
		Δlowtemp_03				Δlowtemp_08	−4.46	−2.45
		Δwind_03				Δwind_08	6.58	4.37
		Δwindtimes_03				Δwindtimes_08		
		Δsunshine_03	−1.51	−4.03		Δsunshine_08	−0.98	−1.72
	Apr	Δrain_04	0.28	2.25	**Sep**	Δrain_09		
booting		Δraintimes_04				Δraintimes_09	−3.65	−3.20
		Δtemp_04	−1.35	−2.04		Δtemp_09	−6.12	−3.28
		Δlowtemp_04	1.70	2.35		Δlowtemp_09	6.82	3.98
		Δwind_04				Δwind_09		
		Δwindtimes_04				Δwindtimes_09	−15.39	−2.82
		Δsunshine_04				Δsunshine_09	0.99	1.80
	May	Δrain_05			**Oct**	Δrain_10		
heading		Δraintimes_05				Δraintimes_10		
milking		Δtemp_05				Δtemp_10	11.36	5.86
		Δlowtemp_05				Δlowtemp_10	−8.77	−5.83
		Δwind_05				Δwind_10	−3.10	−3.31
		Δwindtimes_05				Δwindtimes_10	37.38	2.61
		Δsunshine_05				Δsunshine_10	−3.20	−5.89

Continued

	Jun	Δrain_06	0.15	1.73	**Nov**	Δrain_11		
ripening		Δraintimes_06				Δraintimes_11		
		Δtemp_06	1.25	2.04		Δtemp_11		
		Δlowtemp_06				Δlowtemp_11		
		Δwind_06				Δwind_11		
		Δwindtimes_06				Δwindtimes_11		
		Δsunshine_06				Δsunshine_11		
		_cons	−0.12	−0.05		_cons	0.77	0.26
		No. of obs = 88				No. of obs = 88		
		F(11,76) = 7.8				F(21,66) = 5.13		
		R-squared = 0.53				R-squared = 0.62		
		Adj R-squared = 0.46				AdjR-squared = 0.50		

Table 4. Analysis on the difference between early season and late season rice yield.

stage	variables	Coef.	*t* value	P > t
	T	2.92	3.9	0
Seedling	d_raintimes_01	1.73	2.26	0.027
	d_lowtemp_01	1.04	2.94	0.004
Tillering	d_temp_03	−2.55	−2.99	0.004
	d_rain_03	0.37	3.46	0.001
	d_lowtemp_03	2.70	2.54	0.013
Booting	d_rain_04	−0.15	−2.49	0.015
Heading	d_sunshine_05	−1.38	−3.33	0.001
	d_lowtemp_05	−4.98	−4.05	0
	d_temp_05	6.10	4.41	0
milking	d_wind_06	−2.16	−2.49	0.015
	d_lowtemp_06	0.64	1.47	0.146
	_Istation_2	−59.40	−3.72	0
	_Istation_3			
	_Istation_4	−55.23	−4.43	0
	_cons	102.04	2.34	0.022
	Number of obs = 88			
	F(14,73) = 8.15			
	R-squared = 0.61			
	AdjR-squared = 0.54			

Considering the region difference, Danzhou and Qiongshan have no significant difference, Lingshui and Qiongzhou have obvious difference from Danzhou county.

stepwise regression, the significant variables could only be kept), F-value and R-square show that the model has good fitting degree.

Due to the progress of technology and management, the early season rice yield has obvious increasing; the differences from meteorological factors have significant effects to the yield difference. In seedling stage, more rainy days and higher low-temperature (the lowest temperature averagely in the month) lead to the yield difference; during tillering stage, the difference increasing among precipitation and low-temperature has positive effect but average temperature has negative effect; in booting stage, the increasing difference for precipitation will decrease the yield change; during heading stage, the difference of sunshine and low-temperature have negative effect for the yield change but average temperature; in the milking stage, the gap of low-temperature will decrease the difference of rice yield but low-temperature increase the change.

5. Conclusions and Discussion

This article analyzes the change of season rice yield from two directions. Firstly, the authors discovers the relationship between season rice yield change from average level and the change of meteorological factors; secondly, comparing the yield change between early season and late season rice yield.

The empirical models could explain the yield change from the meteorological factors, but ignore the other material factors such as fertilizer, labor, and irrigation ect..

From the coefficients and the meteorological value, the rice yield change could be forecasted and the difference of rice yield also could be forecasted.

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