PAPER 2:
IMPACTS OF CLIMATE VARIATIONS ON LITCHI YIELD IN CHINA

Wen'e Qi & XiOuyang
South China Agricultural University, Guangzhou, Guangdong 510642, China

ABSTRACT

Climate variations are gradually threatening the production of fresh agro-products especially fruits like litchi which is one of the most demanding tropical fruits for climatic conditions. As China is the largest litchi producer in the world, the yield of litchi in China plays an important role in tropical fruits security in the world. In this paper, two key weather factors — temperature and rainfall were selected as independent variables and a two-way fixed effect model was established to examine the impacts of climate variations on litchi yield in China based on county-level panel data on litchi yields of 39 main producing counties in China and daily weather conditions from 2011 to 2016. The main conclusions are as follows: (1) litchi's yield is negatively related to the days of precipitation during the vegetative and flowering stages; (2) higher daily minimum temperature during the heading stage and maximum temperature during litchi's flowering stage will increase litchi yield; and (3) for different varieties of litchi, there exist some differences between the weather effects on yields.

Keywords: climate, temperature, litchi, yield, China

INTRODUCTION

Litchi is known as "the queen of fruits" due to its unique shape, beautiful color, and mouth-watering taste. Nevertheless, many will miss out on it since litchi's planting region is relatively narrow; mainly in the provinces of Hainan, Guangdong, Guangxi, and Fujian in China. Even in litchi's main producing areas, litchi production tends to be unstable as litchi is one of the most weather-sensitive crops. On the one hand, bitter winters when the temperature is lower than 0°C will lead to freeze injury or death of litchi; while warm winters with high temperatures will have a significant negative effect on litchi's blossoming and fruit.

With global warming, climate is changing more and more frequently in recent years, which is definitely destructive to the growth of agro-products especially tropical fruits that are extremely sensitive to climate conditions such as the litchi. In order to ensure the yield of litchi and reduce the risk of litchi growers, it is of practical significance to study the impacts of climate variations on litchi yield and establish a correlation model between climate variations, phenological period, and litchi yield.

Numerous studies have evaluated the impacts of climate valuations on the yield of agro-products. Some scholars directly established the model between weather variables and the yield of agro-products by controlling other variables that may influence the yield (Anwar et al., 2015; Fang et al., 2017). Others introduced phenological data into the model and examined how meteorological factors during different growth stages affect the final crop yield (Gömann, 2015; Gourdji et al., 2015; Weymann et al., 2015; Liu et al., 2016; Sharma et al., 2016; Lizana et al., 2017) which can reflect the impact of weather on yield more distinctively and exactly since climate variations during different growth stages may generate different effects on the yield.
According to previous empirical researches, meteorological factors that affect the yield of agro-products are mainly temperature and rainfall (Kima et al., 2014; Gömann, 2015; Sarker, Alam, & Gow, 2014; Ma & Maystadt, 2017; Okoro et al., 2017), and there existed differences from the empirical results of the impact of climate variations on the yield of agro-products.

Many studies found that the yield of agro-products is strongly associated with temperature (Campiglia et al., 2015; Vashisht et al., 2015; Lizana et al., 2017; Paul et al., 2017). Some empirical results showed that higher temperatures tended to reduce crop yield. For example, Duncan et al. (2016) found that warmer average temperatures (T_{ave}) have a negative effect on tea yield. Fang et al. (2017) also found that a lower canopy temperature usually produced a higher yield of winter wheat. Similarly, a study by Kim et al. (2017) on marketable tuber also showed that yield would be significantly reduced with a higher temperature between the temperature ranges of 19.1–27.7°C. However, some researchers came to the opposite conclusions that higher temperatures can increase the yield of some kinds of agro-products like early- and late- rice (Liu et al., 2016; Jia et al., 2015). As the climate changes frequently in recent years, some scholars began to pay attention to the impact of extreme weather on crop yield. Zhao et al. (2015) found that higher maximum temperatures (T_{max}) in June would significantly increase the yield of spring maize. However, a study by Conaty et al. (2015) showed that maximum temperature (T_{max}) would correspond to a predicted 23% reduction in lint yield.

Rainfall is another major cause of uncertainty in the yield of agro-products (Campiglia et al., 2015; Nadal-Romero et al., 2015; Zhao, Guo, & Mu, 2015; Shrestha, Chapagain, & Babel, 2017). Most studies showed that rainfall had a negative effect on crop yield such as early- and late-rice (Liu et al., 2016). Nevertheless, some studies showed the impacts of rainfall on the yield are different during different growth stages. For example, Gourdji et al. (2015) found that heavier rains during planting and harvesting would negatively affect bean yield, but the impact would be positive in December and January.

The extents to which different crops are affected by climate are not the same, with some types of crops more susceptible to changes in climate than others (Sarker et al., 2014; Palazzoli et al., 2015; Padakandla, 2016). Even in the same crop, the effects of changes in climate variables vary among the varieties. Although temperature and rainfall have proven to be the major meteorological factors affecting performance of many crop plants, there are a few studies focusing on how weather change influences the production of litchi that is much more vulnerable to climate change and variability than other agro-products. Furthermore, most studies on impacts of weather changes on litchi yield are qualitative researches which cannot reflect the exact impacts. To gain an insight into whether temperature and rainfall influence litchi yield and how they influence the yield, a two-way fixed effect model was established to assess the impacts of climate variations on litchi yield of 39 main litchi producing counties in the provinces of Hainan, Guangdong, Guangxi, and Fujian in China. China is the largest litchi producer in the world with a planting area and annual production accounting for nearly 90% of the world's production and planting area. Variations in litchi yields in the four main litchi producing provinces caused by weather factors will strongly affect the world litchi supply and demand. Therefore, this study provides supportive evidence for litchi producers in adapting to climate change.

RESEARCH METHOD

Data

This paper uses data on litchi's yield, phenological period, and climate variations of 39 main producing counties under the jurisdiction of Hainan Province, Guangdong Province, Guangxi Province, and Fujian Province in China from 2011 to 2016. Litchi's yield was computed as the total production of litchi in a county divided by the total litchi-planted acres in that county. The data on litchi's phenological period, county-specific total litchi's production, and planted acres were obtained from China Litchi and Longan Research System.

Weather data were obtained from the China Meteorological Data Report Network which records daily T_{max}, T_{min} and rainfall for 2290 weather stations of 34 provinces in China. Since county-level data on daily rainfall is not available in public data sources, we used rainy days during each growth period of litchi as the proxy variable for 'rainfall'. This dataset also contained exact coordinates of each weather station of the 39 main producing counties, enabling them to be merged with our county-level litchi's yield data and phenological period data.

Model construction

The panel data model combined information of both cross-section data and time-series data. Therefore, the panel data model not only significantly increased the sample space but also reduced the impact of multicollinearity between explanatory variables on the estimated results, making the estimated results of the parameter more reliable. However, fixed effect model of traditional panel data only considered the individual effect, but not the residual correlation between different regions in different periods, which inevitably lead to the deviation of the results. In order to overcome the bias of model selection, a two-way fixed effect model was used in this paper to examine the impact of climate variations on litchi's yield that could consider both the fixed effect of individuals and the fixed effect of time. The two-way fixed effect model was constructed as follows:

$$y_{it}=x_{it}\,\beta+\alpha_i+\lambda_t+\varepsilon_{it}$$

Where y_{it} denotes county-average litchi yield in county i and year t. x_{it} represents weather variables, including the means of daily T_{max}, T_{min} and the rainy days during each litchi's growth stage. We also controlled for county-level fixed effects (represented by α_i) and year fixed effects (denoted by λ_t) to remove the effects of unobserved factors that are unique to each county and the effects that are common to all counties in a given year on yield. ε_{it} was the error term. β was the parameter vector that gives the responses of rice yield to weather variations.

EMPIRICAL ANALYSIS

Descriptive statistics

Descriptive statistics of litchi yield are provided in Table 1. From Table 1, we can see that the average litchi yield in all main producing counties is 250.8 kg/mu, with a maximum yield of 1063 kg/mu and a minimum yield of 8 kg/mu.

Table1. Descriptive statistics of litchi yield and meteorological factors

Variables	Obs	mean	sd	min	max
yield	234	250.8	194.4	8	1063
vegetative:T_{max}	234	24.8	3.42	13	37
vegetative:T_{min}	234	7.38	3.65	0	21
vegetative:rainfall	234	8.44	8.02	0	64
heading:T_{max}	234	27.72	3.11	12	37
heading:T_{min}	234	8.51	3.79	-1	21
heading:rainfall	234	14.5	9.6	0	48
flowering:T_{max}	234	30.7	2.51	23	40
flowering:T_{min}	234	21.16	11.7	2	21
flowering:rainfall	234	11.19	6.33	0	30
ripening:T_{max}	234	34.47	2.15	26	41
ripening:T_{min}	234	23.26	2.66	12	27
ripening:rainfall	234	40	5.76	0	88

According to the growth characteristics of litchi, the growing season of litchi can usually be divided into four main growth periods; namely vegetative stage, heading stage, flowering stage, and ripening stage. Temperature varies during litchi's different growth period. For maximum temperatures T_{max}, the average in all main producing counties were 24.8°C during the vegetative stage, 27.72°C during the heading stage, 30.7°C during the flowering stage, and 7.38°C during the ripening stage. For the minimum temperatures T_{min}, they were 24.8°C during the vegetative stage, 8.51°C during the heading stage, 21.16°C during the flowering stage, and 23.26°C during the ripening stage.

As for the rainy days, the average were 8.44 days during the vegetative stage, 14.5 days during the heading stage, 11.19 days during the flowering stage, and 40 days during the ripening stage.

Regression Results: Sample with all varieties of litchi

A two-way fixed effect model was established to examine the impacts of climate variations on litchi yield in China. We included weather variables during each phenological period of litchi, namely T_{max}, T_{min} and rainfall as explanatory variables to examine the variations in litchi yield.

Table 2. The effects of climate variations on litchi yield

Variables	All litchi	Feizixiao	Guiwei	Heiye
vegetative:T_{max}	0.924	5.903	-22.98***	-10.86*
	(3.789)	(6.016)	(5.511)	(6.079)
vegetative:T_{min}	1.011	-0.176	6.188	5.661
	(3.744)	(5.256)	(6.227)	(7.065)
vegetative:rainfall	-3.076**	-4.020**	-0.503	-6.715**
	(1.348)	(1.842)	(2.593)	(3.140)
heading:T_{max}	-2.946	-5.026	-7.935	3.430
	(4.101)	(6.522)	(6.535)	(7.076)
heading:T_{min}	7.112**	14.01**	0.485	-0.373
	(3.587)	(5.536)	(5.753)	(6.720)
heading:rainfall	-0.802	-0.113	1.097	-1.500
	(1.280)	(1.762)	(2.007)	(2.290)
flowering:T_{max}	9.930*	20.83***	-7.864	-3.740
	(5.463)	(7.730)	(9.228)	(11.26)
flowering:T_{min}	0.00234	-0.0383	-0.408	-0.0314
	(0.0825)	(0.103)	(5.307)	(0.0983)
flowering:rainfall	-5.865***	-3.850	-2.620	-7.489***
	(1.821)	(2.565)	(2.879)	(2.832)
ripening:T_{max}	4.356	4.998	39.44***	-53.98***
	(8.109)	(13.54)	(13.67)	(19.67)
ripening:T_{min}	3.578	-3.136	3.743	12.94
	(6.322)	(11.29)	(12.07)	(13.62)
ripening:rainfall	-2.597	-3.535	-4.691*	-4.244**
	(2.069)	(3.057)	(2.605)	(1.825)

Table 2 showed parameter estimates of weather variables for the model specification considered in this study. We found that the responses of litchi yield to temperature and rainfall varied by growth stage. Rainfall had statistically significant impacts on litchi yield during the vegetative stage. T_{min} had significant impacts on litchi yield during the heading stage. Excluding the two variables above, litchi yield was also affected by both T_{max} and rainfall during the flowering stage. However, temperature and rainfall did not have significant impacts on litchi yield during the ripening stage.

Coefficient estimates of weather variables showed that rainfall had negative impacts on litchi yield during both the vegetative and flowering stages, while higher T_{min} during the heading stage and T_{max} during the flowering stage had positive impacts on litchi yield. More specifically, it was observed that a 1°C increase of T_{min} during the heading period caused litchi yield to increase by 7.112 kg/mu and 1°C increase of T_{max} during the flowing period caused litchi yield to increase by 9.930 kg/mu. A day increase of rainy days reduced litchi yield by about 3.076 kg/mu during the vegetative stage and 5.865 kg/mu during the flowering stage.

Regression Results: 'Feizixiao' vs.'Guiwei' vs. 'Heiye'

'Feizixiao', 'Guiwei', and 'Heiye' are the three main litchi varieties accounting for more than 70% in yield and planting area of the litchi varieties. As these three litchi varieties are different in their physicochemical properties and genetic traits, it is necessary to examine whether the weather effects on yield estimated above differed by litchi variety. We divided our samples into several subsamples: 'Feizixiao' litchi-producing counties, 'Guiwei' litchi-producing counties, and 'Heiye' litchi-producing counties; calculated each county's litchi yield of the three main litchi varieties, and then replicated the analysis as the sample with all varieties of litchi.

As shown in the last three columns of Table 2, the weather effects on litchi yield differed substantially by litchi varieties during different phenological periods. For 'Feizixiao', its yield was associated with the germination stage, heading stage, and flowering stage; while the yield of 'Guiwei' was related to the germination stage and ripening stage but not the heading stage and flowering stage. As for 'Heiye', the germination stage, flowering stage, and ripening stage had significant influences on its yield, while the effect of heading stage on its yield was not significant.

Specifically, rainfall had a negative but not the same effect on the yield of different litchi varieties during different phenological periods. During the vegetative stage, one rainfall day increase reduced the yield of 'Feizixiao' by 3.26 kg/mu and 'Heiye' by 10.86 kg/mu. During the flowering stage, the yield of 'Heiye' reduced by 5.76 kg/mu when rainfall increased by one day. During the ripening stage, the yield of 'Guiwei' reduced by 5.23 kg/mu and 'Heiye' by 5.01 kg/mu when rainfall days increased by one day.

Temperature impacts on yield also differed considerably by litchi variety. For 'Feizixiao', its yield was significantly related to T_{min} during the heading stage and T_{max} during the flowering stage. The yield of 'Feizixiao' increased by 12.82 kg/mu with 1°C increase in T_{min} during the heading stage and 26.14 kg/acre if T_{max} increased 1°C during the flowering stage. For 'Guiwei', higher T_{max} during different phenological periods had different impacts on its yield. The effect of higher T_{max} on the yield of 'Guiwei' was negative during the germination stage when the yield of 'Guiwei' decreased by 25.97 kg/mu with T_{max} 1°C higher, which is opposite to the ripening stage when the yield of 'Guiwei' increased by 31.10 kg/mu with T_{max} 1°C higher. As for 'Heiye', its yield was mainly affected by T_{max} during the ripening stage when the yield of 'Heiye' decreased by 66.40 kg/mu with T_{max} 1°C higher. Besides, a 1°C increase in T_{max} during the vegetative stage also decreased the yield of 'Heiye' by 10.86 kg/mu.

CONCLUSIONS

This paper examined the impacts of weather variations on litchi yield by using a county-level panel on litchi yield and weather situations in corresponding counties. The main conclusions are as follows:

1. Meteorological factors affecting litchi yield are not the same during different growth periods. During the vegetative stage, litchi yield was significantly influenced by rainfall. During the heading stage, T_{min} was the major parameter determining litchi yield. During the flowering stage, both T_{max} and rainfall played an important role in influencing litchi yield.
2. Litchi yield was negatively related to rainfall during the vegetative and flowering stages and positively related to daily minimum temperatures during the heading stage and maximum temperatures during the flowering stage.
3. The effects of climate variations on different varieties of litchi are not the same. The yield of 'Feizixiao' was highly related to rainfall during the vegetative stage negatively influencing the yield, T_{min} during the heading stage and T_{max} during the flowering period. For 'Guiwei' and 'Heiye', the yield was mainly affected by T_{max} during vegetative stage and ripening stage and rainfall during the ripening stage. However, T_{max} during the ripening stage increased the yield of 'Guiwei' but decreased the yield of 'Heiye' significantly.

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