Article ID: 1006-8775(2018) 02-0199-10

CLIMATIC RISK ZONING OF DOUBLE CROPPING SUPER RICE CULTIVATION IN HUNAN PROVINCE

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Abstract: Based on meteorological data including daily sunshine duration, temperature and precipitation from 97 meteorological stations in Hunan province during the period of 1981—2010, in combination with the field experiment in different places at different sowing dates, the precise climatic risk zoning of double cropping super rice cultivation has been studied by using the spatial interpolation method and other Geographical Information System (GIS) technologies. Three key climatic factors were selected including chilling in May, high temperature heat damage during July to early August and low temperature damage in autumn in this study. Furthermore, based on the analysis of climatic conditions suitable for double cropping super rice cultivation and climatic disasters, 8–22 ℃ active accumulated temperature, sunshine duration from late March to October, climatic risk index of the low temperature in autumn, and climatic risk index of chilling in May were selected as key climatic factors to study the precise agro-meteorological regionalization of double cropping super rice in Hunan province. The results showed that: the high-yielding zones of double cropping super rice in Hunan were mainly located in Zhuzhou, Hengyang, Yongzhou and Chenzhou City, the moderate-yielding zones were primarily located in the east and north reaches of Dongting Lake, together with most of Changsha, Zhuzhou and Xiangtan City, and other regions in Hunan were not suitable for double cropping super rice. These findings can provide valuable information for the large-scale cultivation of double cropping super rice in Hunan province.

Key words: high yield zoning; risk zoning; double cropping super rice; small grids reckoning

CLC number: S162.2 **Document code:** A

doi: 10.16555/j.1006-8775.2018.02.008

1 INTRODUCTION

The world is now facing a great risk of food security. It is estimated that the world population will increase 2.3 billion before 2050, which will need 170% of the current food supply [1]. Since China has a great population, food security is highly associated with the national strategic security of the country. So far, there are many potential risks for food security in China, including the shortage of cultivated land resources, low level of agricultural development, and frequent occurrences of natural disasters, which severely constrain the development of agriculture[2]. Nowadays it is increasingly difficult for China to increase grain yield in some conventional ways, such as expanding the planting area or increasing the production input. However, super-high-yielding cultivation in rice is expected to play a key role in solving the problem of food security in China. Cultivation techniques of super-high-yielding super hybrid rice are thought to be the most effective ways to achieve high grain yield in rice.

The regionalization of crop cultivation is of great importance to serving as a guide for rice production, it also has great significance for food security in China in the future. Several studies have been done on climatic suitability regionalization of rice planting at the state level, in some river valleys, or in some provinces[3–7]. Du et al. reported precise climate regionalization of double cropping super rice maturity in Hunan province and recommended that certain incentives should be taken to expand the planting area of double cropping super rice in Xiangjiang River basin and Dongting Lake district while stabilizing the existing acreage [8]. Liao and Song et al. studied the effects of climate change on the planting structure of double-cropping rice in Hunan and the climatic adaptability of double-cropping super rice and found that effects of climate change on double-cropping rice were closely related to changes in rice maturity [9, 10]. Duan et al. studied the climatic

Received 2017-09-14; **Revised** 2018-04-03 **Accepted** 2018-05-15

Foundation item: China Special Fund for Meteorological Research in the Public Interest (201206045)

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suitability of double rice planting regions based on the maximum entropy model and recommended that the east part of Hunan province was the most suitable region for double rice planting[11, 12]. These studies above are primarily focused on the climatic suitability regionalization of rice, including double cropping rice. However, only few studies have been carried out to investigate the agricultural climatic regionalization of double cropping super hybrid rice. Especially, it is still unclear how meteorological disasters and high-yielding rice cultivation techniques influence the climatic suitability and regionalization.

It is in urgent need for high-resolution meteorological data on precise regionalization of double super hybrid rice cultivation. In this study, we analyzed the effects of several climatic factors on the climatic risk regionalization of double-cropping hyper rice cultivation in Hunan using the small grid spatial interpolation model in combination with other meteorological techniques, and obtained the precise climatic risk regionalization of climatic factors in Hunan including chilling in May, and high temperature heat damage from July to early August and low temperature damage in autumn. Based on the comprehensive climatic risk index, we obtained the precise climatic suitability of double cropping super rice cultivation in Hunan province. This study will provide a lot of valuable agro-meteorological data for the production layout and variety selection of the high-yielding double cropping super rice cultivation in Hunan which are most suitable for local climatic and ecological features.

2 STUDY AREA

Hunan is an inland province, located between 108°47′–114°15′E and 24°38′–30°08′N with an area of 211,800 km^2. The landscape is characterized primarily by mountains and hills, followed by basins, plains and water systems. The area of mountains, hills, basins, plains and water accounts for 51.2%, 15.4%, 13.9%, 13.1%, 6.4% of the total gross area, respectively. Hunan is surrounded by mountains on the east, south, and west, and the province slopes downward to the central and northeast, forming a U-shaped horseshoe with asymmetrical openings to the northeast. It belongs to subtropical monsoon humid climate, featuring full sunshine, both rain and heat come in the same season, and the province is suitable for the development of agricultural and forestry production.

3 MATERIALS AND METHODS

3.1 *Source of meteorological data*

Meteorological observation data, including daily temperature, precipitation and sunshine, were obtained from Hunan Meteorological Administration, which were observed at 97 meteorological observation stations during the period of 1981—2010. The national 1:50,000 digital elevation data were obtained from the National Administration of Surveying, Mapping and Geoinformation. The precise regionalization for double cropping super rice was calculated based on the small grid spatial interpolation of daily temperature and sunshine duration[13].

3.2 *Climatic risk factors*

There are several primary meteorological disasters, such as cold injury, heat damage, the drought and the flood, etc., greatly influencing the growth of double cropping super rice in Hunan [14, 15]. Though the drought and the flood are directly influenced by the rainfall amount [16, 17], they are also affected by irrigation condition, irrigation capability, water holding capacity of soils, and other human factors, which are difficult to be quantitatively described in climatic risk assessment. By comparison, cold injury and heat damage are generally natural disasters and are not affected by water conservancy facilities and have been proven to greatly affect the growth of double cropping super rice. In this work, we mainly studied effects of cold injury and heat damage on the growth of double cropping super rice by selecting three key climatic factors, including chilling in May, high temperature during July and early August, and the low temperature in autumn[18, 19]. Chilling in May exerted adverse effects on the early rice at the tillering and panicle differentiation stages, characterized by delayed reviving period, decreased number of effective panicles, or decreased panicle differentiation resulting in increased empty grain rate. High temperature during July and early August mainly affected the early rice during the period of grain filling resulting in the phenomenon of high-temperature-induced maturity with the decreased filling rate and thousand-grain weight, and high temperature also affected the late rice at the reviving and tillering stage after the seedling of late rice were transplanted [20]. The low temperature in autumn mainly affected the late rice at the heading-flowering stage, resulting in increased empty grain rate[21].

The characteristics of chilling in May, high temperature during July and early August [22] and low temperature in autumn were summarized in Table 1. Climatic risk indices of three climatic factors above were calculated according to the equations (1)-(3), respectively.

3.3 *Spatial interpolation of climatic factors*

3.3.1 TEMPERATURE

The inverse distance weighting method in combination with the Gaussian weighted model was used to carry out the interpolation of the temperature in this study. Briefly, the geographic elevation data in Hunan were integrated into the 500m×500m grid maps, then constituted a multiple regression model which combined meteorological observation data with latitude and longitude elevation of the stations, and calculated the geographic residuals. At the same time, the grid values were estimated using the multiple regression model, then residuals were put into the grid to calculate

Table 1. Damage degrees of primary meteorological disasters.

Factors	Chilling in May		High temperature from July to early August		Low temperature in autumn	
Grades of damage	Daily average temperature (℃)	Duration /d	Daily maximum temperature(℃)	Duration /d	Daily average temperature (℃)	Duration /d
Slight (Tier 1)	18～20	5～6	≥35	5～10	20～22	3～5
Moderate (Tier 2)	18～20 15.6～17.9	7～9 7～8	≥35	11～15	20～22 18.5～20	6 and more 3~5
Serious (Tier 3)	18～20 ≤15.5	≥10 ≥5	≥35	≥16	≤20 ≤18.5	≥6 ≥3

Note: Climatic risk index of chilling in May=1 frequency per year×1+2 frequency per year×2+3 frequency per year×3 (1)
Climatic risk index of high temperature=1 frequency per year×1+2 frequency per year×2+3 frequency per year×3 (2)
Climatic risk index of low temperature in autumn=1 frequency per year×1+2 frequency per year×2+3 frequency per year×3 (3)

the final grid values [8]. By taking the altitude into account, the improvement of inverse-distance weighted model was used in the equation below.

$$T_{i,j}=\sum_{k=1}^{n}(T_k+(H_{i,j}-H_k)\beta)d_k^{-2}/\sum_{k=1}^{n}d_k^{-2}$$

where H_k is the height above sea level of the k^{th} point, and β is the lapse rate between elevation and climatic variables. The ultimate calculated value of grid points is the sum of a lattice estimating value and a residual amendment value. Among them, the square parameter controls how the weight coefficient decreases when one grid node increases. For a larger square, the nearest data points are given a higher weight share. For a minor square, the weights are evenly distributed to each data point. The accuracy of the results was analyzed by the cross-validation test.

3.3.2 SUNSHINE DURATION

We obtained the total sunshine duration per month by extrapolating the daily available sunshine duration of meteorological sites and grid points, and obtained the percentage of monthly sunshine duration by using the actual s unshine duration per month divided by the possible sunshine duration per month. The percentage of monthly sunshine duration was interpolated to the grid points, and was then multiplied by the monthly sunshine duration to calculate the monthly sunshine duration [13]. Some topographical factors, such as the slope and the aspect, were considered in daily available sunshine duration. The results derived from spatial interpolation of daily mean temperature and monthly sunshine duration during 1981—2010 (new 30-year decadal period) are shown in Table 2. Similarly, the accuracy of the results was also analyzed by the cross-validation test.

Table 2. Cross-validation analysis of the spatial interpolation of daily average temperature and monthly sunshine during the period 1981—2010.

	Correlation coefficient	Mean absolute error	Root mean square errors
Daily average temperature	0.99	0.49℃	0.71℃
Monthly sunshine duration	0.96	12.54 h	16.20 h

3.3.3 SPATIAL DATA CLUSTER

Daily climatic data during 1980—2012 were interpolated into small grid of 500m ×500m, and the spatial data cluster of long-sequence indices were formed based on various zoning indices of double cropping super-rice.

4 RESULTS AND ANALYSIS

4.1 *Climatic risk regionalization*

According to the varying extents to which each of three climatic factors affected the growth of double cropping super rice in Hunan province, four agro-climatic zones were established and referred to as (1) slight-risk zone, (2) low-risk zone, (3) moderate-risk zone, and (4) high-risk zone, respectively. Furthermore, the comprehensive index (P) was calculated by taking the weight (Q) of each climatic factor among the overall effects into account, and correspondingly classification index of each grid points was determined to conduct the following assessment of climatic regionalization. Climatic risk regionalization of double cropping super rice was shown in Table 3.

As for meteorological disasters caused by temperature anomaly, Wang et al. analyzed the agricultural meteorological disasters from 1978 to 2003 that seriously affected the crop output, and found that cold injury and floods were the main disasters influencing the output of early rice and late rice [23]. Liu et al. studied the frequency of disasters, loss rate and intensity of major agricultural meteorological disasters including flood, drought, hail and low temperature during 1976—2015, and revealed that the number of major agricultural meteorological disasters decreased, but the frequency of the low-temperature induced disasters gradually increased in the past years [24]. Similarly, Feng et al. found that agricultural meteorological disasters, except the low temperature disaster, decreased significantly in recent 10 years [25]. Relative to disasters of low temperature, drought and cold injury, there are few studies on high-temperature induced heat damage [26]. Therefore, this work analyzed the high-temperature heat damage index in the analysis of climatic risk zoning, and studied the index of cold injury and low temperature in the agro-meteorological regionalization of double cropping super rice.

Table 3. Meteorological risk regionalization of double cropping super rice.

Factors	Slight risk	Low risk	Moderate risk	High risk	Weight coefficient (Q)
Chilling in May	≤0.5	0.5～1.5	1.5～2.0	≥2.0	0.3
High temperature	≤1.0	1.0～2.0	2.0～2.5	≥2.5	0.2
Low temperature in autumn	≤1.0	1.0～2.0	2.0～2.5	≥2.5	0.5
Serial Number (T)	1	2	3	4	
Comprehensive index (P)	1～2.3	2.3～2.7	2.7～3.1	≥3.1	

Based on the assessment of climatic suitability and climatic damage in Hunan province, four climatic factors were selected to determine the regionalization of high-yielding double cropping super rice, including 8—22℃ active accumulated temperature, sunshine duration from late March to October, climatic risk index of low temperature in autumn, and climatic risk index of chilling in May. Four regions of high-yielding double cropping super rice cultivation were developed including: (1) the region with high-yielding rice, (2) the region with moderate-yielding rice, (3) the region with low-yielding rice and (4) the region unsuitable for rice cultivation. The comprehensive index of each area was calculated based on the weight of its corresponding climatic factor among the overall damage. Climatic regionalization of high-yielding double-cropping super rice cultivation was shown in Table 4.

Table 4. Regionalization of high-yielding double cropping super rice.

Factors	High yield area	Moderate yield area	Low yield area	Non-suitable area	Weight (Q value)
8～22 ℃ active accumulated temperature (℃)	≥4400	4200～4400	4000～4200	≤4000	0.6
Sunshine duration from late March to October (hours)	≥1150	1050～1150	950～1050	≤950	0.2
Climatic risk index of low temperature in autumn	≤0.3	0.3～0.8	0.8～1.5	≥1.5	0.1
Climatic risk index of chilling in May	≤0.3	0.3～0.8	0.8～1.5	≥1.5	0.1
Serial Number (T)	1	2	3	4	
Comprehensive index (P)	1～1.5	1.5～2.3	2.3～3.5	≥3.5	

4.2 *Spatial distribution of climatic risk zoning for double-cropping super rice*

4.2.1 SPATIAL DISTRIBUTION OF CLIMATIC RISK INDEX OF CHILLING IN MAY

Figure 1 shows the spatial distribution of climatic risk index of chilling in May in Hunan province. The risk index sloped from the western part of the province to the eastern part, and sloped from the northern part to the southern part, as shown in Fig.1. There was the highest risk index (2.0 and above) of chilling in May in mountainous areas with the greater height above sea level in the western part and southern part of Hunan, including most parts of Zhangjiajie, most of the west part of Hunan, Tujia & Miao autonomous prefecture, the west part of Yiyang, the north and south parts of Huaihua, the west part of Loudi, the southwest part of Shaoyang, the east and south part of Chenzhou, the south part of Yongzhou. The peripherals of the cities above had the moderate classification index of 1.5–2.0. The climatic risk indices in both the Dongting Lake area and the middle and west Hunan province were between 0.5 and 1.5, including Changde, most parts of Yueyang, the north part of Yiyang, Changsha, Xiangtan, the east part of Loudi, the north part of Zhuzhou, most parts of Zhaoyang, the southeast part of the Xiangxi Tujia & Miao autonomous prefecture, the central part of Huaihua, the north part of Henyang. The climatic risk index in the upper Xiangjiang River basin was under 0.5 with the lowest climatic risk, including the south part of Henyang, the south part of Zhuzhou, most of Yongzhou and most parts of Chenzhou.

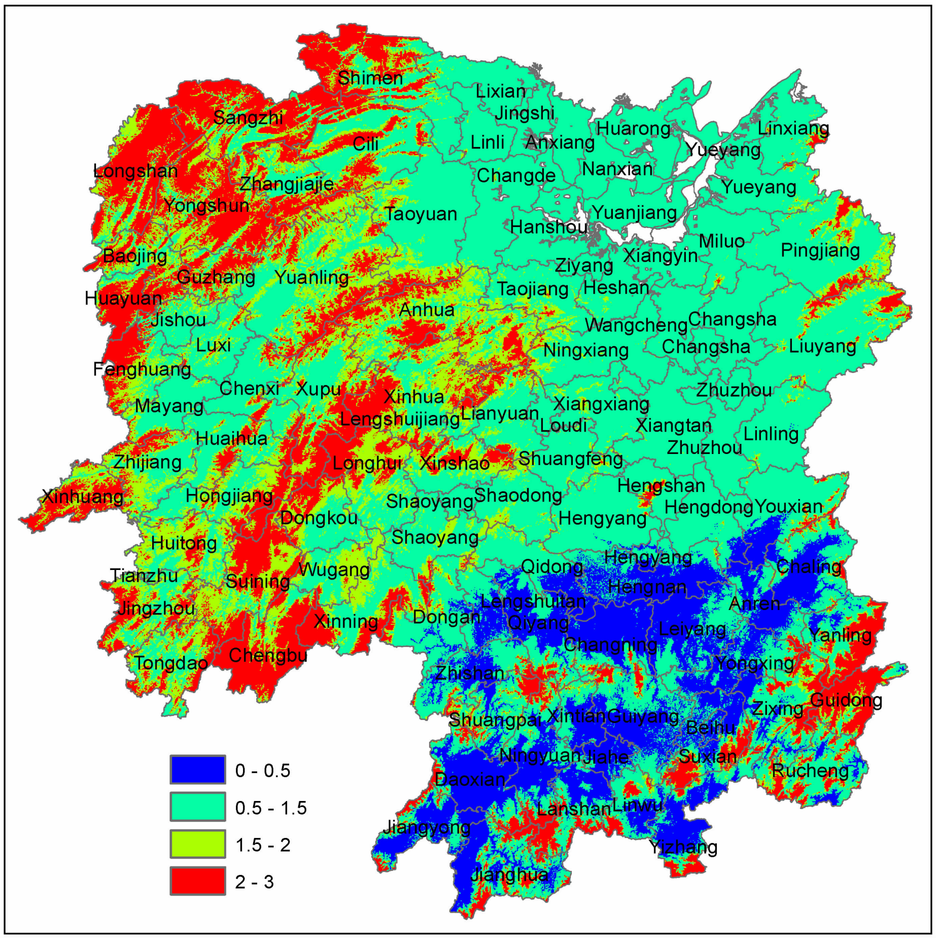

Figure 1. Spatial distribution of climatic risk index of chilling in May for double-cropping super rice cultivationin Hunan.

4.2.2 SPATIAL DISTRIBUTION OF CLIMATIC RISK INDEX OF HIGH TEMPERATURE HEAT DAMAGE

Figure 2 shows the spatial distribution of climatic risk index of heat damage in Hunan province. There was the highest risk index of heat damage of 2.5 and above in most of Henyang, the east part of Changsha and most of Zhuzhou. The relatively high risk index of heat damage between 2.0 and 2.5 was found in the south part of Dongting Lake basin, the west region of the middle and lower Xiangjiang River basin, the lower Yuanshui River basin, the lower Zishui River basin, including the south part of Changdi, the central part of Yiyang, the south part of Yueyang, the west part of Changsha, most of Xiangtan, the east part of Loudi, the north part of Hengyang, the north part of Yongzhou, the north part of Binzhou. The risk index of heat damage between 1.0 and 2.0 was found in the north part of Changde, the north part of Yiyang, the north part of Yueyang, the east part of Zhaoyang, the central part of Huaihua, the central part of Yongzhou. The lowest risk index of heat damage under 1.0 was found in the mountainous area in most of Xiangxi basin and the east and south Hunan province, including most of Zhangjiajie, the Xiangxi Tujia & Miao autonomous prefecture, most of Huaihua, most parts of Loudi, the west part of Zhaoyang, the east part of Yueyang, the south part of Zhuzhou, the south part of Yongzhou, and the east and south part of Chenzhou.

4.2.3 SPATIAL DISTRIBUTION OF CLIMATIC RISK INDEX OF LOW TEMPERATURE IN AUTUMN

Figure 3 shows the spatial distribution of the climatic risk index of the low temperature in autumn in Hunan province characterized by the higher indices in the west and the lower indices in the east. There was the highest risk index of 2.5 and above for low temperature in autumn in the mountainous areas with the greater height above sea level in the west, east and south regions of Hunan province, including most of Zhangjiajie, most of the Xiangxi Tujia & Miao autonomous prefecture, the south part of Yiyang, the south and north parts of Huaihua, the west part of Zhaoyang, the west part of Loudi, the east part of Yueyang, the east and south parts of Chenzhou and the south part of Yongzhou. The peripherals of the cities above had the relatively high risk index of 2.0–2.5. The risk index of 1.0–2.0 was found in the east region of Hunan province and the central part of the west Hunan province, including the south part of Changde, most of Yueyang, the north part of Yiyang, most of Changsha, the east part of Loudi, Xiangtan, most parts of Zhuzhou, Henyang, most parts of Zhaoyang, the central part of Huaihua, the north and central part of Yongzhou, and most parts of Chenzhou. The lowest risk index of 1.0 and under for low temperature in autumn was found in the southeast region of Hunan province, including the south part of the Lengshui basin in Yongzhou, most of Dao county, the central part of Jiangyong county, the west part of Jianghua county, and so on.

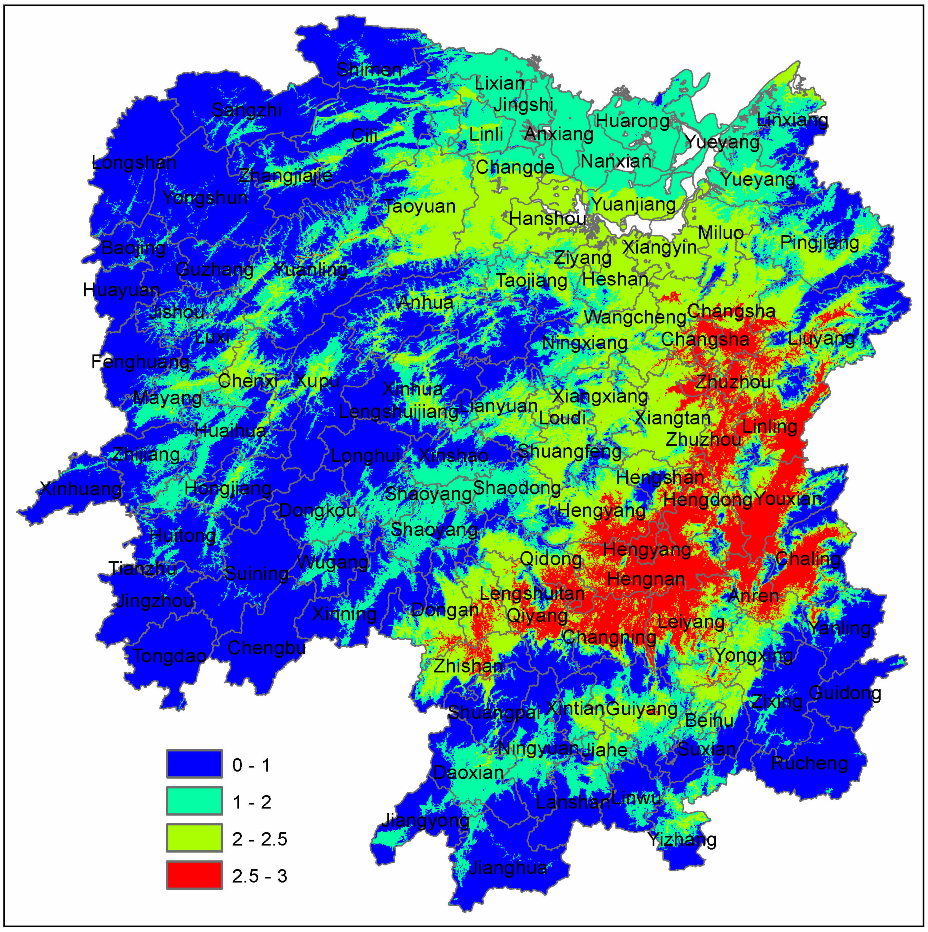

Figure 2. Spatial distribution of climatic risk index of high temperature damage from July to early August for double-cropping super rice in Hunan.

4.2.4 SPATIAL DISTRIBUTION OF THE COMPREHENSIVE INDICES OF THREE CLIMATIC DISASTERS

According to the comprehensive index (P) in Table 3, spatial distribution of the comprehensive indices of three climatic disasters is shown in Fig.4. The slight comprehensive index of the double-cropping super rice cultivation was mainly found in the south region of Hunan province, including Dao county, Jiangyong county and Jianghua county. The low comprehensive index was primarily found in the north part of Changde, the north part of Yiyang, the north part of Yueyang, most parts of Zhaoyang, the central part of Huaihua, the south part of Yongzhou and the west part of Chenzhou. The moderate comprehensive index was found in the middle and lower Xiangjiang river basin and the south basin of Dongting Lake basin, including the central part of Changde, the central part of Yiyang, the south part of Yueyang, most of Changsha, most parts of Zhuzhou, Xiangtan, the east part of Loudi, Henyang, the north part of Yongzhou and the north part of Chenzhou. The highest comprehensive index was found in the mountainous areas with the greater height above sea level in the west, east and south regions of the Hunan province, including Zhangjiajie, the Xiangxi Tujia & Miao autonomous prefecture, the north part of Changde, the south part of Yiyang, the east part of Yueyang, most of Huaihua, the west part of Loudi, the west part of Zhaoyang, the south part of Yongzhou and the south part of Chenzhou.

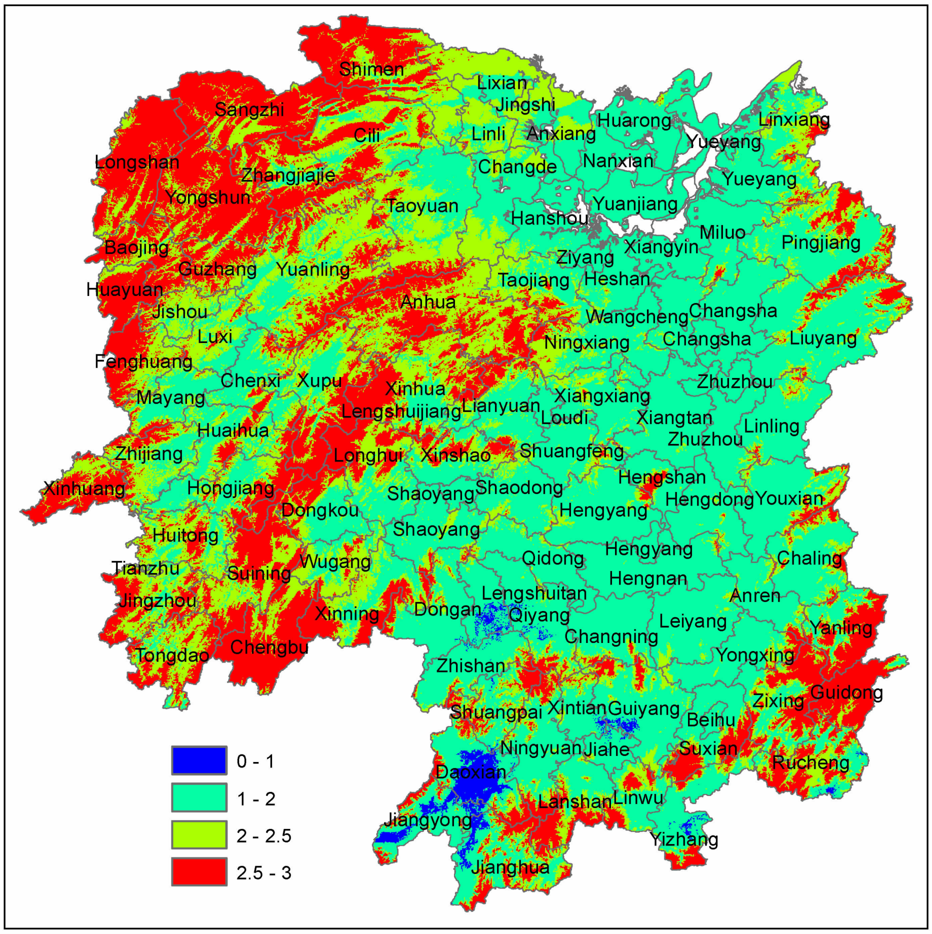

Figure 3. Spatial distribution of climatic risk index of the low temperature in autumn for double-cropping super rice in Hunan.

4.3 *Regionalization of high –yielding double –cropping super rice cultivation*

Based on the assessment of climatic suitability and climatic damage in Hunan province shown in Table 4, the precise regionalization of high-yielding double-cropping super rice cultivation was determined as shown in Fig. 5. The high-yield regions included Zhuzhou, Hengyang, Yongzhou and Chenzhou, as well as urban areas, such as the suburban area of Zhuzhou, Zhuzhou county, You county, Liling, Chaling, the suburban area of Henyang, Henyang county, Hengdong, Hengnan, Leiyang, Qiyang, Changning, Anren, Qidong, Dongan, Lengshuitan, Daoxian, Jiangyong, Xintian, Jiahe, Guiyang, Yizhang, and other urban areas. The moderate-yield regions included Dongting Lake region (such as Jinshi, Linli, Dingcheng district, Hanshou, Ziyang, the east and north regions of He Mountain); Changde, Zhuzhou, Xiangtan, Hengqi basin (Shaodong, Hengshan county, and the north part of Hengyang); the valley from Jiangyong, Dao county toward west till Zhouzhou and Chaling, and Yongzhou (Dongan and Zhishan county). The low-yield regions included Shaoyang, the middle and lower Yuanshui River basin, the northwest region of the Dongting Lake basin and Bing Lake plain northwest from Taoyuan and Li county, part of Pingjiang basin, Liuyang, some parts of the south regions of Hunan province. The unsuitable regions included the Xiangxi Tujia & Miao autonomous prefecture, Huaihua, Zhangjiajie, Xuefeng Mountain, the mountainous areas along Anhua-Yuanling-Chenxi, the mountainous areas (including Yangming Mountain) in the south regions of Hunan province, the mountainous areas in the west and south regions of Shaoyang.

5 DISCUSSION AND CONCLUSIONS

The risk indices of the precise climatic risk zoning for double-cropping super rice cultivation were calculated based on the spatial interpolation of average temperature and sunshine duration. The average temperature was calculated using inverse distance weighted methods with the Gaussian correction factor, and daily sunshine duration was interpolated into the grid using MRG method to calculate the monthly sunshine duration by multiplying the sunshine day percentage per month with the available sunshine duration per month. The interpolation of daily average temperature and monthly sunshine duration was tested by cross-validation method. We found that the correlation coefficient of daily average temperature during the period 1981—2010 was 0.99, mean absolute

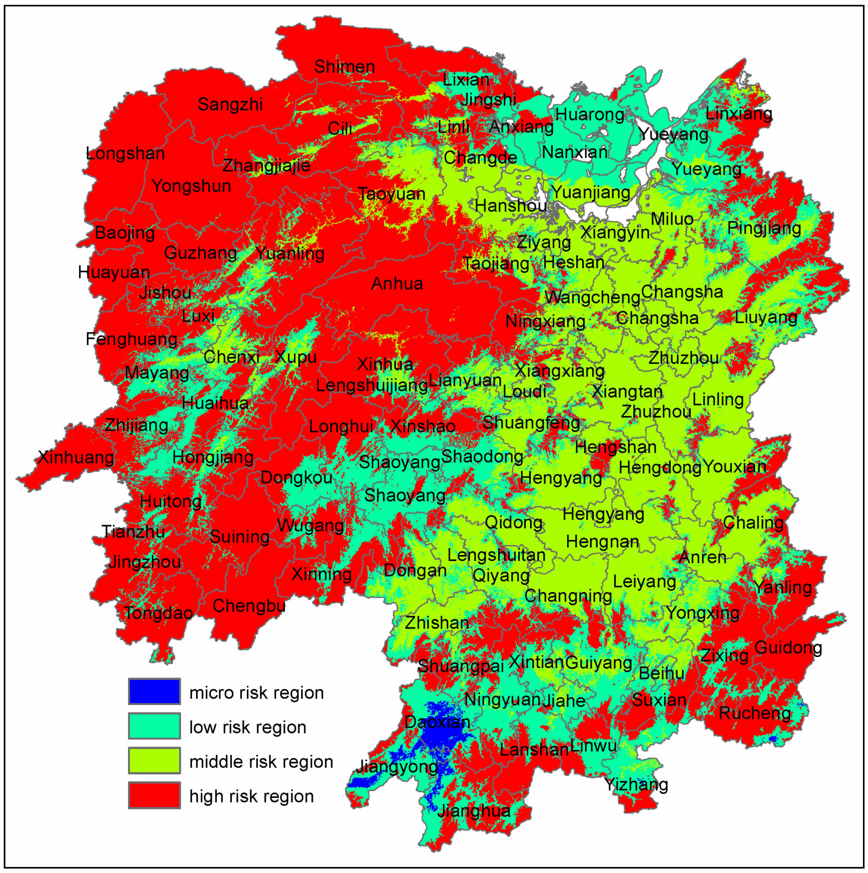

Figure 4. Spatial distribution of the comprehensive index of climatic risk zoning for double cropping super rice in Hunan.

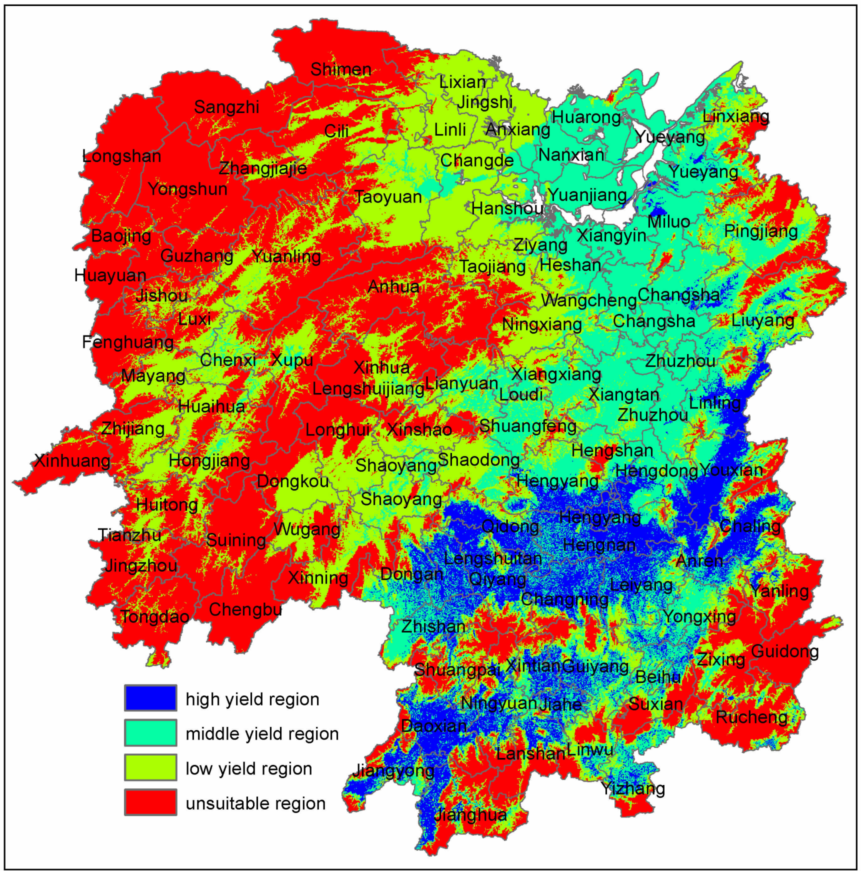

Figure 5. Spatial distribution of high-yielding double cropping super rice cultivation in Hunan.

error was 0.49℃, and root mean square error was 0.71℃. As for monthly sunshine duration during the period 1981—2010, the correlation coefficient was 0.96, mean absolute error was 12.54 hours, and root mean square error was 16.20 hours.

Based on meteorological data during the period of 1981—2010 and the field experimental data of sowing by stages in different geographical locations, we studied the precise climatic risk zoning for double-cropping super hybrid rice cultivation in Hunan province using spatial interpolation of three important climatic disasters including chilling in May, high temperature heat damage during July to early August and the low temperature in autumn. Furthermore, based on the analysis of the climatic condition suitable for double-cropping super rice cultivation and climatic disasters, we studied the precise agro-meteorological regionalization of high-yielding double-cropping super rice in Hunan province by selecting 8–22℃ active accumulated temperature, sunshine duration from late March to October, meteorological risk index of cold dew wind, and meteorological risk index of chilling in May as key climatic factors in order to explore the characteristics of meteorological resources for high-yield double-cropping super rice cultivation in different regions of Hunan province, as well as the frequencies of primary climatic disasters.

According to the climatic risk zoning of double-cropping super rice in Hunan province based on the extents of climatic disasters during the rice cultivation, we found that the highest climatic risk regions were mainly located in the mountains with the greater height above sea level in the west, east and south regions of Hunan province; the moderate climatic risk regions were located in middle and lower Xiangjiang River basin as well as the south region of Dongting Lake basin, and there are relatively low climatic risk regions in other areas of Hunan province. Furthermore, according to the precise agro-meteorological regionalization of high-yielding double-cropping super rice in Hunan province with the comprehensive consideration of meteorological resources and the occurrence frequency of climatic disasters, we found that the high-yielding double-cropping super rice in Hunan were mainly located in four regions, including Zhuzhou, Hengyang, Yongzhou and Chenzhou; The moderate-yielding double-cropping super rice were primarily located in the areas east and north from Dongting Lake, together with most of Changsha, Zhuzhou and Xiangtan; and other regions in Hunan were low-yield ones or unsuitable for double-cropping super rice cultivation.

In this study, based on practical experiences of double-cropping super rice cultivation in Hunan, three important climatic factors including chilling in May, high temperature heat damage during July and early August and low temperature in autumn were selected to develop the climatic risk zoning. These climatic factors have been proven to have greater effects on the growth of double-cropping super rice, and they were also not influenced by human activity. It is needed to further identify other climatic factors [27]. Besides, this research did not study the physiological features of double-cropping super rice[28]. More works are needed to consider simultaneously physiological features of rice and climatic resources, and to quantitatively study the effects of temperature and sunshine resources on grain filling.

REFERENCES:

[1] LIU He-guang, QIN Fu. Scientific understanding of grain security in China [N]. Economics Daily, 2013-07-12(13) (in Chinese).

[2] HAN Xi-ling, ZOU Feng-yu. Grain Economy and Policy [M]. Beijing: China Business Press, 1998 (in Chinese).

[3] Associate Research Group for Agroclimtological Study of Cropping Systems in South China. Regionalization of cropping systems in rice-growing regions in south China [J]. Sci Agric Sinica, 1982, 15(4): 35-42 (in Chinese).

[4] LU Yi-mei. Regionalizaton of agricultural climate for cotton growing in Zhejiang province [J]. Acta Agric Zhejiangensis, 1990, 2(4): 161-164 (in Chinese).

[5] GUO Shu-min, CHEN Yin-jun, SU Yong-xiu, et al. Study on precise comprehensive agricultural climate regional planning and application of Leechee in Guangxi [J]. Chin Agric Bull, 2011, 27(2): 205-209 (in Chinese).

[6] LAI Chun-jia, QIAN Huai-sui, DUAN Hai-lai, et al. Climate suitability and its change trend of double-cropping rice in Huaihe River Basin [J]. Chin J Ecol, 2009, 28(11): 2339-2346 (in Chinese).

[7] ZHU De-feng, CHEN Hui-zhe, ZHANG Xiu-fu, et al. Evolvement of rice cropping system and planting zonation in Zhejiang province [J]. Acta Agric Zhejiangensis, 2007, 19(6): 423-426 (in Chinese).

[8] DU Dong-sheng, LIAO Yu-fang, LU Kui-dong, et al. Refined climate regionalization of double cropping super rice maturity in Hunan province [J]. China Rice, 2015, 21 (4): 49-52 (in Chinese).

[9] LIAO Yu-fang, WANG Kuo-jun, ZHAO Fu-hua. Modern Agricultural Climate Regionalization in Hunan Province [M]. Changsha: Hunan University Press, 2010 (in Chinese).

[10] SONG Zhong-hua, DU Dong-sheng, ZHANG Yan-gui, et al. Human cotton refining climatic regionalization based on GIS and interpolating preference [J]. Chin Agric Bull, 2011, 27(20): 146-150 (in Chinese).

[11] DUAN Ju-qi, ZHOU Guang-sheng. Dynamics of decadal changes in the distribution of double-cropping rice cultivation in China [J]. Chin Sci Bull, 2013, 58(13): 1213-1220 (in Chinese).

[12] DUAN Ju-qi, ZHOU Guang-sheng. Climatic suitability of double rice planting regions in China [J]. Chin Agric Sci, 2012, 45(2): 218-227 (in Chinese).

[13] DU Dong-sheng, LIAO Yu-fang, ZHAO Fu-hua. Study on the spatial interpolation method for daily mean air temperature over complex terrain in Hunan province [J]. Chin J Agrometeor, 2011, 32(4): 607-614 (in Chinese).

[14] LU Kui-dong, HUANG Wan-hua, SHEN Jian-bin, et al.

A study on climatic regionalization of one season super rice planting in Hunan province [J]. Chin J Agrometeor, 2006, 27(2): 79-83 (in Chinese).
[15] HUANG Shu-e, TIAN Jun, WU Hui-jun. Evaluation on climatic suitability during growth season of double rice in Jiangxi province [J]. Chin J Agrometeor, 2012, 33(4): 527-533 (in Chinese).
[16] ZHANG Jian-ming, ZHANG Xin-ping, LI Zu-xian. Climatological features of annual precipitation in Hu'nan Province during 46 A [J]. J Trop Meteor, 2008, 24(5): 512-518 (in Chinese).
[17] WU Xian-yun, DING Yi-hui, YE Cheng-zhi. Diagnosis of persistent drought/flood events in two inner lakes' region of China [J]. J Trop Meteor, 2013, 19 (2): 264-275 (in Chinese).
[18] WANG Kuo-jun, SHUAI Xi-qiang, LIU Jia-qing, et al. Climatic ecological diagnoses on seed production of two line hybrid rice [J]. J Appl Meteor Sci, 2003, 14(1): 93-100 (in Chinese).
[19] YANG Jian-ying, HUO Zhi-guo, WU Li, et al. Flood risk assessment and zoning for rice in Southwest China [J]. Trans Chin Soc Agric Eng, 2016, 37 (5): 564-577 (in Chinese).
[20] YAO Peng-juan, WANG Chun-yi, ZHANG Ji-quan. Hazard assessment of cold and hot damage for double-season early rice (DSER) in lower-middle reaches of the Yangtze River Basin [J]. Adv Earth Sci, 2016, 31 (5): 503-514 (in Chinese).
[21] HUANG Zhen-zhu, WANG Chun-lin, CHEN Hui-hua. The characteristics of anomalously lower temperatures in autumn and their impact on the late rice yield under climate change in Guangdong Province [J]. J Trop Meteor, 2014, 30(2): 382-386 (in Chinese).
[22] Administration of Quality and Technology Supervision of Hunan Province. DB43/T234-2004, Meteorological Disaster Terminology and Classification [S]. Changsha: Administration of Quality and Technology Supervision of Hunan Province, 2004 (in Chinese).
[23] WAGN Chun-yi, LOU Xiu-rong, WANG Jian-lin. Influence of agricultural meteorological disasters on output of crop in China [J]. J Nat Disaster, 2007, 16(5): 37-43 (in Chinese).
[24] LIU Xiao, HE Xue-min, YOU Song-cai. Characteristics of agricultural meteorological disasters in China from 1976 to 2015 [J]. Chin J Agrometeor, 2017, 38(8): 481-487 (in Chinese).
[25] FENG Ying, YAO Shun-bo, GUO Ya-jun. Unit area crop yield response to effective irrigation in China based on a panel data model [J]. Resour Sci, 2012, 34(9): 1734-1740 (in Chinese).
[26] ZHANG Qian, ZHAO Yan-xia, WANG Chun-yi. Advances in research on major agro-meteorological disaster indexes in China [J]. J Nat Disaster, 2010, 19(6): 37-43.
[27] XUE Li-fang, WANG Chun-chang, WANG Chun-lin, et al. Agricultural climatic regionalization for longan cultivation in Guangdong Province [J]. J Trop Meteor, 2011, 27(3): 403-409 (in Chinese).
[28] NING Jin-hua, LU Kui-dong, SONG Zhong-hua, et al. Relationship of yield components and temperature and light factors for super double-cropping late rice [J]. Chin J Ecol, 2015, 34(3): 688-694 (in Chinese).

Citation: HU Xue-yuan, WANG Chun-yi, DU Dong-sheng, et al. Climatic risk zoning of double cropping super rice cultivation in Hunan province [J]. J Trop Meteor, 2018, 24(2): 199-208.