Bangladesh J. Bot. **49**(3): 799-808, 2020 (September) Special

DROUGHT RISK ASSESSMENT AND ZONING OF WINTER WHEAT (*TRITICUM AESTIVUM* L.) BASED ON CLIMATE CHANGES IN JIANGSU PROVINCE, CHINA

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Keywords: Drought index, Risk assessment, Winter wheat, Meteorological elements

Abstract

On the basis of the principle of field water balance, a drought risk index model was established to evaluate the risk of winter wheat (*Triticum aertivum* L.) in the Jiangsu Province of China. A total of 12 growth stages of winter wheat were fed into the model and analyzed by using the meteorological data along with the meteorological observation network in Jingsu province. Results showed that the winter wheat drought index of the risk assessment in the whole growth period of Jiangsu province showed parabolic distribution and high-risk periods were mainly determined in sowing to tillering stage and jointing stage to mature period. The drought risk in zonal distribution presents a tendency of increase from south to north of the study area.

Introduction

The frequency of drought occurrences for the cultivation of winter wheat in China is as high as 79.21% (Zhang *et al.* 2013). It is of practical significance to assess the impact of drought on winter wheat production in Jiangsu province. Many researchers in meteorology and agriculture have made great efforts in drought-resistant planting techniques (Zhao *et al.* 2013, Ali *et al.* 2014a,b, Jin *et al.* 2014, Gimeno *et al.* 2014, Marzieh and Ezatollah 2014, States Mcclaran and Wei 2014, Zhang *et al.* 2014). The present research was aimed at studying the extent of drought risk levels to winter wheat corps in Jiangsu province of China which might be occurring due to climate change. Regional meteorological data and appropriate mathematical model will be the tools to find the result.

Materials and Methods

Winter wheat (*Triticum aestivum* L., Family: Poaceae) is the principal agricultural crop in the Jiangsu province of China. In this area drought is a big problem which might limit the production of wheat with the advances in climate change factors. Agrometeorological disaster risk assessment is based on the destruction mechanism of natural disaster, and the disaster risk index and its influencing factors are established by comprehensive method. Based on the comprehensive drought index of field water balance, the drought signal and drought situation of crops were reasonably reflected, so a crop drought risk evaluation model to evaluate and divide the drought risk index of winter wheat growing period (late October to late May of the next year) was established.

The meteorological observation data as a secondary data source from China Meteorological Administration's (CMA) were used. The data used for the present study were: daily precipitation, sunshine, wind speed, soil relative humidity and some more. The collection sources were based from the 37 representative stations in Jiangsu province (Fig. 1) monitored by CMA during the period of 1961-2013 Other data such as drought affected region, its impact on wheat yield, etc. were also obtained from the meteorological observations and statistical yearbooks published for the region covering the same period of study.

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The wheat cultivation area in the Jiangsu are divided into three distinct regions such as northern, central and southern Jiangsu. According to the observation criteria of wheat growth period (CMA 1993) the winter wheat growth stages in Jiangsu province were divided as follows: sowing (SOW), sprouting (SPR), triphyllous (TRI), tillering (TIL), overwintering (OWI), regreening (REG), setting (SET), jointing (JOI), booting (BOO), heading (HEA), anthesis (ANT) and milk (MIL). Frequency or proportion represents the percentage (%) of the total number of occurrences. The rate of change is the number of dependent variables that increase by 1 unit.
The relative significance was evaluated through path analysis, and the regional distribution map was drawn through contour line (CN) interpolation processing in GIS software. Each month is divided into the first, middle and last ten days (abbreviated to Li, mi and La, respectively) and different elements were combined by using "/". For example, the relative drought index in early November is expressed as "11/LI/RCI".

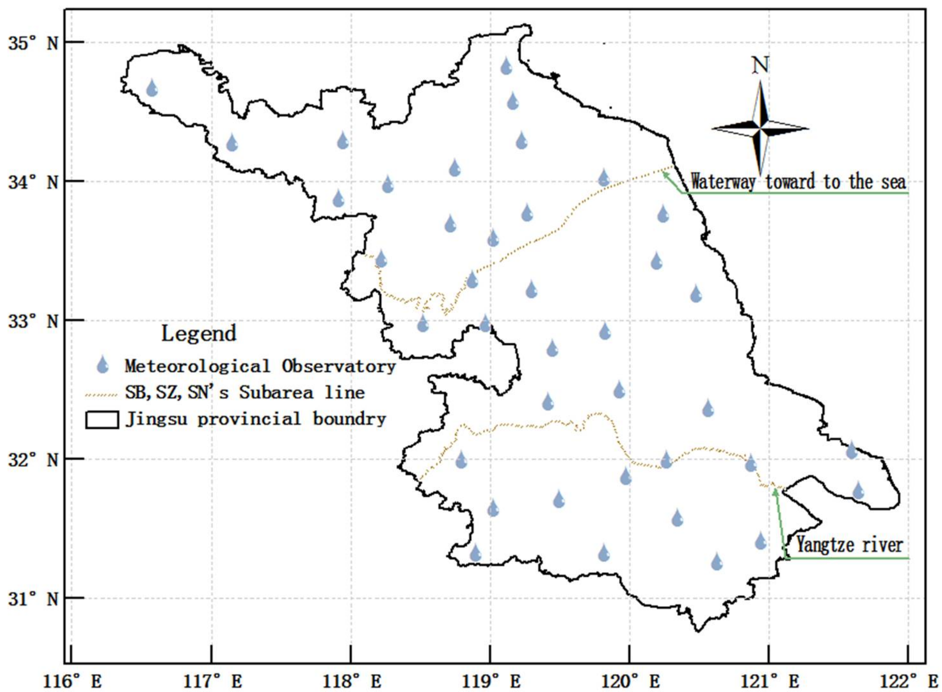


Fig.1. Subarea and distribution of observation stations (37) of Jiangsu province after CMA.

Water budget index is an integrated index that can well reflect the water balance of winter wheat fields under natural conditions (Xu *et al.* 2013). In rainfed condition, the moisture revenue and expenditure on winter wheat fields are precipitation (PA) and field evapotranspiration (ET), respectively. The relative dynamic variations of the two quantities determine the degree of drought. Suppose the influence degree of drought is index I, then

$$\mathrm{I} = 1 - \frac{\mathrm{PA}}{ET} \tag{1}$$

As known from eq. (1), the larger the I value, the more severe the drought situation is; I = 0 means the water balance, and I < 0 means waterlogging.

According to the actual conditions of Jiangsu province, Penman equation (Liu *et al.* 1999) was revised to generate the following formula of standard evapotranspiration (mm · d^{-1}):

$$\mathrm{ET} = \frac{\frac{P_0}{P} \times \frac{\Delta}{\gamma} \times R_n + K \times \frac{1 + \frac{V_2}{100}}{e_a - e_d}}{1 + \frac{P_0}{P} \times \frac{\Delta}{\gamma}} \qquad (2)$$

where, P_0 is standard atmosphere pressure (P_0 =1.013.25 hPa); P is the average atmosphere pressure of the study site; Δ is the slope of saturation vapor pressure curve at mean temperature ($hP_a \cdot C^{-1}$); γ is psychrometric constant; R_n is net radiation; V_2 is the wind speed at the height of 2m; e_a is saturation vapor pressure of moist air; e_d is actual vapour pressure; K is a coefficient; January to August were assigned with the value of 0.35, and September to December 0.72.

Soil moisture at a moment before sowing is mainly the accumulative result of water revenue and expenditure at early stage. That is, the higher the precipitation and the less the evaporation at early stage, the higher the soil moisture before sowing will be. Otherwise, the soil moisture before sowing will be insufficient. Hence, relative drought index must consider the comprehensive influence of index I in some period of time. Suppose this comprehensive influence is CI, then

$$\mathrm{CI}_i = a + \sum_{j=1}^{n} b_j \times I_{i-j} \qquad (3)$$

Results and Discussion

In Jiangsu agrometeorological services, the advantages and disadvantages of meteorological conditions were generally analyzed in the unit of ten-day period. Thus, I_i was calculated in ten-day periods. According to historical statistics, the effect of precipitation two months ago on the soil moisture before sowing can be ignored. Therefore, only the I_i values within 2 months (the last six ten-day periods) were used to calculate CI. With the largest historical fitting rate as criterion, the time, range and damage degree of historical droughts were used to determine b_i values, which are 0.7, 0.4, 0.2, 0.15, 0.1 and 0.08. Then eq. (3) can be written as

$$\mathrm{CI}_i = I_i + 0.7 \times I_{i-1} + 0.4 \times I_{i-2} + 0.2 \times I_{i-3} + 0.15 \times I_{i-4} + 0.1 \times I_{i-5} + 0.08 \times I_{i-6} \qquad (4)$$

Relative drought indices of winter wheat at various growth stages in Jiangsu Province can be calculated by eq. (4). The threshold values determined by the analysis of historical drought observations of Jiangsu province are shown in Table 1. It is evident from Table 1 that the threshold value used for risk grade classification varies with the growth stage. For the comparison of relative drought situations at different growth stages, CI values were standardized. Considering that relative drought assessment index is RCI, slight drought threshold is MD, severe drought threshold is SD, slight waterlogging threshold is MW and severe waterlogging threshold is SW, then the formula can be written as

$$\mathrm{RCI} = \begin{cases} 1.0 & CI \geq SD \\ 0.5 & MD \leq CI < SD \\ 0.0 & MW \leq CI < MD \\ -0.5 & MW < CI \leq SW \\ -1.0 & CI < SW \end{cases} \qquad (5)$$

It can be seen from eq. (5) that RCI is a dimensionless relative quantity and can achieve the organic combination of drought and waterlogging for analysis, though this work only focused on drought.

Table 1. The threshold of relative drought index on the different growth periods of winter wheat.

Time	Growth period	No drought (CI<MD)	Slight drought (MD≤CI＞SD)	Severe drought (CI≥SD)
10-LA	SOW-SPR	1.5	1.5 - 1.7	1.8
11-LI	SPR-TRI	1.7	1.7 - 1.9	2.0
11-MI	TRI-TIL	1.7	1.7 - 1.9	2.0
11-LA	TRI-TIL	1.7	1.7 - 1.9	2.0
12-LI	TIL-OWI	2.3	2.3 - 2.5	2.6
12-MI	TIL-OWI	2.3	2.3 - 2.5	2.6
12-LA	TIL-OWI	2.3	2.3 - 2.5	2.6
1-LI	OWI-REG	2.3	2.3 - 2.5	2.6
1-MI	OWI-REG	2.3	2.3 - 2.5	2.6
1-LA	OWI-REG	2.3	2.3 - 2.5	2.6
2-LI	OWI-REG	2.3	2.3 - 2.5	2.6
2-MI	OWI-REG	2.3	2.3 - 2.5	2.6
2-LA	REG-SET	1.8	1.8 - 2.0	2.1
3-LI	SET-JOI	1.8	1.8 - 2.0	2.1
3-MI	SET-JOI	1.8	1.8 - 2.0	2.1
3-LA	JOI-BOO	1.5	1.5 - 1.9	2.0
4-LI	JOI-BOO	1.5	1.5 - 1.9	2.0
4-MI	BOO-HEA	1.5	1.5 - 1.9	2.0
4-LA	HEA-ANT	1.5	1.5 - 1.9	2.0
5-LI	ANT-MIL	1.3	1.3 - 1.7	1.8
5-MI	ANT-MIL	1.3	1.3 - 1.7	1.8
5-LA	MIL-MAT	1.3	1.3 - 1.7	1.8

Future drought risk of some region is composed of current risk (represented by relative drought assessment index) and future drought risk change rate (FDRCR), and thus

$$FDR = f(RCI, FDRCR) \qquad (6)$$

Using addition model, it can be written as

$$FDR = RCI\ (1 + FDRCR) \qquad (7)$$

Drought is a meteorological disaster, so its future change depends on the current risk foundation and climate change, which is generally described by climate trend rate (CTR). In this article, the relative degree of future climate change is described with the proportion of CTR deviating from the normal value, and it was called relative climate change rate (RT). Then the following formulas can be obtained:

$$RCI_t = a + b \times t \tag{8}$$

$$RCI/CTR = 10 \times b \tag{9}$$

$$RCI/RT = \frac{RCI/CTR}{\overline{RCI_t}} \tag{10}$$

$$\overline{RCI_t} = \frac{1}{n}\sum_{t=1}^{n} RCI_t \tag{11}$$

It can be known from eq. (10) that the more significant the climate change, the larger the absolute value of RCI/RT is. Hereby, substituting FDRCR with RT, eq. (7) can be written as

$$FDR = RCI\left(1 + \frac{RCI/CTR}{\overline{RCI_t}}\right) \tag{12}$$

According to eq. (12), the drought risk indices of winter wheat at various growth stages were calculated and then used for the analysis and zoning of future drought risks of winter wheat in Jiangsu province.

The drought risk of winter wheat at production period was divided into low risk, moderate risk and severe risk. Hierarchical cluster analysis (Tang 2010) was adopted for the risk zoning (RZ) of droughts. With low-moderate risk threshold set as 0.2 and moderate-severe risk threshold as 0.4, RZ has the following grade classification.

$$RZ = \begin{cases} \text{Low risk} & FDR < 0.2 \\ \text{Moderate risk} & 0.2 \le FDR < 0.35 \\ \text{Severe risk} & FDR \ge 0.35 \end{cases} \tag{13}$$

Drought risk assessment and zoning: As seen in Fig. 2, the drought risks of SB (North area of Jiangsu province), SZ (Middle area of Jiangsu province) and SN (South area of Jiangsu province) area in various growth stages showed decrease tendency, i.e., a general declining tendency in Jiangsu province from North to South. In terms of the distribution of drought risks with growth stage (x), all the three areas displayed the feature of parabolic distribution. Take the averages of WP (whole Jiangsu province) as an example, the expressions were as follows:

$$\overline{FDR_{WP}} = 0.0022x^2 - 0.0502x + 0.3319 \tag{14}$$

It is understood from eq. (14) that during the growth period of winter wheat in Jiangsu province, the drought risk is the lowest in overwintering stage. That is to say, the drought risk gradually becomes small from sowing to overwintering stage, while it increases from overwintering to mature stage. The period from sowing to tillering decides whether most seeds can sprout and become strong enough to overwinter, and the latter has great effect on yield and quality. The period from jointing to maturation is also fundamental to the yield and quality and faces high drought risk. With the climate changes, the droughts in Jiangsu province have very adverse effect on the improvement of yield and quality of winter wheat. Therefore, the development of drought-resistant cultivation technology is important for winter wheat production in Jiangsu Province to cope with climate changes.

Fig. 2 reveals the risk condition of SN and SZ area - below the low level; SB area - exceeded the low level in the whole study period and may be severe in few stages. Results obtained at different growth stages of winter wheat have been furnished below:

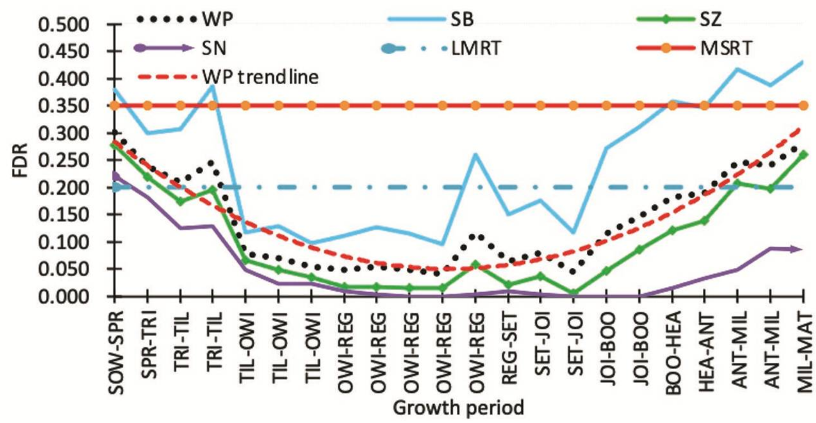


Fig. 2. Drought risk distribution in different zones for different growth periods of winter wheat in Jiangsu province.

Sowing-sprouting: As seen from Fig. 3a, the risk coefficient was 0.132 - 0.561. Main South of SN area - low risk, South of SB area to the middle of SN area - moderate risk; middle and north of SB area - severe risk.

Sprouting-triphyllous: Fig. 3b showed the risk coefficient of 0.006 - 0.490. SN area to the west of SZ area and the south of SN area to the southeast of SZ area - low risk; Middle of SN area to the middle and north of SB area - moderate risk; East and northwest of SB area - severe risk.

Triphyllous-tillering: Fig. 3c shows the risk coefficient in the early stage was 0.058-0.470; SN area and the east and west of SZ area - low risk; middle of SZ area to the middle of SB area - moderate risk; East and northwest of SB area - severe risk.

In the late stage, the risk coefficient was 0.023 - 0.590. South to the JIA of SZ area - Low risk; Junction of SZ and SB areas - moderate risk. Severe risk regions spread from north to south, reaching the middle and south of SB area.

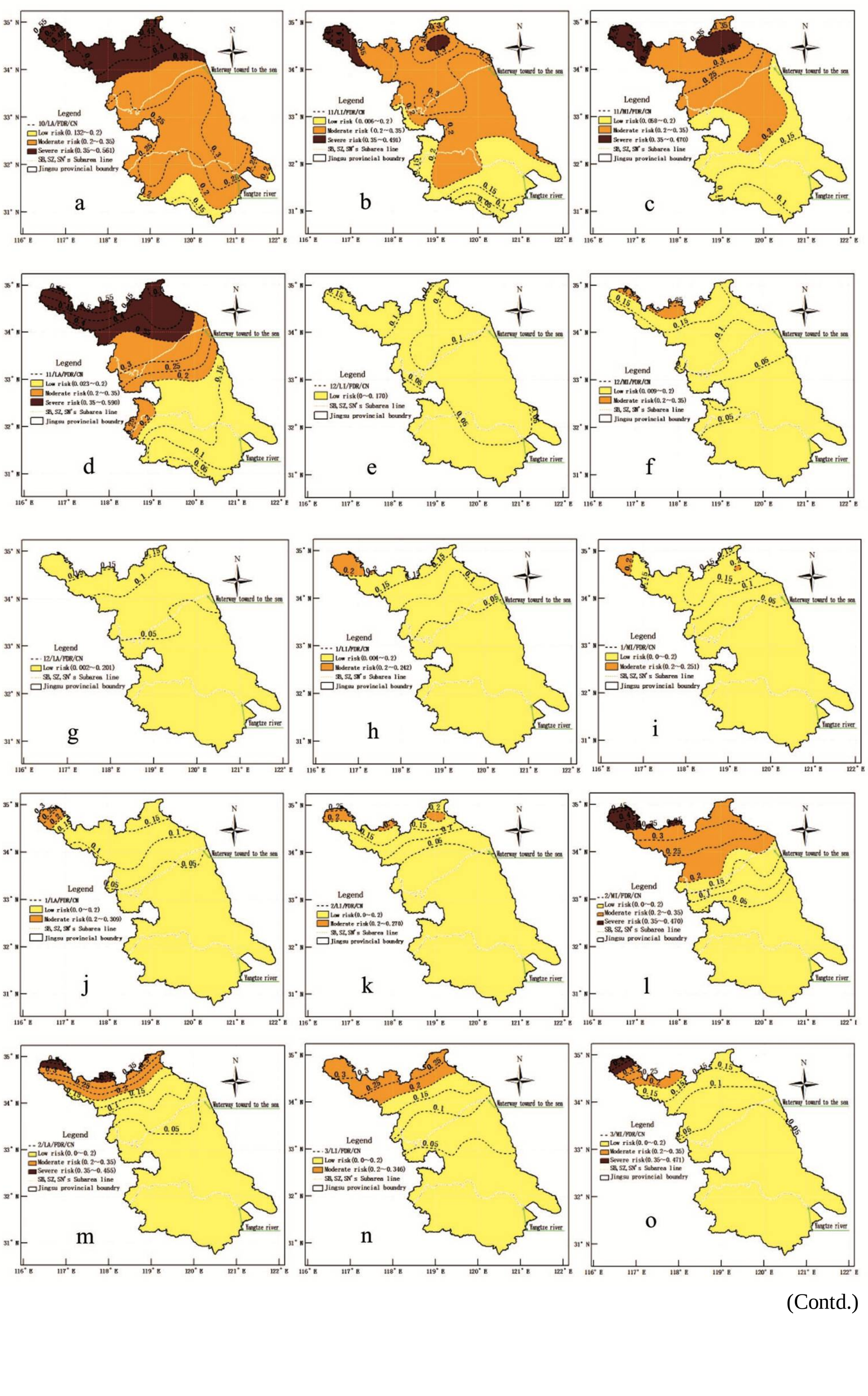
Tillering-overwintering: Fig. 3e-g shows that risk coefficient was 0.00 - 0.35, and all the regions belong to low risk region except for few in the north of SB area.

Overwintering-regreening: Fig. 3i-l shows the risk coefficient of 0.00 - 0.47. Besides a few regions in the north of SB area had moderate risk in the late stage (excluding February), all the regions had low risk in the whole period. In the late stage (Fig. l), SZ and SN area still had low risk, but the risk evidently increased in SB area, where the risk was severe in the northwest and moderate in the remaining.

Regreening-setting: As seen in Fig. 3m, risk coefficient was 0.00 - 0.455, and the risk was low in all regions except few in the north of SB area had severe risk and its middle-north part had moderate risk.

Setting-jointing: Fig. 3n-o shows the risk coefficient of 0.00 - 0.471. Except the north SB area had moderate risk with severe risk locally, all the regions had low risk.

Jointing-booting: Fig. 3p-q shows the risk coefficient of 0.00 - 0.632. There was severe risk in the middle and north of SB area and moderate risk in its middle part. The remaining regions all had low risk.



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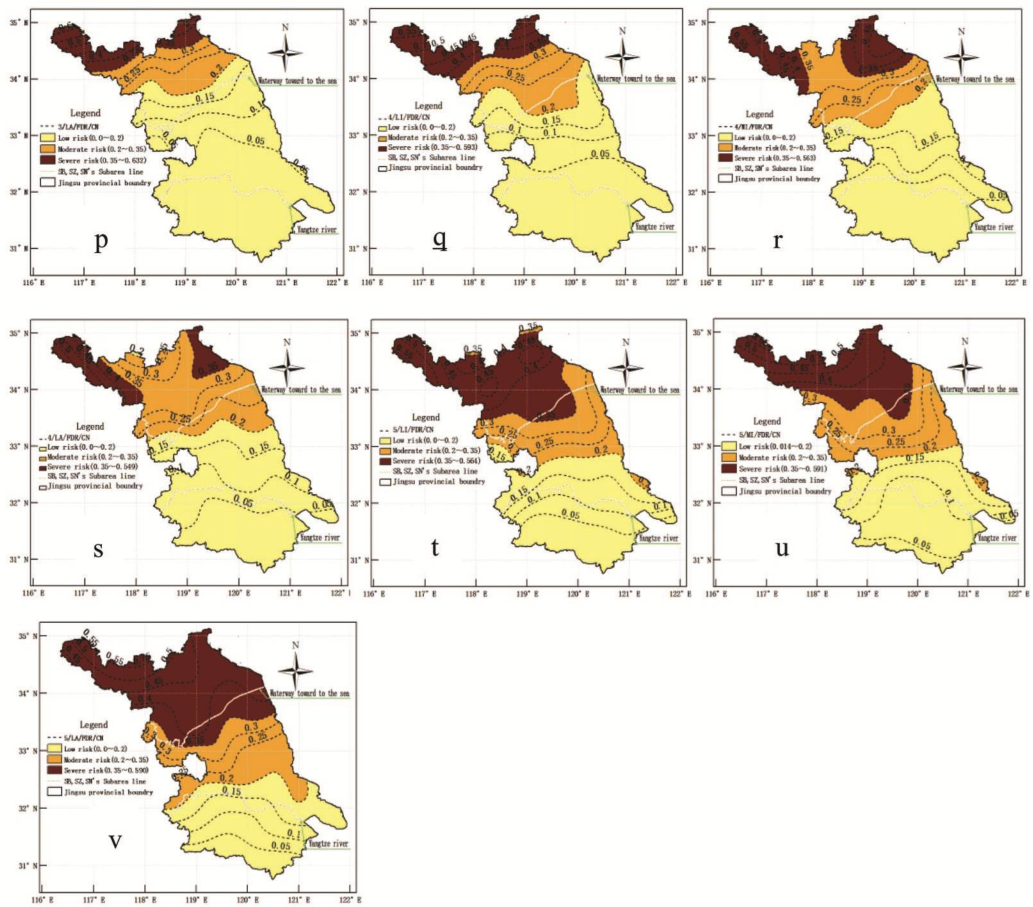

Fig. 3. Showing the zones of drought risks for different growth periods of winter wheat from Jinangsu province.

Booting-heading: Fig. 3r shows risk coefficient was 0.00 - 0.563. In SB area, the northwest and northeast part had severe risk and the other parts had moderate risk. The risk was low in SZ and SN area.

Heading-anthesis: As seen from Fig. 3s, risk coefficient was 0.00 - 0.549. Like the last stage, the risk was severe in the northwest and northeast of SB area and moderate in its remaining regions to the north SZ area. The risk was low in the middle of SZ area and the whole SN area.

Anthesis-milk: Fig. 3t-u shows the risk coefficient of 0.00 - 0.591. Most of the SB area had severe risk, and from some regions in the south SB area to the middle SZ area, the risk was moderate. The south SZ area and the whole SN area had low risk.

Milk-maturation As seen in Fig. 3v, risk coefficient was 0.00 - 0.590. From SB area to the north of SZ area, the risk reached severe level. The risk was moderate in the middle of SZ area and low in the south of SZ area and the whole SN area.

After analyzing the results of the present investigation, it could be stated that the latitudinal distribution of drought risk grade, which coincides with the regional distribution characteristic of precipitation in Jiangsu Province. That is, water resource is one of the major determinants of regional distribution of drought risks. For this reason, it is necessary to strengthen irrigation and water conservancy facilities in order to prevent drought damage.

The study also reveals that the regions of severe drought risk are mainly located in SB area, and those signify exactly the areas most susceptible to drought in the province. Along with climate changes, the winter wheat planting regions in SB area are facing larger risk. This suggests the urgency to develop anti-drought technologies and measures for winter wheat cultivation in the local area, so as to promote the response capacity to climate changes and ensure high and stable production.

At the stage of jointing, severe and moderate drought risk occurred mainly which were aggravated with growth progress and the affecting regions spreading from north to south. This period is crucial for the yield and quality of winter wheat. In terms of the wheat's sensitivity to water stress, the degree in various stages is ranked as follows: booting-heading-anthesis stage > jointing stage > sowing stage > seedling stage before winter > slow growth stage in winter > milk-harvest stage. Such drought risk as affected by climate changes produces significant adverse effect on wheat yield and quality. Full stand after one sowing and overwintering by strong seedlings are important planting measures for high and stable yield of winter wheat. However, with the climate change, drought risk obviously increased in the early winter period (from sowing to overwintering). It impedes the normal emergence and healthy growth of seedlings. Consequently, drought risk increased with climate changes, and especially in SB area (middle and north part), difficulties in field management increased, causing a higher instability of interannual yield and quality.

Acknowledgements

This research work was funded by the Jiangsu Province Meteorological Scientific Research Open Fund (Grant No. 200712: Agricultural meteorological disaster weather pattern library and Grant No. 200807: Research and application with high yield and good quality cultivation techniques on wheat and barley in Lixiahe wetland).

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(Manuscript received on 29 July, 2020; revised on 13 November, 2020)