Preliminary study on China's grain storage region according to its climate

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Abstract

The authors studied, in regional and seasonal aspects, the consistence and variance of climatic conditions in different parts of China Seven types of grain storage area are established according to accumulated temperature (≥10℃) and annual dryness. To adapt the weather conditions of each region, different series of storage treatments are suggested to ensure the safety of stored grain. Finally, the concept of grain storage region, its dividing methods and strategy for storage are further discussed.

Introduction

China is in the east of Eurasia continent. Its northwest area goes into Asia continent and the southeast area faces the ocean. The longitude from east to west varies 62 degrees and the latitude from north to south is 49 degrees China is very large, and the climate, which has great influence on grain storage, differs notably in each area of the country Based on the equilibrium moisture content theory and the long term weather information of grain harvest period, an analysis on the feasibility of low temperature drying of grain producing areas in China has been conducted. The current and future technologies on grain storage under low temperature and drying under normal atmospheric temperature have been reviewed. From these studies, China's climate is the basic factor of grain storage technologies in each area. Thus, grain storage methodology must fit to the climatic conditions of each area Here we suggest the methods of dividing climate regions in China and propose the principles of grain storage in each area.

Chinese Climate

Chinese climatic characteristics can be summarized as continental monsoon climate and the complexity of climatic types.

Continental monsoon climate

This is the most noticeable characteristic of China's climate. Monsoon climate is obvious, its structure is very complex. The winter monsoon is cold and dry, whereas the summer monsoon is temperate and humid. Strength of these two types is great, and the monsoon changes with seasons apparently. The monsoon area, which includes the large areas southeast of linked line of Da Xing'an Ling – Yin Shan – Helan Shan – Wusao Ling – Qilian Shan – Bayan Har Shan – Tanggula Shan – Gangdise Shan, which accounts for about half China (Fig. 1). The precipitation concentrates mainly in summer, when the atmospheric temperature is also very high The precipitation changes are great As a result, the flood and drought often occur.

The second characteristic is a strong continental climate. That is, China has a cold winter, a warm summer, a great annual range, a great daily range and a not well-distributed rainfall in different regions The annual temperature range in China reaches 10～30℃, while in extremity it reaches 35～45℃ The coldest month and the hottest month often come right after Winter Solstice (January) and Summer Solstice (July) respectively. Except for the Southeast, spring temperature in most area is higher than autumn temperature. In about half of Chinese area and over, annual precipitation is less than 300 mm. The above mentioned is obvious in the Northwest, where the typical continental climate can be seen In China, from the southeast coastal area to the northwest inland, climatic continental level increases.

The characteristics of continental monsoon climate may be summarized as follows: 1. The change from the dry monsoon to the wet monsoon is obvious. It is cold and dry in winter but humid and hot in summer. Precipitation concentrates mainly in summer. 2. Both annual range and daily range are great 3 Precipitation variation is great, rainfall is smaller in about half of China and over.

The complexity and variety of climatic types

According to temperature difference, accumulated temperature (≥10℃) is served as a standard. From south to north, China can be divided into five types of temperature zones and one type of Qinghai-Tibet plateau climatic area (which is called Qingzang plateau climatic area for short)

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(Fig.2). The five types of temperature zones are: tropics, subtropics, warm temperate zone, central temperate zone and cool temperate zone According to moisture conditions (annual dryness, annual precipitation), China can be divided into humid area (<1.0,≥800mm), sub-humid area (1.0~1.49, 400~800mm), semi-arid area (1.5~4.0, 200~400mm) and arid area (>4.0,≤200mm) (Fig 3) What is more, China has large mountainous area and many high mountains, where its vertical climatic distributions are obvious. Its moisture and heat vertically changes in different location and different altitude. Therefore, China's moisture and heat spatial combinations are very complex, and the climatic types are various. The vast Qingzang plateau, which rises in the southwest of China, influences neighboring climate except that it possesses the special plateau climate. For this reason, China's climate becomes more complex.

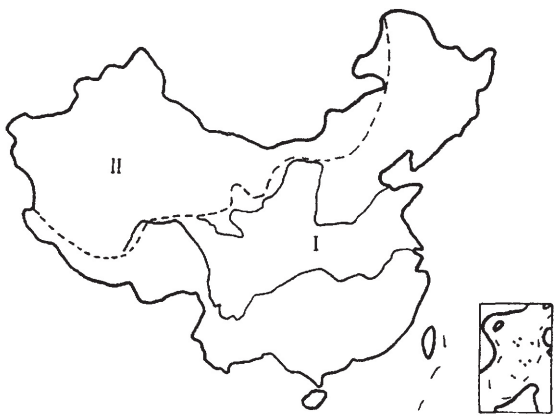

Fig.1. Monsoon area and non-monsoon area of China.
I Monsoon area II Non-monsoon area

China's climate types may be summarized as follows: 1. Multiple temperature zones and arid-humid areas. 2. Special Qingzang plateau climate. 3. Vertical climatic changes of mountainous area.

The Division of the Grain Storage Region

Methods

Based on rice, wheat and maize storing characteristics, human beings fully use natural conditions (especially climatic conditions) so that grain quality satisfies a set standard and the insect and mould do not exist during storage period. Both grain and the insect-mould on the grain are all living organisms. If human beings make them in the normal life state and complete certain stage growth, the definite quantity of heat must be satisfied above the development zero. The definite quantity of heat is called effective accumulated temperature (for short, accumulated temperature). The greater the accumulated temperature is, that is to say, the better the heat quantity condition is, the more difficult it is to keep grain dormancy state, to maintain its normal quality and to control insect and mould. In this paper, annual accumulated temperature is selected for measuring every area's grain storage heat quantity conditions in China Heat quantity conditions have been measured by means of accumulated temperature((10℃) by atmospheric department in China. Based on this, five types of temperature zones and a Qingzang plateau climatic area have been divided (Fig 2). We may refer to them.

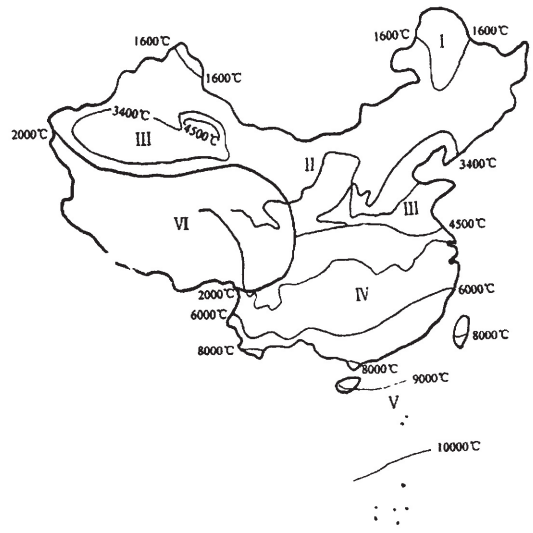

Fig.2. Accumulated temperature (≥10℃) and division of temperature zones in China.
I Cold temperate zone (<1600~1700℃, <100days)
II Central temperate zone (1600~1700℃ to 3100~3400℃, 100~160 days)
III. Warm temperate zone (3100~3400℃ to 4250~4500℃, 160~220 days)
IV Subtropics (4250~4500℃ to 7500~8000℃, 220~365 days)
V Tropics (>7500~8000℃, 350~365 days)
VI Qingzang plateau climatic area (<2000℃, <100days)

The determination of accumulated temperature(≥10℃): Firstly, we must determine initial and closing date of daily mean temperature(≥10℃) and , moreover, mean value of daily mean temperature of arbitrary continuous five days between initial and closing date must be more than or equal to 10℃, and then the accumulation of daily mean temperature between initial and closing date is accumulated temperature(≥10℃).

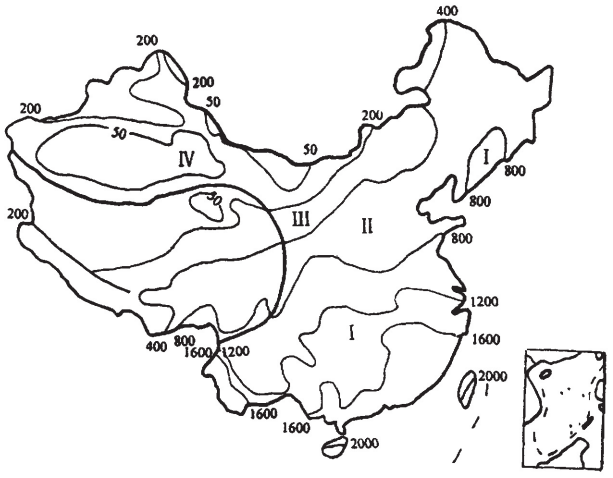

Fig.3. Annual precipitation (mm) and division of 'arid-humid' area in China.

Ⅰ Humid area (≥800mm)

Ⅱ Sub-humid area (400～800mm)

Ⅲ. Semi-arid area (200～400 mm)

Ⅳ Arid area (≤200mm)

Grain storage is closely related to climatic 'arid-humid' conditions of each area, which has been measured by annual dryness that is often used in meteorology. Annual dryness is the ratio of maximum probable evaporation over precipitation The meteorological department uses it to divide Chinese territory into four types (Fig. 3) In this paper, we also choose annual dryness for measuring grain storage climatic 'dry-humid' extent of each area in China.

It is worth noticing that 1.0 annual dryness isoline corresponds to 800 mm iso-pluvial in a year, while 1.5 and 4.0 annual dryness isolines correspond to 400 mm and 200 mm iso-pluvial respectively. Therefore, in this paper, we use annual precipitation to indicate the corresponding annual dryness.

Summing up the above-mentioned, we choose accumulated temperature(≥10℃) and annual dryness as the standards to divide grain storage regions in this paper, together with consistence and variance of climatic factors in time and space.

The division of seven types of grain storage regions

China's climate is continental monsoon climate. There are many kinds of temperature zones and 'arid-humid' areas in China (Fig. 2, Fig. 3). The general climatic tendency is temperate and humid in the southeast coastal district, whereas in the northwest inland it is cold and arid. Considering monsoon influence on China, firstly, it can be divided into the Eastern half of the territory monsoon grain storage area and the Western half of the territory non-monsoon area. The boundary of two areas approximately corresponds to the dividing line of monsoon area and non-monsoon area in meteorology (Fig. 1). Only considering Qingzang plateau integrity, when stretching to the east reaches of Qilian Shan , this dividing line farther extends along the margin of the east of Qingzang plateau. In the monsoon grain storage area east of this boundary, which is not far from 400 mm isohyet, the annual precipitation is more than or equal to 400 mm. Compared with the Western non-monsoon grain storage area, therefore the feature of the Eastern monsoon area is 'humid'

The Western non-monsoon grain storage area includes Inner Mongolia-Xinjiang (for short, is called Monxin area) and Qingzang plateau area. Monxin area is located in the northwest inland, and in central temperate zone (only a few in warm temperate zone), arid and semi-arid area in meteorological term. In this area, accumulated temperature (≥10℃) is 1600～3400℃, annual precipitation is less than or equal to 400mm. Xinjiang district in this area is very arid, where annual precipitation is less than or equal to 200 mm, so the remarkable feature is 'arid'; With special topography and geographical location of Qingzang plateau, the region has a thin air, an intense solar radiation and an accumulated temperature below 2000℃. Except in river valley of Yarlung Zang Bo Jiang, the accumulated temperature is below 500℃ in overwhelming majority area, and even in North Xizang plateau it is 0℃. For above-mentioned reasons, the difference between Monxin area and Qingzang area is obvious, so we should divide them independently. The boundary line is the linked line of Kunlun Shan－Altun Shan－Qilian Shan.

The span of latitude of the Eastern monsoon grain storage area is great. In the view of temperature and moisture the region leaps over five types of temperature zones and two types 'arid-humid' areas, so the climate still has difference, and we should further divide it. The linked line of Qin Ling and Huai river. It is served as boundary line to divide the Eastern monsoon grain storage area into two. Choosing the line for boundary is based on three reasons: 1. Firstly, the line is almost north boundary of subtropics zone; Secondly, It is also 0℃ isotherm in January; Thirdly, It is quite close to north boundary of humid area (annual precipitation≥800mm); The last is generally south and north boundary line recognized in meteorology; 2 This line is approximately served as boundary of culture area between rice and wheat in agriculture; 3. The literature tells us that the Northeast and the North China are the most suitable areas for low temperature grain drying in the Eastern monsoon area. The climatically remarkable feature of the northeast area north of this line is 'cold and humid': The long and cold winter lasts 6～8 months with average temperature of －12～－30℃ in January, and half a year below 0℃; The warm and short summer, only lasting 1～2 months, does not have intense heat with a July mean temperature of mostly over 20℃; The precipitation is comparatively plentiful, the relative humidity is great (65～75%); Whereas in North China the

climate belongs to warm temperate zone, continental climate. That is, in the region, four seasons in a year are distinct, and the summer has high temperature and high precipitation (the mean temperature of July is mostly over 24℃; Rainfall concentrates in summer, most of which come in storm); The winter is cold and dry (the mean temperature of January varies form 0℃ to −10℃, rainfall is smaller) To draw a conclusion from this, the climatic difference between the Northeast and North China is comparatively distinct, the two areas should be divided. 3200℃ isopleth or −10℃ (mean temperature of January) isotherm is served as boundary line between the Northeast and North China. This line corresponds to linked line of Yalu Jian margin − Fushun − Changtu − Fuxin − Weichang − Zhangbei − Great Wall − Wusao Ling. In the area south of Qin Ling and Huai He, the farther you go south, the more abundant the rainfall and heat. Nan Ling sleeps horizontally in a westeast direction, so it becomes a climatic defense. Taking Nan Ling as boundary, in the area south of Nan Ling, summer is very long and winter does not exist, so spring of next year comes after autumn of previous year. Whereas in area north of Nan Ling, the situation is not like this. It is obvious that Nan Ling may be served as boundary to divide the area south of Qin Ling into two. According to the custom, the area south of the mountain is called South China. The area between Qin Ling-Huai He and Nan Ling is located in subtropics-humid area, but owing to difference of topography and geographical location between the East and the West of this area (Central China, the Southwest), the climate also has difference between the two areas. Generally speaking, the climate of the Southwest may be summed up as a warm winter, an arid spring, a hot summer and a high autumn rainfall. On the contrary, Central China has a cold winter, a high spring rainfall, an intense heat summer often with drought of dog days and a sunny autumn with low humidity Thus the area between Qin Ling-Huai He and Nan Ling should be divided into two. Because Southwest China and Central China are located in the second ladder and the third one respectively, so the contour of 1000 meters above sea level is served as boundary (linked line of mountainous area in the west of Hubei Province and Xuefeng Shan).

In short, the Chinese territory can be divided into seven types of grain storage areas (Fig. 4).

1. The grain storage region of Qingzang plateau;
2. The arid grain storage region of Monxin;
3. The cold-humid grain storage region of Northeast China;
4. The grain storage region of North Chin;
5. The grain storage region of Central China;
6. The grain storage region of Southwest China;
7 The humid-hot grain storage region of South China.

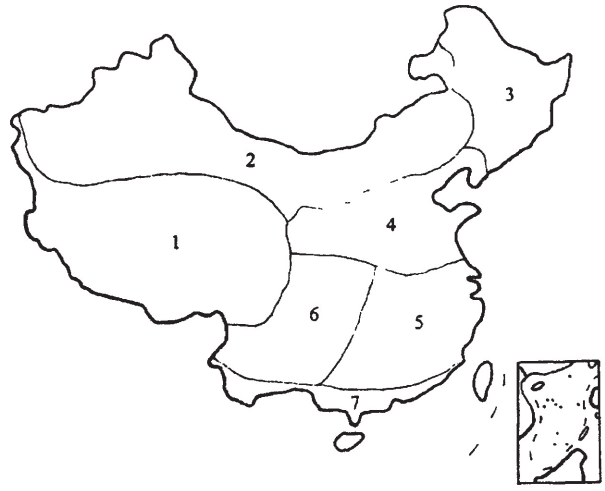

Fig.4. The seven types of grain storage regions of China.

Grain Storage Strategy in Each Region

The grain storage region of Qingzang plateau

The area has a thin air, an intense solar radiation (annual radiation is as much or above 200 kcal. /cm^2. year), and long sunshine hours (annual sunshine hours is 2200 ~ 3600 hours). Besides, it has a lower temperature (the mean temperature of January is 0 ~ −16℃, the mean temperature of July is 6 ~ 18℃), a small annual range and a large daily range. The four seasons are not distinct, but the difference between the dry season and rainy season is clear. The dry season is from November to April of next year, when the region has a very dry air, a little rainfall and strong wind; The rainy season is from May to October, when the rainfall accounts for 90 per cent of the annual precipitation and over. The climate in Qingzang plateau is represented by thirty year's climatic statistic data of Lhasa in this paper (Table 1 and Table 2). We should fully use cold and arid climates in dry reason and avoid influence of humid climate on stored grain as far as possible in rainy season.

Dai Tianhong and Cao Chongwen have published an article whose title is 'feasibility analysis on low temperature drying of grain in China' in 1996. This article is only related to the Eastern monsoon grain storage area, but not related to the Western non-monsoon area. When discussing Western non-monsoon area, we use the same calculating method as Dai used to keep coherence with Dai Tianhong's article.

Table 1. Average monthly temperatures of major cities of China (℃).

City	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Lhasa	−2.1	1.1	4.6	8.0	11.9	15.6	15.3	14.5	12.8	8.1	2.3	−1.6
Urumqi	−12.7	−10.5	−2.1	9.4	16.4	21.2	23.7	22.4	16.6	7.5	−3.0	−9.7
Huhhot	−12.5	−8.4	−0.2	8.5	15.9	20.4	22.2	20.2	14.1	6.8	−2.5	−10.5
Harbin	−19.4	−15.4	−4.8	6.0	14.3	20.0	22.8	21.1	14.4	5.6	−5.7	−15.6
Tianjin	−4.0	−1.6	5.0	13.2	20.0	24.1	26.4	25.5	20.8	13.6	5.2	−1.6
Shijiazhuang	−2.9	−0.4	6.6	14.6	20.9	25.6	26.6	25.0	20.3	13.7	5.7	−0.9
Taiyuan	−6.6	−3.1	3.7	11.4	17.7	21.7	23.5	21.8	16.1	9.9	2.1	−4.9
Shanghai	3.5	4.6	8.3	14.0	18.8	23.3	27.8	27.7	23.6	18.0	12.3	6.2
Nanjing	2.0	3.8	8.4	14.8	19.9	24.5	28.0	27.8	22.7	16.9	10.5	4.4
Hangzhou	3.8	5.1	9.3	15.4	20.2	24.3	28.6	28.0	23.3	17.7	12.1	6.3
Hefei	2.1	4.2	9.2	15.5	20.6	25.0	28.3	28.1	22.9	17.0	10.6	4.6
Fuzhou	10.5	10.7	13.4	18.2	22.1	25.5	28.8	28.2	26.0	21.7	17.5	13.1
Nanchang	5.0	6.4	10.9	17.1	21.8	25.7	29.6	29.2	24.8	19.1	13.1	7.5
Chengdu	5.5	7.5	12.1	17.0	20.9	23.7	25.6	25.1	21.2	16.8	11.9	7.3
Guiyang	4.9	6.5	11.5	16.3	19.5	21.9	24.0	23.4	20.6	16.1	11.4	7.1
Kuming	7.7	9.6	13.0	16.5	19.1	19.5	19.8	19.1	17.5	14.9	11.3	8.2
Guangzhou	13.3	14.4	17.9	21.9	25.6	27.2	28.4	28.1	26.9	23.7	19.4	15.2
Nanning	12.8	14.1	17.6	22.0	26.0	27.4	28.3	27.8	26.6	23.3	18.6	14.7
Changsha	4.7	6.2	10.9	16.8	21.6	25.9	29.3	28.7	24.2	18.5	12.5	7.1

Table 2. Average monthly relative humidity of major cities of China (%).

City	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Lhasa	28	25	28	37	44	53	64	67	64	50	39	34
Urumqi	79	77	72	49	43	44	41	39	44	58	75	79
Huhhot	56	53	46	41	41	48	62	68	64	61	58	58
Harbin	74	70	58	51	51	66	77	78	71	65	67	73
Tianjin	53	56	56	53	54	64	78	78	69	66	63	59
Shijiazhuang	52	55	55	51	53	57	75	80	72	69	64	58
Taiyuan	51	50	52	48	49	57	72	76	72	67	64	55
Shanghai	75	77	78	79	81	84	83	82	81	77	77	76
Nanjing	73	75	74	75	75	77	81	80	80	76	76	75
Hangzhou	77	80	80	80	81	83	80	81	84	80	79	78
Hefei	75	75	75	76	75	77	81	79	78	75	75	74
Fuzhou	74	78	80	80	83	84	78	78	77	71	70	72
Nanchang	74	78	82	82	82	83	75	75	74	71	72	73
Chengdu	80	80	78	78	77	81	85	85	85	86	84	83
Guiyang	78	77	75	74	77	78	77	78	76	78	78	79
Kunming	68	63	58	58	66	78	83	84	83	81	77	73
Guangzhou	70	78	83	85	86	86	83	83	80	73	68	68
Nanning	75	79	83	82	80	82	82	83	79	75	75	75
Changsha	81	83	84	83	83	82	75	77	78	79	80	80

Using equilibrium moisture content theory of grain drying and average monthly temperature data and relative humidity data in Lhasa, we can calculate corresponding equilibrium moisture content of rice, wheat and maize under every month's weather conditions by means of improved Henderson equation (Table 4, Table 5, Table 6). M_e – equilibrium moisture content (%, d.b.).

$$M_e = \left[\frac{-\mathrm{Ln}(1.0 - \mathrm{RH})}{A(T+B)} \right]^{1/C}$$

RH – relative humidity, %; T – temperature, ℃ (we, like Dai Tianhong, believe that the air temperature may be raised by 1.1℃ when the air goes through the blower) A, B, C – coefficient, is related to grain types (Table 3).

Table 3. Coefficients of improved Henderson equation.

Cereals	Coefficients		
	$A \times 10^5$	B	C
Maize	8.6541	49.81	1.8634
Wheat	2.3007	55.82	2.2857
Rice	1.9187	51.16	2.4451

Table 4. Equilibrium moisture content of maize under monthly weather conditions in Lhasa, Urumqi, Huhhot (%, w. b).

City	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Lhasa		8.52	8.80	11.2	10.9	12.0	13.9	14.5	13.5	12.2	11.0	
Urumqi				12.0	10.5	10.3	9.7	9.4	10.5	13.7		
Huhhot				10.7	10.1	10.9	13.0	14.1	14.0	14.3		

Table 5. Equilibrium moisture content of wheat under monthly weather conditions in Lhasa, Urumqi, Huhhot (%, w. b).

City	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Lhasa		9.5	9.8	10.9	11.7	12.7	14.2	14.7	14.4	12.8	11.7	
Urumqi				12.6	11.3	11.1	10.6	10.4	11.4	13.9		
Huhhot				11.5	11.0	11.7	10.8	14.5	14.3	14.5		

Table 6. Equilibrium moisture content of rice under monthly weather conditions in Lhasa, Urumqi, Huhhot (%, w. b).

City	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Lhasa		9.1	9.4	10.4	11.0	11.9	13.3	13.7	13.5	12.0	11.0	
Urumqi				11.8	10.6	10.5	10.0	9.8	10.8	13.1		
Huhhot				10.9	10.4	11.0	12.6	13.5	13.4	13.5		

We, like Dai, also regard the safe moisture content of maize, wheat and rice as 14.0%, 13.0% and 13.5% respectively. As can be seen from Table 4, Table 5 and Table 6, Qingzang plateau is also the most suitable area for low temperature grain drying

The harvest period of rice and maize in Qingzang plateau is from September to October, when rainy season is drawing to an end, so we can dry grain in the sun and reduce moisture content. When relative humidity suddenly drops in November, it enters dry season, and we can reduce grain moisture content and lower the temperature by means of natural ventilation. Winter wheat and spring wheat are harvested from June to August when rainy season is coming, so we can use the feature of intense solar radiation of sunshine to dry the grain in the sun, and then send the grain to granary and seal it at the same time. When dry season comes, we can reduce moisture content and lower the temperature by natural ventilation. Next year, before rainy season comes in May, we can use grain protestant, and then seal grain. As for old heating grain and the grain whose moisture contents is at different levels, we can also treat them by ventilation.

In addition to natural ventilation, natural drying, spreading out grain to dry by air, drying in the sun, mechanical ventilation in granary and in stack, transferring grain from one granary to another in winter, turning the

grain over and pushing the grain aside are all good methods of grain storage Low temperature throughout the year and very aridness in dry season makes this area one of the most suitable areas for grain storage.

The arid grain storage region of Monxin

The area has a cold winter with the January mean temperature of −8～−20℃ and a hot summer with the July mean temperature of 18～24℃. In Xinjiang region, the mean temperature of July is about 25℃, the extreme one is 30～40℃. Both annual range and daily range are great in Monxin region, they reach as high as 30～50℃ and 13～20℃ respectively; The region has a sufficient sunshine and an intense solar radiation. In Xinjiang region, Annual sunshine are 2700～3500 hours and the total solar radiation is 120 ～ 170kcal./cm^2, which is only next to Qingzang plateau. The precipitation is below 400mm, where its annual precipitation is only about 100mm, extremely arid. Its relative humidity is only 40～50%, therefore, this area is the driest area in China. Monxin area has much dust storm weather, especially in winter and spring this weather often appears. Inner Mongolia is in the north of China, where its climate, lying between the northwest arid climate and the northeast cold-humid climate, belongs to transition types. Besides above common climatic feature, compared with Xinjiang's climate, Inner Mongolia's climate has its own characteristics. In Inner Mongolia, the severe winter lasts over half a year and the summer lasts only 1～3 months. Annual precipitation is 200 ～ 400mm, most of which concentrates in summer, therefore, winter and spring are arid. This area's climate is represented by Urumqi and Huhhot climatic data (Table 1, Table 2).

We also use Henderson equation to calculate corresponding equilibrium moisture content of maize, wheat and rice under every month's weather conditions of Urumqi and Huhhot (Table 4, Table 5, Table 6). As can be seen from these three tables, Monxin arid area is also the most suitable area for low temperature grain drying.

Rice and maize are harvested from September to October in this area, as is shown in Table 4 and Table 6, that harvested grain moisture contents can attain safe ones by natural ventilation. Wheat is harvested in July, which is right in summer, so we may fully use sufficient sunshine and dry air to dry in the sun and spread out in the air, then send the grain to granary and close the door tightly while the grain is hot. After August, wheat may be ventilated to lower the temperature by natural dry air. In winter and spring of next year, all the cereals should be stored by natural low temperature. Before the end of April we may use grain protestant and seal grain to spend summer safely. By the way, in winter and spring, we should avoid dust storm weather in ventilation and drying in the sun and spreading out in the air. In summer, we may use the great daily range to lower the grain's temperature by opening the windows and ventilating in the night.

Inner Mongolia's winter is long and its summer is short, thus we should fully use this feature to carry out natural low temperature storage. After harvesting, this area's high moisture maize and rice should are reduced moisture content without delay by means of mechanical ventilation both in granary and in stack, natural ventilation, drying in the sun and spreading out in the air, air-drying etc. If the grain is not totally treated, through low temperature storage in winter, no treated grain must be done by same methods before early summer. As for old heating grain and one whose moisture contents in different levels are different, we may ventilate to treat them.

The unusual arid climate and comparatively low grain moisture contents make Monxin area one of the most suitable areas for grain storage.

The cold-humid grain storage region of Northeast China

This area's climate belongs to cold temperate zone, middle temperate zone, monsoon climate, and its feature is cold and humid. The severe winter is very long, lasting 6～8 months. The period with average daily temperature which is below 0℃ last about half a year, and the average mean temperature of January is −12～−30℃; The region has a short and warm summer only lasting 1～2 months with a July average temperature mostly over 20℃, but sunshine hours are long. Precipitation, which reaches as high as 400～800mm in a year, is comparatively plentiful. Rainy season is from June to September, thus rainfall is very litter in winter and spring. The relative humidity of the region, which mostly reaches as high as 67～75%, is great (Table 1, Table 2).

We should fully use cold climate and avoid negative influence of humid climate on stored grain. The long severe winter determines that grain storage under natural low temperature should be adopted as main method in this region, which is very important to grain, especially to high moisture grain which needs drying most Here from February to June, we have warmer and drier weather and a lot of wind, so the grain through low temperature storage in winter should be air-dried and sun-dried and ventilated (if ventilation facilities are available). Before April, the grain should be mixed with protestant, and then covered by rice chaff or other things and sealed to separate from the environment. As for old grains, we can ventilate to solve the problems of grain temperature rising and moisture content leveling in grain stack.

As is learned from the Dai's article, grain is more suitable for low temperature drying in the northeast, That is, after grain harvesting and before winter coming, we may carry out natural ventilation to reduce grain moisture content and

lower the temperature. In the Northeast, there are many high temperature drying facilities, thus driers provide another method to reduce a lot of wet grain moisture content, which is worth noticing in this area

The grain storage region of North China

The region has a warm temperate, sub-humid and semi-arid continental monsoon climate. The region has a hot and rainy summer with the daily average temperature of more than 20℃ lasting 3 months generally The average temperature of July is mostly over 24℃. In the valley-land area of Wei He and south part of the North China plain, which are well known as one of the high-temperature centers of China, the maximum temperature in summer is over 40℃. The rainfall of the region concentrates in summer, most of which comes in storm. The region has a cold and dry winter The average temperature of January is 0～－10℃. The minimum temperature is below －30℃. The time with a temperature of below 0℃ amounts to 3 months in the plain of North China and Shandong peninsula and 3.5 months in the Loess plateau and the mountainous area of North Hebei. The temperature of the region in spring rises quickly. In April the temperature is over 10℃, in May the temperature reaches 20℃ quickly. The data about the climate of the region are shown in Table 1 and Table 2.

The longer, colder and drier winter and the hot and rainy summer of the region make it necessary to store the grain especially humid grain, under low temperature and dry it by ventilation; Besides, we should avoid the negative influence of high temperature in summer.

In the region wheat is harvested in June After wheat harvesting its moisture content should be immediately reduced to the level for safe storage by natural ventilation. Meanwhile the high summer temperature can also be utilized to dry wheat in the sun and destroy grain insects. Then the hot wheat should be stored and sealed immediately; Corn is harvested in September. Before winter comes the corn moisture content should be reduced to or near that for safe storage by air-drying, natural ventilation in stack and in granary and sun-drying; The damp wheat and corn stored under low temperature during winter should be sun-dried, air-dried and ventilated by the warm and dry wind in the spring of next year. Before the quick rise of temperature in April the grain with insect and mould should be fumigated and the grain with no grain insects should be treated with protectant. And then all the grain should be immediately sealed to spend summer. In summer the grain temperature should be watched closely and be regulated by ventilation when necessary, especially in the so-called high-temperature areas of the region. The influence of the temperature changes from winter to spring and from autumn to winter should be watched closely so as to protect the old grain by ventilation

The grain storage region of Central China

The region has a subtropical, humid monsoon climate. It has four obvious seasons with warm winter and hot summer Its winter is not cold with a average temperature of January from 0℃ to 10℃ (12℃) If cold wave invades toward south the minimum temperature comes down to －4～－20℃; Its summer has high temperature with the average temperature of July reaching about 28℃, and the weather with the temperature reaching 35℃, even over 40℃, often occurs from May to September; Meanwhile Dongting lake basin, Poyang lake basin and the valley-land plain along Chang Jiang river form the high-temperature centers of the region; Its spring and autumn are warm with average temperature in April and October ranging from 16℃ to 21℃ respectively. Its autumn temperature is a little higher than that of its spring. The four seasons in a year are distinct, winter and summer last four months respectively. It has a annual rainfall of 800～1600mm, which is 2 times as much as that of North China; The rainfall distribution is 70% in spring and summer, 20 ～ 30% in autumn and below 10% in winter. It is the area with the most plenty of spring rainfall in China, wellknown as 'plum rain'. The plum rain lasts about 1 month and its rainfall accounts for about 40% of the annual precipitation. The weather in July is sunny, hot with a little rainfall and thus the drought of dog days often occurs. From September to October, the weather is cool and sunny with low humidity and typhoons and rainstorms also occur in the coastal area of Southeast China. The relevant data are shown in Table 1 and Table 2

Generally speaking, the temperature and relative humidity of the region are much higher than these of North China; Its rainfall is also higher than that of North China and mainly concentrates between April and October. So the grain drying in the region should be carried out by means of ventilating and heating facilities. It is worth noting that natural ventilation can not produce good drying results. If the ventilation is adopted, the temperature of air current should be increased by 2～5℃ by supplementary heating facilities. Considering the grain storage measures, the newly harvested grain should be immediately dried to reduce its moisture content, and during winter the grain should be stored under low temperature. The grain that there is not enough time to be dried should be dried in the spring and early summer of next year, and then grain should be treated with protectants and sealed to spend summer. For the stale grain and the grain spending summer, mechanical ventilation should be adopted to lower the grain temperature and reduce grain moisture content

In the region, wheat, early-maturing rice and late-maturing rice are harvested in May, July and October respectively. Wheat is harvested in the rainy season and

thus it should be dried by drier or mechanical ventilation for safe summer storage. Because of the drought of dog days and the cool and dry autumn, the harvested early and late-maturing rice can be sun-dried, air-dried, cured or dried in the storehouse or stack by means of mechanical ventilation. The climatic conditions of Nanchang and Fuzhou between July and October, Changsha in June make it possible to use natural ventilation to reduce the moisture content of rice in corresponding time. The grain can be stored under natural low temperature in winter, and the high moisture grain should be dried by stoving and ventilating in spring or the early summer. Then the grain should be mixed with grain protectants and sealed for safe summer storage. Because of the high summer temperature the temperature of stored grain in summer should be regulated properly

The grain storage region of Southwest China

The region has a subtropical plateau basin climate. It has warm winter and hot summer and its summer temperature is a little high than its autumn temperature. The mean temperature ranges from 2℃ to 10℃ in January and is higher than that of Central China at the same latitude; The minimum temperature is generally higher than 7℃; The average temperature varies between 18℃ and 28℃ in July and most of the region except Sichun basin is not as hot as Central China; Its annual range is small and most of the region has a annual temperature range of less than 20℃ (more than 20℃ in the Central China). The annual range of Kunming is only 12.3℃; It has high rainfall and humid climate. Its annual rainfall is about 1000 mm and mainly distributes in summer and autumn, so its spring and winter are dry. The rainfall during summer (about 3 months) accounts for 40 ~ 70% of the annual preparation and the autumn rainfall accounts for 20~30%.

Its topography includes plateau and basins. So its climate varies a little from place to place. Sichuan basin has a warm and short winter with a mean temperature of 5 ~ 8℃ in January . Its spring is about one mouth earlier than middle-lower reaches of Chang Jiang river; By the way its summer is long and hot and thus it is one of the well-known high-temperature centers in China; Its average temperature is more than 26℃ in July and its extremely high temperature can reach more than 40℃; Its relative humidity keeps at 70 -80% around the year. It has more foggy days and more overcast-rainy days. The situation that its foggy and overcast-rainy time is so long, its humidity is so high and its sunshine is so short is seldom seen in China; The winter of Guizhou plateau is not cold while its summer is not hot. Its rainfall mainly concentrates between May and October. It also has more foggy and more overcast-rainy days and high relative humidity; The four seasons of Yunnan plateau all resemble spring and its division of dry season and rainy season is very clear. Its dry season goes from November of previous to April of next year. The climatic data of Chengdu, Guiyang and Kunming are selected to represent the climatic conditions of the grain storage region of Southeast China (refer to Table1 and Table 2).

In general, its climate is warm and humid with a small annual range and indistinct division of 4 seasons; Meantime it has more foggy days , more overcast-rainy days, higher relative humidity and shorter sunshine. All the climatic characteristics make the grain storage, especially the moisture content reducing, difficult to some extent. So sun curing and ventilating facilities should be set up to overcome the difficulties met in grain storage.

In the region, wheat, early-maturing rice and late-maturing rice are harvested in April, July and October respectively. In Sichuan basin and Guizhou plateau the grain moisture content can not be reduced to that for safe storage by natural ventilation and it is necessary to set up subsidiary heating facilities that can raise the temperature of air current by 2~5℃; Kunming has clear division of dry season and rainy season and warm climate, so the wheat can be dried by natural ventilation immediately after harvesting and the late-maturing rice also can be done by the same methods between February and March of next year, their moisture content can be reduced to that for safe storage. The harvest time in Kuming region of the early-maturing rice overlaps the rainy season with high temperature, so the rice should be dried immediately after harvesting. If mechanical ventilation is adopted for early-maturing rice drying, the air current must be heated.

In general, we can reduce the moisture of the harvested grain by sun curing and mechanical ventilation. If some insects invade the grain, the grain should be fumigated. Because the period from November of previous year to February of next year is dry and cold, both the natural low temperature and mechanical ventilation can be used and then the grain can be mixed with protectant and sealed for storage; The late-maturing rice, because of its high moisture content, should be dried before April-May of next year. In Yunnan the late-maturing rice can be sun-dried, air-dried and dried in storehouse and storing piles by mechanical ventilation before May of next year; The temperature and moisture contents of the stored grain in summer (especially in Sichuan basin) and stale grain should be watched carefully and be accordingly regulated for safe storage by mechanical ventilation.

The humid-hot grain storage region of South China

The region has a subtropical, tropical monsoon climate and it is the hottest and the most humid area in China. It has a long hot summer, which lasts 8~9 months except for its Western part whose summer lasts only 3 ~ 5 months. Its mean temperature is 23~28℃ in July; It has a warm winter during which frost and snow are seldom seen. The mean

temperature is 10～26℃ in January Therefor, the region does not have winter in real sense and its spring of next year comes right after autumn of last one That is, it does not have a clear division of four seasons; The annual range generally is about 13～17℃ in its continental part and only 10℃ in Hainan province. It has a high annual precipitation of 1400～2000 mm and a relative humidity of about 80%. In most of the region the rainfall mainly concentrates from May to October and the rainfall during this period accounts for 70～80% of the annual rainfall. In the west part of the region the division of dry season and rainy season is clearer than that in its east part; it has rich heat resource which ranks first among all the regions of China For example, it has an accumulated temperature of 6000 (6500) ～ 10000℃ above 10℃ and has an annual mean temperature of 20～26℃ ; The typhoon season in the region is from May to November, during this season the rainfall accounts for 10～40% of the annual rainfall. The climatical data of Guangzhou and Nanning are selected to represent the data of the region (seen in Table 1 and 2).

In terms of the climatic condition of the region, the storage in this region is the most difficult in China. The key problems are how to lower grain temperature, how to reduce grain moisture content, how to cut grain off from the outside world and how to protect the grain from insect and mould. So the sun curing and ventilating facilities should be set up. In the grain storehouses some equipment that can be used to lower temperature and absorb moisture may be adopted. In the place with good economic conditions it is suggested that low temperature storehouse should be constructed

Wheat, early-maturing rice and late-maturing rice are harvested in Guangzhou and Nanning in March, June and October respectively. After wheat harvesting the wheat should be dried immediately. If mechanical ventilation is adopted, the air current should be heated. Then the dried wheat is mixed with grain protectant and sealed for safe storage in storehouses; After the early-maturing rice is harvested, the rice can be stored or ventilated for drying. If ventilation is adopted for rice drying, the air current should be also heated; For the dried rice that will be stored through summer, proper attention should be paid to regulating temperature, insulating moisture and killing grain insects After late-maturing rice is harvested, the climatic conditions (rainy season ends and high temperature season begins) basically satisfy the needs of natural ventilation for drying. Before November the rice should be fumigated; because the period between November of previous year and April of next year belongs to dry season, the cereals is managed according to its temperature and moisture content. Drying in the sun and natural ventilation can also be adopted for some ways to reduce grain moisture content. The insect-invaded grain should be fumigated. Before April of next year the cereals will be mixed with grain protectants and sealed for safely spending summer; Careful attention should be paid to the temperature, moisture content, insects and mould of the stale grain and grain in summer; If any problem occurs proper measures should be implemented immediately

Discussion

Grain storage regions

In the paper, China is divided into seven types of grain storage regions; The division is identical with the natural division described in the text book 'Geography of China' The difference between the two divisions is only that in the natural division the arid grain storage region of Monxin is divided into Northwest China and Inner Mongolia area. The natural division described in the text book is mainly intended to serve agriculture, forestry, animal husbandry and hydraulic causes, and its division indices are accumulated temperature and annual dryness, which are closely related to water and heat conditions in agriculture. Whereas we take safety of the stored grain as the first consideration and then consider consistence and variance of climatic factor in seasonal and regional aspect, and at last further study the division of grain storage region First considering climatic factor is common in above two kinds of division. What is more, as the follow-up project of agricultural production, the grain storage should also be considered in relation with planting system, which plays an important role in the natural division. So it is natural that the grain storage regions are roughly identical with the regions of the natural division.

In the paper the accumulated temperature of higher than 10℃ is chosen to evaluate the heat resources of all the regions in China. The daily mean temperature of higher than 10℃ is very helpful to most crop growth, that is , the higher the accumulated temperature of more than 10℃ is, the better the heat conditions of crop growth, but the more difficult it is to keep crop seeds in dormancy. In fact 15℃ is extensively used as the critical temperature in grain storage under low temperature at home and abroad. So the accumulated temperature of more than 10℃ can be used to appraise the temperature conditions of the grain storage regions in China objectively and logically to large extent. Even so the accumulated temperature of more than 15℃ in different regions of China had been estimated (Fig. 5). According to Fig 5 the isopleths of the accumulated temperature of more than 15℃ can divide China into different regions. The isopleth of 4000℃ basically goes along Qing Ling and Huai He; The isopleth of 2500℃ roughly corresponds to the boundary line between North China and Northeast China; Qinghai-Tibet plateau becomes an independent grain storage region, in which accumulated temperature is not over 2500℃. 5500℃ isopleth basically

corresponds to Nan Ling, but the region south of the isopleth of 5500℃ includes most of Yunnan, which is not completely identical with the research results in the paper. If the climate of Yunnan plateau is further compared with that of South China, it can be found that the climate of Yunnan plateau stands between that of Southwest China and South China and it shows some interim characteristics When the isopleth of the accumulated temperature of more than 15℃ is used as the division index, Yunnan and South China possess the same heat quantity condition. Besides, in both Yunnan and South China, the division of four seasons is not clear and the year can be divided into dry season and rainy season (in the high-temperature months of the dry season, the grain moisture can be reduced by natural ventilation). But the rainfall of Yunnan is significantly lower than that of South China and Yunnan's climate is like spring all the year around with mean temperature of less than 10℃ in January, less than 20℃ in July, which bears a strong resemblance to climate in the Southwest and is different from that in South China (the region has a mean temperature of over 10℃ in January and 23～28℃ in July). In general, the grain storage of South China is much more difficult than that of Yunnan plateau, so Yunnan plateau seems to be designated to Southwest China

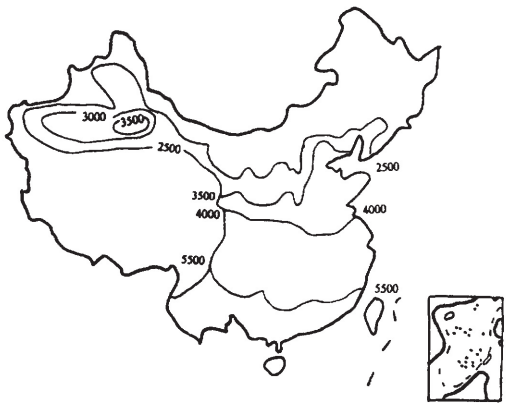

Fig.5. Distribution of accumulated temperature higher than 10℃ in China.

According to the research results mentioned above in the paper the climatic conditions vary from place to place in one type of grain storage region. For instance, Xinjiang and Inner Mongolia are in the arid grain storage region of Monxin. Therefor the current regions of grain storage can also be subdivided.

In the paper the grain storage regions are studied only from the angle of climatical conditions. But the concept 'Grain storage region' is connected with geographical environment, social and economic development, educational level and local customs Undoubtedly, climatical conditions are the essential aspect in studying grain storing regions and making decisions for grain storage.

Grain storage measures

According to the study in the paper, the natural low temperature storage is suitable in the dry and cold region. If it is applied with ventilating measures its storage effects will be much better. For example, it is extensively used in the dry seasons of Inner Mongolia-Xinjiang area, North China and Qinghai-Tibet plateau; In the cold and humid regions such as Northeast China and Central China, the low temperature storage may be better used in spring and winter, and then the grain will be dried in comparatively warm and dry seasons(such as autumn, late spring and early summer); In the regions that are hot and humid all the year around, the immediate measures to dry the grain, to lower grain temperature, to insulate heat and moisture and to stop insect and mold should be carried out after crop harvesting; In the regions such as South China and Southwest China, it is suggested that low temperature storehouses and storehouse with temperature dropping and moisture and absorbing facilities be constructed

After wheat harvesting proper time should be chosen to dry the wheat so as to kill grain insects and help the physiological late-maturity of wheat seed, Other cereals should be sun-dried in spring and autumn so that the grain quality is not lowered. Sun curing and air-drying are still good measure to dry grain, especially in the middle and small storehouses with a low level of mechanization. As a grain moisture-reducing measure, sun curing has been effectively used from very early time. Compared with the mechanical ventilation, which has been widely adopted not only to regulate grain temperature and its moisture content levels but also to reduce its moisture content directly in recent years, sun curing costs more and increases the damaging rate of grain; Therefore the mechanical ventilation should be advocated But the mechanical ventilation can not completely replace the sun curing because of the actual conditions of China

Currently the 'three low' techniques of grain storage have been used extensively. For the techniques the natural low temperature – oxygen deficit grain storage (in short, 'double low' grain storage) is the most commonly used methods in China. The adoptions of the grain storage under low temperature, low oxygen and low dosage is generally a dynamic process. The proper combination of cereal protectants and the 'three low' techniques has been tried in recent years and many good results have been obtained

Now the underground storehouses have been extensively used in China It is worth noting that the underground storehouses in loess plateau have good storing functions because of low water-table, small rainfall, low soil water and low humidity (40～50% rh) inside the storehouses, so we should fully utilize the region's underground storehouses

for storing grain.

As all mentioned above, the key problem of the grain storage in China is: how to reduce grain moisture in the north of China and how to prevent grain from insects in the south of China. Since different regions have different climatic conditions the measures adopted for grain storage are different.

Because the climate of China varies greatly from place to place, the technical standards to store grain are diverse and the grain storage should be carried out in line with the local conditions. Without doubt, it is the first step to conduct the study of the division of grain storage regions according to the climate and the needs of grain storage.

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