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# FLUCTUATION OF AGROCLIMATIC ZONES AND ITS IMPACT ON AGRICULTURAL PRODUCTION IN CHINA

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**ABSTRACT:** Accumulated temperature above 100℃ ($\sum t$) and minimum annual temperature ($Tm$) are the major indexes for demarcating agroclimatic thermal zones. The paper calculated the return period ($\tau$) of $\sum t$ and $Tm$, and the shift of $\sum t$–and $Tm$–isopleths with $\tau$. The results show: (1) According to the magnitude of shift of $\sum t$–and Tm–*isopleths, in Northeast China, Inner Mongolia and northern Xinjiang the fluctuation of thermal resources in growing season from year to year is the greatest and strongly impacts the yield of annual thermophilous crops, but in the Changjiang River basin the fluctuation of the low temperature in winter is the greatest and seriously injures the perennial subtropical tree crops. (2) In the anomalous cool summer year with* $\tau = 30$, *the northern boundaries of the southern subtropical, northern subtropical and warm temperate zones and the southern boundary of the frigid temperate zone in China could be expected to shift southward 150, 220, 250 and 300 km from their normal positions, respectively. (3) In the anomalous cold winter year with* $\tau = 30$, *the northern boundaries of the tropical, southern subtropical, northern subtropical and warm temperate zones, and the southern boundary of the frigid temperate zone in China could be expected to shift southward 270, 150, 450, 290 and 350 km from their normal positions, respectively. The extremely low temperature seriously injures not only the subtropical tree crops in the Changjiang River basin, but also the tropical tree crops in South China and even in southern Yunnan.*

**KEY WORDS:** accumulated temperature, minimum annual temperature, return period, agroclimatic zone, agricultural production

## I. INTRODUCTION

China has a continental monsoon climate with greatly seasonal and interannual variations. Climatic fluctuation and anomaly in the alternation of cold and warm directly influence agricultural layout and the fluctuation of grain crop yield. Accumulated temperature above 10℃ ($\sum t$) and minimum annual temperature ($Tm$) are the major indexes for demarcating agroclimatic thermal zones[1-2], the former is the characteristic of the thermal resources in growing season for most annual thermophilous crops, and the latter is that of the overwintering condition for the winter crops and the perennial economic tree crops. Agroclimatic thermal zones are perpetually shifting because these two indexes have greatly interannual variation in their spatial distribution[3-5]. In this paper, according to the return period of $\sum t$ and $Tm$, the shift of agroclimatic thermal zones in different patterns of the warm / cold year is determined and the possible impact of them on the agricultural production is analyzed.

## II. RETURN PERIOD OF $\sum t$ AND $Tm$

The return period is calculated by

$$\tau(j) = \frac{2N}{2j-1} \qquad j = 1,2,3,\cdots,N \tag{1}$$

where $\tau(j)$ is the return period of the possible maximum or minimum of $\sum t$ or $Tm$ corresponding to $j$ in $N$ samples. The $\tau(j)$ of $\sum t$ and $Tm$ in several localities of China is shown in Fig.1.

From the analysis of meteorological data with a longer series and in a lot of localities, 30 years and 135 stations for $\sum t$ and above 40 years and more than 40 stations for $Tm$ in China except the Qinghai–Xizang (Tibet) Plateau, the relationship between $\sum t$ or $Tm$ with $\tau$ and its mean value ($\overline{\sum t}$ or $\overline{Tm}$) can be represented by

$$Z = 1 \pm \frac{\tau}{a + b\tau} Cv \tag{2}$$

where $Z = \sum t(\tau) / \overline{\sum t}$ or $Tm(\tau) / \overline{Tm}$, $Cv$ is the variation of $\sum t$ or $Tm$, $\tau$ is the return period, and $a$ and $b$ are the empirical constants [3-4]. The values of $a$, $b$ and $Cv$ for $\sum t$ and $Tm$ are shown in Table 1.

**Table 1 Values of $a$, $b$ and $Cv$ in equation (2)**

| Element | $a$ | $b$ | $Cv$ |
|---|---|---|---|
| $\sum t$ | 386.4 | 41.4 | $15653.4(\overline{\sum t})^{-0.976}$ |
| $Tm$ | 457 | 41.58 | $128.4\lvert\overline{Tm}\rvert^{-0.77}$ |

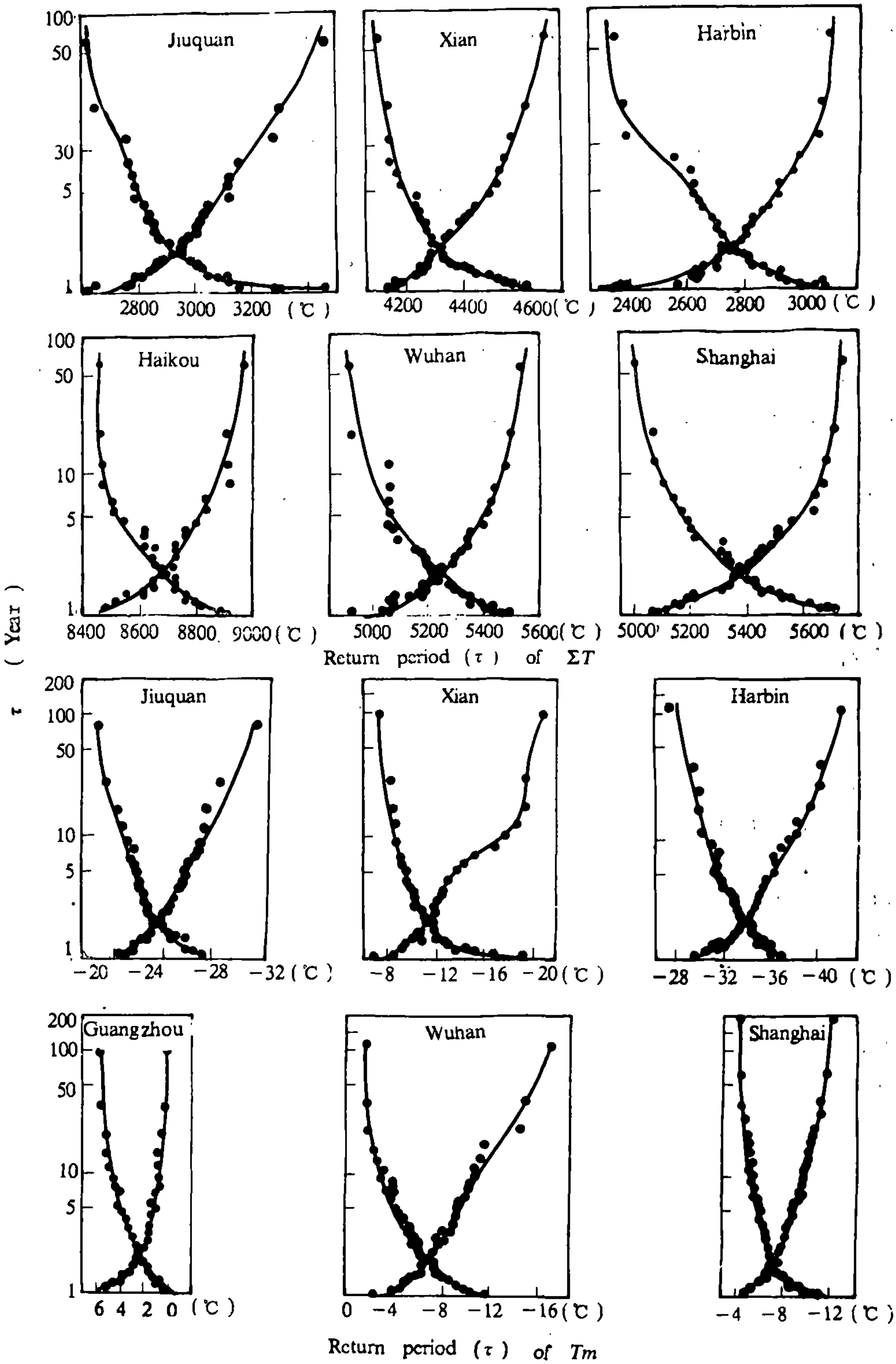


**Fig.1** Return period (τ) of maximum and minimum possible Values of $\sum t$ and $Tm$ in several localities

In equation (2) the choice of sign is denoted by the following:

| | |
|---|---|
| For $\sum t$, | max ( +), min ( − ) |
| For $Tm$ when $\overline{Tm} < 0$, | max(− ),min( + ) |
| For $Tm$ when $\overline{Tm} > 0$, | max( + ),min(− ) |

## III. SHIFT OF $\sum t$− AND $Tm$−ISOPLETHS

$\sum t$ and $Tm$ are fluctuating around their mean values from year to year, so there is a shift of the position of $\sum t$− and $Tm$− isopleths with $\tau$ from that of $\overline{\sum t}$− and $\overline{Tm}$−isopleths due to the temperature fluctuation from year to year, namely it often has a shift southward or northward of $\sum t(\tau)$ − and $Tm(\tau)$ − isopleths from their normal positions.

The southward or northward shift of $\sum t(\tau)$− and $Tm(\tau)$− isopleths can be calculated by the following equations:

$$\text{For} \sum t, \qquad \Delta\varphi = \frac{d\varphi}{dA_t}\left[\overline{\sum t} - \sum t(\tau)\right] = \frac{d\varphi}{dA_t}(1 - Z)\overline{\sum t} \tag{3}$$

$$\text{For}\, Tm, \qquad \Delta\varphi = \frac{d\varphi}{dA_m}\left[\overline{Tm} - Tm(\tau)\right] = \frac{d\varphi}{dA_m}(1 - Z)\overline{Tm} \tag{4}$$

where $\Delta\varphi$ is the shift of $\sum t(\tau)$− and $Tm(\tau)$−isopleths (in degree of latitude), and $A_t$ and $Am$ are the latitudinal mean of $\overline{\sum t}$ and $\overline{Tm}$(℃), respectively.

In China except the Qinghai−Xizang Plateau (the same to the following), the variations of $d\varphi / dA_t$ with $A_t$ and $d\varphi / dA_m$ with $A_m$ are shown in Fig.2, and they can be given by ①

$$\frac{d\varphi}{dA_t} = -\ 9.184 \times 10^{-3} + 6.962 \times 10^{-7} A_t + 3.556 \times 10^{-11} A_t^2 \tag{5}$$

$$\frac{d\varphi}{dA_m} = -\ 0.634 - 0.0063 A_m - 0.0001284 A_m^2 \tag{6}$$

Substituting $d\varphi / dA_t$ and $d\varphi / dA_m$ and the corresponding values of $Z$ into equations (3) and (4), the shift of $\sum t(\tau)$ − and $Tm(\tau)$−isopleths ($\Delta\varphi$) can be determined.

From equation (3):

$\Delta\varphi > 0$ (northward shift), when $\overline{\sum t} - \sum t(\tau) < 0,\ Z < 1$

$\Delta\varphi < 0$ (southward shift), when $\overline{\sum t} - \sum t(\tau) < 0,\ Z < 1$

① In the Changjiang River basin (25° < $\varphi$ < 34° N) it is denoted the $d\varphi / dA_m = -1.136$ (see [4]).

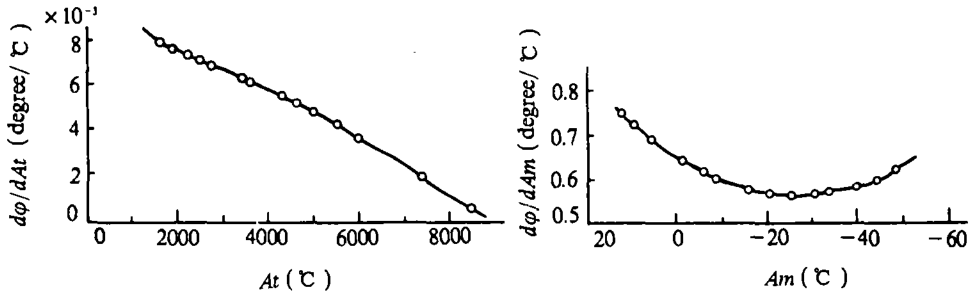


**Fig.2** Variations of $d\varphi / dA_t$ with $A_t$ and $d\varphi / dA_m$ with $A_m$

From equation (4):

$$\left.\begin{array}{l}\Delta\varphi > 0 \text{(northwardshift)} \\ \Delta\varphi < 0 \text{(southwardshift)}\end{array}\right\} \quad \text{When } \overline{Tm} > 0 \left\{\begin{array}{l}\overline{Tm} - Tm(\varphi) < 0, Z > 1 \\ \overline{Tm} - Tm(\varphi) > 0, Z < 1\end{array}\right.$$

$$\left.\begin{array}{l}\Delta\varphi > 0 \text{(northwardshift)} \\ \Delta\varphi < 0 \text{(southwardshift)}\end{array}\right\} \quad \text{When } \overline{Tm} < 0 \left\{\begin{array}{l}\overline{Tm} - Tm(\varphi) < 0, Z > 1 \\ \overline{Tm} - Tm(\varphi) > 0, Z < 1\end{array}\right.$$

The shift of $\sum t-$ and $Tm-$ isopleths in different return periods in China calculated by equations (3) and (4) is shown in Fig.3. It is seen that the shift of $\sum t-$ isopleths ($\Delta\varphi$) with $\tau$ increases with increasing of $\varphi$, but its increasing rate gradually decreases with increasing of $\varphi$ and increases with increasing of $\tau$. And the shift of $Tm-$ isopleths ($\Delta\varphi$) displays a V−shape with the change of $\varphi$, its smallest value is near the Nanling Mountains in the latitude of 25° N because there is the smallest absolute value of $Tm$. To south and north from there it is gradually increases, and the increasing rate of $\Delta\varphi$ also increases with increasing of $\tau$.

## IV. IMPACT OF FLUCTUATION OF AGROCLIMATIC THERMAL ZONES ON AGRICULTURAL PRODUCTION

In general, the warm year with positive temperature departure is favorable to agricultural production, but contrarily, the cold year with negative temperature departure is unfavorable and even dangerous. In China the cool summer and the cold winter frequently occur and involve a large area[6]. Therefore, in this paper it is emphasized to analyze the regularities of the cool summer①and the cold winter and their danger to the agricultural production, by using the negative value of $\Delta\varphi$ with $\tau = 30$ of $\sum t$ and $Tm$ as the index of the

①In this paper the so−called "summer" is not properly indicated by the three months from June to August in northern hemisphere, but generally defined by the duration when the daily mean temperature is above 10℃, which is wholly or mostly in the summer half year in China.

anomalous cool summer year and cold winter year respectively.

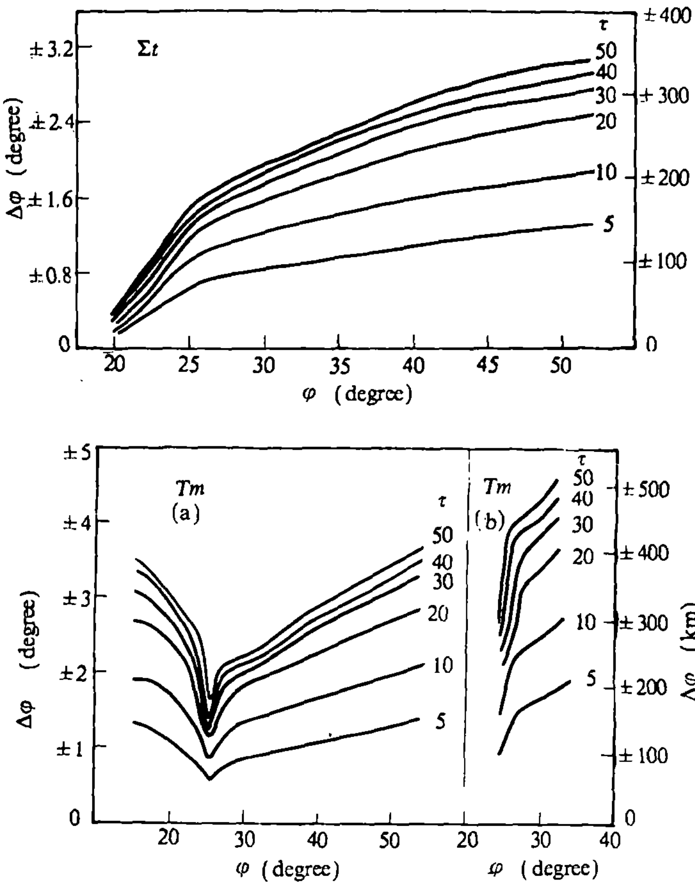


**Fig.3** Shift of $\sum t$— and *Tm*—isopleths with change in thermal regime

$\sum t$ and *Tm(a)* —in China except the Qinghai–Xizang Plateau

*Tm(b)* — in the Changjiang River basin

Table 2 shows the shift of $\sum t$— and *Tm*— isopleths with $\tau$ in different regions, it is seen that: (1) The shift of isopleth with the same $\tau$ in different regions is various, for $\sum t$ the greatest shift is in Northeast China, Inner Mongolia and northern Xinjiang, but the smallest in South China, and for *Tm* the greatest shift is in the Changjiang River basin, but the smallest also in South China. It shows the fluctuation of thermal resources in growing season is very great in Northeast China, Inner Mongolia and northern Xinjiang, so the thermophilous crops in these areas with one cropping in a year are easily injured due to delayed growth in the cool summer year with the further southward of $\sum t$—isopleths. It is also noted that if once the cool summer year occurred, the probability of late rice injured by cool damage in autumn is increasing although the shift of $\sum t$—isopleths is smaller in the

Changjiang River basin and South China. In the Changjiang River basin the fluctuation of low temperature in winter is the greatest, the perennial subtropical tree crops especially the citrus may be severely injured by the cold damage. In south China, it is noteworthy that if once the dangerous low temperature occurred the tropical tree crops such as *Hevea brasiliensis* may be seriously injured although the fluctuation of *Tm* is smaller. (2) With the same $\tau$, the shift of *Tm*–isopleths is larger than that of $\sum t$–isopleths, it means that in the same return period the area influenced by the cold winter year is larger than that by the cool summer year.

S.A. Sapozhnikova et al[7] and Z.Uchijima[8] analyzed the shift of $\sum t$–isopleths in the former Soviet Union and Japan, respectively, the results calculated in this paper are in agreement with theirs.

**Table 2 Shift of $\sum t$– and *Tm*–isopleths with $\tau$ in different regions (km)**

| Area | Element | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\sum t$ | | | | *Tm* | | | |
| | $\tau$ | | | | | | | |
| | 5 | 10 | 20 | 30 | 5 | 10 | 20 | 30 |
| South China ($\varphi$< 25° N) | ± 10–70 | ± 20–100 | ± 25–130 | ± 30–150 | ± 60–130 | ± 90–190 | ± 130–260 | ± 150–300 |
| Changjiang River basin (25° < $\varphi$< 34° N) | ± 70–100 | ± 100–140 | ± 130–190 | ± 150–220 | ± 110–190 | ± 170–290 | ± 230–390 | ± 250–450 |
| North China and southern Xinjiang (34° < $\varphi$< 40° N) | ± 100–110 | ± 140–170 | ± 190–220 | ± 220–250 | ± 110–120 | ± 170–190 | ± 230–250 | ± 250–290 |
| Northeast China, Inner Mongolia and northern Xinjiang ($\varphi$> 40° N) | ± 110–140 | ± 170–200 | ± 220–270 | ± 250–300 | ± 120–150 | ± 190–220 | ± 250–300 | ± 290–350 |

### 1. Impact of the Cool Summer Year

From Fig.3, in the anomalous cool summer year with $\tau = 30$, the northern boundaries of the southern subtropical, northern subtropical and warm temperate zones and southern boundary of the frigid temperate zone in China could be expected to shift southward by 150, 220, 250 and 300 km from their normal positions, respectively, it shows that the spatial fluctuation of the thermal resources in growing season and its impact on agriculture are much greater in the higher latitudes than in the lower latitudes.

In Northeast China and the east part of Inner Mongolia the cool damage caused by low temperature in cool summer is one of the main damages, injuring to the annual thermophilous crops (spring planting) such as rice, sorghum, corn, soybean and millet, etc. Since 1949, the cool summer with a large area has occurred three times (1969, 1972 and 1976) in Northeast China, it causes the grain reduction by about 5 billion kg each year. The grain production averagely decreases by about 10% whenever the accumulated temperature during May to September reduces by 100℃. In Northeast China the accumulated temperature during May to September is approximately in agreement with the accumulated temperature above 10℃ in the year. From the calculation in this paper, the negative departure of $\sum t$ with $\tau = 30$ can reach 320–340℃ (it could be expected to reduce the crop yield over 30%), while the duration above 10℃ is correspondingly to shorten by about 15 days. In 1969 and 1972 the negative departure of $\sum t$ exceeded the value with $\tau = 30$ in most localities of Heilongjiang and Jilin provinces, but in 1976 it mostly had the value with $\tau = 3-5$ except individual localities with near $\tau = 30$. After the middle of the 1960s, the variations of crops with a longer growing period had been widely adopted in Northeast China, so that the growing period of crops being 10–12 days longer than that in the past was needed and the requirements of accumulated temperature should be increased by 200–400℃[9], being equivalent to increase by 1–2 maturity classes. According to the above mentioned calculation, such late variety may be cultivated only in the warm summer year with a return period longer than 10 years, and therefore it is frequently and seriously injured by cool damage because such warm year rarely occurs.

The cultivated area of early maturing variety of cotton in t the north of China (northern Xinjiang, the Gansu Corridor, northern part of North China and Liaoning Province) is located in the northern boundary of cultivated area of cotton in China. The thermal condition in cotton growing season is originally rigorous. If once the cool summer year occurs, mature period of cotton will be delayed and the autumn frost will be earlier. Therefore, cotton will have a large percentage of lint after killing frost and a poor quality of cotton fibre. In such area the $\sum t$ with $\tau = 5$ and in the anomalous cool summer year with $\tau = 30$ may be reduced by about 150℃ and 300℃ and the growing season correspondingly shortened by 5–6 days and 12–13 days, respectively. The accumulated temperatere during the sowing to open boll stages of cotton is 3,000–3,200℃[10], and the $\sum t$ with $\tau = 5$ and 30 are reduced to 1/ 20 and 1/ 10 of it respectively, so that their probable impacts must be noticed.

In the middle and lower reaches of the Changjiang River valley and South China, the cool summer damage of the second cropping rice in the double cropping rice system is directly caused by the low temperature in autumn, cool summer year can strengthen the cool damage in the later growing stage. The cool damages to late rice in the middle and lower reaches of the Changjiang River valley in 1972 and 1980 were the cases.And in these two years there were only a few days with dangerous low temperature for late rice and the dangerous low temperature were not reached a heavy level, but they occurred early just to meet the heading and flowering stages of late rice, heavy damages being resulted[11].

In the Changjiang–Huaihe Plain with $\sum t = 4,600-4,800$℃ the double cropping of rice may be only cultivated in some localities of the middle and south parts of this area, but the thermal condition are not quite sufficient, The $\sum t$ and duration above 10℃ with $\tau = 5$ will be reduced by 160–180℃ and 6–7 days respectively in the cool summer year, having a great danger for cultivating the double cropping of rice.

In the middle and north parts of Ynunan Plateau there are a large amount of accumulated temperature but a lower temperature in summer and a greater fluctuation. The $\sum t$ with $\tau = 10$ may be reduced by 160 –180℃ , having a certain impact on the growth of thermophilous crops, and in fact the cool damage not only injures the double cropping of rice, but also sometimes the single cropping of rice. It shows that the temperature condition for rice is more severe.

**2. Impact of the Cold Winter Year**

From Fig.3 in the anomalous cold winter year with $\tau = 30$, the northern boundaries of the tropical, southern subtropical,northern subtropical and warm temperate zones, and the southern boundary of the frigid temperate zone could be expected to shift southward by 270, 150, 450, 290 and 350 km from their normal position, respectively. It is seen that in the anomalous cold winter year the southward shift of *Tm*–isopleths universally has a large width in China especially in the Changjiang River basin. The Changjiang River basin and South China belong to the subtropical and tropical areas in China, so the extremely low temperature in the cold winter year has a serious injury to the subtropical and tropical tree crops. If once the subtropical and tropical perennial economic tree crops are injured by the cold damage, it not only directly influences the economic and social benefits in that year, but also continues its effect for several successive years. Therefore, in such sense, sometimes the impact of the cold winter year on the agricultural production is more profound than that of the cool summer year.

Citrus is a typically subtropical economic tree crop,distributed in the provinces to the south of the Changjiang River in China. From the historical records, the citrus is often injured by cold damage in the middle and lower reaches of the Changjiang River valley, and only since 1949, in this region it has been suffered from heavy cold damage for three times (during the winter 1954/ 1955, 1968/ 1969 and 1976/ 1077). Its production can be reduced by 40–70% in these years and some varieties with little cold–resistant performance even be completely destroyed. Cold damage begins to injure at −7℃ for *Citrus reticulata* with a greater cold resistance but at −5℃ for *Citrus sinensis* with a less cold resistance. For both of them, the degree of injury will be risen one grade, while the extremely low temperature is dropped by 2℃[12]. In this region, the *Tm* in the cold winter year with $\tau = 10$ and 30 may be expected to decrease by 2℃ and by 3–3.5℃ , the cold damage being strengthened one and two grades respectively. Such anomalous cold winter once occurs, the citrus in the northern subtropical zone (north of the latitude 30° N in the middle and lower reaches of the Changjiang River valley will be destroyed, and that in the middle subtropical zone (south of the latitude 30° N ) will be seriously injured. For the three years with a heavy cold damage since 1949 mentioned above, the extremely low temperature in most localities were 3—5℃ lower than that in the normal year, corresponding to the anomalous cold winter year with $\tau=30$—50. In the middle and lower reaches of the Changjiang River valley, the southern boundary of injury to citrus by cold damage in the anomalous cold winter year with $\tau=30$—50 approximately agrees with that of the death of citrus by cold damage in the historical period [13]. Therefore, it is very important to select the optimum microenvironments to avoid the cold damage for citrus. According to the author's study, in this region some beneficial microtopographies, such as the horseshoe—shaped topography with a gap southwards and the southward slopes, may increase the minimum temperature by 1—2℃[14], corresponding to decrease by one grade of cold damage or to shift southward by 1.5℃ latitude (170 — 190 km).

Because of the strong winter monsoon in China, sometimes the strong cold air from Siberia can intrudes into South China and southern Yunnan,and even in Hainan Island the tropical crops can also be injured by cold damage. *Hevea brasiliensis* is a typically tropical economic tree crop, distributed in South China and southern Yunnan in China. Except the region to south of the Wuzhi Mountain in Hainan Island it can be injured almost everywhere by cold damage with different degree, especially in South China the cold damage is more frequent and serious. In southern Yunnan the cold damage can not be avoided although it is very seldom and with a lighter degree. In South China in January 1955 and in Xishuangbanna Prefecture of southern Yunnan in January 1974,the extremely low temperatures in meteorological records occurred, causing a lot of rubber tree being died from cold damage. For rubber tree, a slight injury by cold damage occurs at the minimum temperature of 10℃ , a heavier injury at 5℃ and a serious injury or death below 0—2℃ , respectively[15—16]. The percentage of injury will be increased by about twice to three times as temperature decrease by one degree each time when temperature below 0℃[16—17]. In the cold winter with $\tau=10$, the Tm may be reduced by 1—3℃ in South China and by 2—3℃ in southern Yunnan, respectively, and rubber tree may be injured seriously by cold damage in the above mentioned areas except the region to south of the Wuzhi Mountain in Hainan Island. The serious cold damage in South China in January 1955 and in southern Yunnan in January 1974 mentioned above are two examples. Therefore, to select the beneficial microtopography avoiding the cold damage for the rubber tree planting in China has a very important and practical value, and it has been verified by the practice for many years. According to the observations, the beneficial microtopography in South China may make the minimum temperature increase by more than 5—7℃ ; corresponding to shift southward by 3—5℃ latitude[16],and in Xishuangbanna Prefecture of southern Yunnan it is proved that using the thermal belt of the temperature inversion layer in the mountain region for cultivating the rubber tree is a very effective technique for avoiding the cold damage besides the rational utilization of microtopography[18].

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