Influence of Climatic Conditions on the Growth and Yield of Mangoes in Jingdong County, Yunnan Province

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Abstract In order to gain a deeper understanding of the impact of climatic conditions on mango cultivation in Jingdong County, according to the requirements for meteorological conditions from the biological characteristics of mango trees, the climatic conditions of Jingdong station and the main mango production areas in Yunnan Province were compared, and the climatic characteristics in the high- and low-yield year were analyzed. The results show that in the middle and low altitude areas of Jingdong County, winter was dry and relatively warm, and summer was not extremely hot (the average temperature in the hottest month 23.8 ℃); the dry and wet seasons were distinct, and rainy and hot weather occurred in the same season (from June to September); there was sufficient sunshine in the winter half year. The main climatic advantages for mango cultivation in Jingdong County are manifested as follows: the overwintering temperature and light conditions were relatively favorable (the average temperature in the coldest month was 11.3 ℃, and average sunshine duration in the three months of winter was 6.3 h/d); the annual total heat was moderate, and ≥10 ℃ accumulated temperature was 6 600 ℃ · d; the temperature effectiveness during the main growing season of mangoes was relatively higher; the sunshine duration and climate humidity during the flower bud differentiation period were moderate (sunshine duration was 6.4 h/d, and monthly precipitation was 19.2 mm); the rainfall was abundant during the maturation period of fruits. The insufficient light and heat intensity during the maturation period of fruits (average sunshine duration was 4.4 h/d, and average temperature was 23.2 ℃ from June to September), the susceptibility to the influence of spring drought during the young fruit stage of mangoes (precipitation was 141 mm from March to May), and relatively lower temperature during the flowering and pollination period in some years jointly constituted the main climatic constraints on local mango yield.

Key words Mango cultivation; Climatic conditions; Jingdong County, Yunnan Province

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Jingdong County is located in the southwest of Yunnan Province and the north of Pu'er City, with an altitude of 795 - 3 371 m. It has a subtropical monsoon climate, with no severe cold in winter and no extreme heat in summer. The dry and wet seasons are distinct (the rainy season is from May to October). Rain and heat occur in the same season, and there is abundant sunshine. Jingdong County is not a traditional main production area of mangoes in Yunnan Province. Its mango cultivation originated from the grafting and cultivation by the villagers of Dashuitang in Wenmao Village, Manwan Town, Jingdong County, Pu'er City. The characteristics of its mangoes are good growth, early fruiting, late maturing (the maturing time of ivory mangoes in Jingdong is about 20 d later than that of Jinggu, Yuanjiang, Jinghong and other places[1]), high yield, few cracked fruits, and long retention time of fruits on the tree. They are harvested from middle September to middle October. In December 2012, it was recognized as a superior variety by the Forest Tree Variety Approval Committee of Yunnan Province (number: Yun R-SV-MI-013—2012)[2]. Over the past decade, the cultivation of late-maturing mangoes in Jingdong has developed rapidly. They are now grown in all 13 towns of the county, among which Manwan Town, Wenjing Town and Jinping Town have the largest planting area. The total planting area in the county has increased from 466.67 hm^2 in 2016 to 2 700 hm^2 in 2024. Mango planting and production are gradually becoming an important industry in Jingdong County. However, the output of mangoes has fluctuated greatly from year to year in the past nine years. With global warming, the growth period of mango trees changes, which has a significant impact on the yield and quality of mangoes. Meteorological elements such as temperature, sunlight, precipitation and humidity directly or indirectly affect the growth cycle, photosynthesis, nutrient absorption and the occurrence of pests and diseases of mangoes. Therefore, analyzing the impact of climatic conditions on the growth and yield of late-maturing mangoes in Jingdong is of great practical significance for local economic development and the prevention of agricultural meteorological disasters.

1 Data and methods

1.1 Data The adopted planting climate indicators and climate elements include average temperature, average maximum temperature, average minimum temperature, ≥10 ℃ active accumulated temperature, 20 cm ground temperature, extreme maximum temperature, extreme minimum temperature, precipitation and sunshine duration. Among them, ≥10 ℃ active accumulated temperature reflects the total heat of warm-loving crops[3], while 20 cm ground temperature shows the temperature level of the root system

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of most crops, so they can better represent the heat conditions for crop growth than air temperature[4], and can also reflect the compensation effect of sunlight on temperature[5]. In this paper, the data of climate elements at four county-level meteorological stations (they are located in the main production areas of mangoes in their respective counties) in Jingdong, Yuanjiang, Huaping and Yongren of Yunnan Province were used. The data were sourced from the operation platform V2.3 of meteorological data business system (MDOS). At the same time, the data on the annual planting area and total output of mangoes in Jingdong County from 2016 to 2024 were used, which were sourced from the Jingdong Bureau of Statistics.

1.2 Methods Comparative analysis method was applied to the following three aspects: ① the climatic characteristics of mango cultivation in Jingdong County and the main production areas in the province (Yuanjiang, Huaping and Yongren counties) were compared, including the total annual heat, the low temperature during the overwintering period, the temperature in the hottest month, precipitation, average relative humidity and annual sunshine duration; ② the main climatic indicators at different growth stages of mangoes between Jingdong and the main production areas in the province were compared; ③ the climatic differences in the typical years with high yield and low yield of mangoes per unit area in Jingdong were analyzed. The univariate regression method was used to analyze the historical changing trend of the yield per unit area of mangoes, and based on this, the years with high yield and low yield can be further identified.

2 Results and analysis

2.1 Basic climatic characteristics for the cultivation of late-maturing mangoes and their vegetative growth in Jingdong

2.1.1 Basic climatic characteristics. The main production areas of mangoes in China are mainly located in Guangdong, Guangxi, Fujian, Hainan, southern Yunnan and other places, and there is also a certain scale of mango cultivation in the Jinsha River valley and the southwestern river valley of Guizhou[6]. The annual data of the main climatic elements in the four major growing areas of mangoes (Jingdong, Yuanjiang, Huaping and Yongren) in Yunnan Province from 1991 to 2020 are shown in Table 1. As shown in Table, the annual average temperature and ≥10 ℃ accumulated temperature at Jingdong station were significantly higher than that at Yongren station, meaning that its total heat conditions were not bad. The average temperature in the coldest month at Jingdong station was higher than that of Yongren and comparable to that of Huaping. Moreover, the highest temperature in January at Jingdong station was higher than that of Yongren and Huaping. At the same time, the annual extreme minimum temperature at Jingdong station was also higher than that of Yongren. That is, the temperature conditions for mangoes to overwinter were still acceptable, and the daytime heat intensity in winter was at a medium level. At Jingdong station, the annual extreme maximum temperature and the average temperature in the hottest month were relatively low, and the daily temperature range was moderately small, indicating that the harm of high temperatures in summer was extremely small, and the temperature validity was relatively high. However, the average temperature in the hottest month was relatively low, revealing that the temperature intensity during the vigorous growth period of mangoes was insufficient. The annual average precipitation and annual average relative humidity at Jingdong station were significantly higher than those of the other three stations, showing that Jingdong has a relatively humid climate. However, due to the distinct dry and wet seasons, the average relative humidity during the dry season was less than 68%. The annual sunshine duration at Jingdong station was the least among the four stations, but the average daily duration throughout the year was more than 5.6 h, and especially in the first half of the year (the dry season was dominant), the average daily duration was more than 6.5 h, indicating that the lighting conditions were not bad.

Table 1 Comparison of annual averages of climatic elements in four mango production areas in Yunnan from 1991 to 2020

Meteorological element	Jingdong County	Yuanjiang County	Huaping County	Yongren County
Altitude//m	1 165.4	400.6	1 260.0	1 531.3
Annual average temperature//℃	19.1	24.1	19.8	17.8
Annual extreme maximum temperature//℃	38.5	43.1	41.3	37.8
Annual extreme minimum temperature//℃	−1.4	2.0	−0.6	−4.1
Average temperature in the coldest month//℃	11.6	16.7	11.7	9.7
Average temperature in the hottest month//℃	23.8	31.1	27.5	25.1
The highest temperature in January//℃	28.9	35.2	27.5	23.7
The lowest temperature in January//℃	0.0	4.0	3.4	3.8
Annual precipitation//mm	1 101.5	802.3	1 082.2	850.7
Annual average relative humidity//%	75.0	67.0	62.0	66.0
Annual sunshine duration//h	2 057.2	2 308.4	2 509.3	2 525.7
Sunshine durationin the first half of the year//h	1 196.7	1 269.8	1 435.1	1 422.6
Rainfall during the flowering period (January – March)//mm	63.4	62.6	89.1	71.0
Rainfall during the fruit development period (April – July)//mm	5 16.9	410.6	520.4	422.8
≥10 ℃ annual accumulated temperature//℃	6 924.8	8 796.5	7 134.3	6 164.7
Annual average daily temperature range//℃	12.4	11.5	13.3	13.3

Note: The data are sourced from the Yunnan Meteorological Bureau.

2.1.2 Vegetative growth of roots, stems and leaves of late-maturing mangoes. Mango trees live sunlight. The experience of mango cultivation in the low-heat river valleys of Southwest China shows that the vegetative growth of roots, stems and leaves of mangoes has strict requirements for sunlight. Under sufficient light conditions, the vegetative growth of mangoes is fast, and their growth vigor is good. Conversely, if lighting conditions are poor, their branches and leaves will not be lush, and their development will be poor. The annual average sunshine duration in Jingdong County over the years is 2 057.2 h, and the annual sunshine percentage is 57.4%. Moreover, the sunshine percentage in each month from December to next April is above 51.3% –66.0%. The abundant sunshine is conducive to the growth and development of roots, stems, leaves and flowers of mangoes.

The vegetative growth of mangoes is not very strict about water requirements. Mangoes can grow in tropical and subtropical regions with an annual precipitation of 500 –2 500 mm. Even in hot areas with extremely little rainfall throughout the year, mangoes can grow well as long as there are appropriate irrigation conditions. According to statistics, the annual average precipitation in Jingdong County over the years is 1 101.5 mm. Rain and heat occur in the same season (from June to September), and precipitation conditions can meet the growth and development needs of mangoes. Especially in autumn, precipitation is moderate and suitable for the growth of autumn mango shoots. Autumn shoots grow after the harvest of fruits in the current year, and are the mother branches of fruits in the following year, having a significant impact on the formation of yield in the following year.

2.2 Reproductive growth of late-maturing mangoes

2.2.1 Flower bud differentiation period. In the tropical rainforest climate zone with year-round high temperatures and abundant rainfall, the vegetative growth of branches and shoots of mangoes is vigorous, which affects their transition to reproductive growth and is thus not conducive to the emergence of flower clusters. Appropriate high-temperature dryness and a certain degree of low temperatures are actually conducive to flower bud differentiation[6]. After the rainy season ends in the middle and late October every year in Jingdong County, it enters a dry and cool season with less rain, which can inhibit the vegetative growth of mangoes, promote their reproductive growth by inducing the differentiation and development of flower buds.

The climatic conditions during the flower bud differentiation period of mangoes in Jingdong and three other production areas in Yunnan Province from 1991 to 2020 were compared. As shown in Table 2, except that the flower bud differentiation period of mangoes in Yongren was from November to next February, it was from December to next February in other places. During the flower bud differentiation period, the average temperature at Jingdong station was 12.8 ℃, higher than that of Yongren and comparable to that of Huaping. However, the daytime temperature was not low (the average maximum temperature reached 22.3 ℃, and the daily temperature range was 15.3 ℃, second only to Yongren). At Jingdong station, the monthly average sunshine duration during the same period was 191.1 h (*i. e.* 6.4 h/d), and was the lowest among the four places, but only slightly less than that of Yuanjiang. The 20 cm ground temperature at Jingdong station was 15.8 ℃, which was higher than that of Yongren and Huaping. To sum up, the heat conditions during the flower bud differentiation period of mangoes at Jingdong station were better than those in Yongren and comparable to those of Huaping. Only the sunlight duration at Jingdong station was slightly less.

Table 2 Averages of climatic elements during the flower bud differentiation period of mangoes in Jingdong and three other production areas in Yunnan Province from 1991 to 2020

Station	Altitude m	Flower bud differentiation period	20 cm ground temperature ℃	Average temperature ℃	Average maximum temperature // ℃	Daily temperature range // ℃	Sunshine duration h/d	Monthly average rainfall // mm
Jingdong	1 165.4	From December to next February	15.8	12.8	22.3	15.3	6.4	19.2
Yongren	1 531.3	From November to next February	14.2	11.1	20.2	16.9	7.9	5.8
Yuanjiang	400.6	From December to next February	20.6	17.7	25.4	12.5	6.5	19.7
Huaping	1 260.0	From December to next February	15.0	13.0	22.5	22.5	7.9	4.4

2.2.2 Flowering and pollination period. The favorable meteorological conditions during the flowering period of mangoes are shown in Table 3. According to the observation of the flowering period of mature mango trees by the Jingdong Meteorological Bureau, the flowering period of mangoes in Jingdong County is mostly from February to March. In the flowering period, mangoes have the strictest requirements for meteorological conditions. The most ideal meteorological conditions during this period are warm, sunny and less humid weather[7]. The meteorological conditions during the flowering period of mangoes are a key factor determining the yield and quality of mangoes in the hot areas of eastern China. Relevant research on the planting areas of mangoes in the low-heat river valley in the southwest of Guizhou Province shows that under the conditions of higher temperatures and more sunshine hours in winter and spring, the flower bud differentiation rate and fruit setting rate would increase significantly[8]. It is also pointed out that the sunny side of the tree crown has characteristics of more flower spikes, flowering earlier and more fruits, and the appearance quality of the fruits is excellent. However, the internal branches with dense leaves and poor ventilation and light penetration, as well as the branches on the shady side, have few fruits. Moreover, they are prone to pests and diseases, suffer from severe fruit drop, have poor fruit appearance and poor quality, and are not suitable for storage.

Table 3 Favorable meteorological conditions during the flowering period of mangoes[9]

Index level	Influence on mango flowering	Meteorological condition
1	Very beneficial	Daily average temperature ≥20 ℃, total daily sunshine duration ≥4 h, or daily average temperature ≥16℃, and the total daily sunshine duration ≥8 h
2	Beneficial	Daily average temperature ≥20 ℃, 2 h≤total daily sunshine duration <4 h, or 16 ℃≤daily average temperature <20 ℃, and 4 h≤total daily sunshine duration <8 h

The influence of temperature on the flowering period is mainly reflected in the length of the flowering period and pollination[8]. If temperature remains persistently low for 15 – 20 d, the flowering period of mangoes from the opening of the first flower to the complete blooming of all the flowers on the cluster will be extended to 30 – 35 d. After the first flowering fails due to low temperature, the flower spikes can be reproduced for the second or even the third time. Precipitation also has certain impact on flowering. For instance, rainwater easily causes pollen loss, affecting insect pollination. If it rains for a long time, the flower spikes will mold and rot, resulting in flower drop. Besides, continuous rainy weather can cause persistently high humidity, easily lead to the outbreak of diseases such as anthracnose and powdery mildew, resulting in a large number of flower drops and dead ears of mangoes.

The favorable meteorological conditions during the pollination period of mangoes are shown in Table 4. Mango pollination can only be carried out when certain temperature conditions are met. The meteorological condition indicators for mango pollination adopted by major growing areas of mangoes in China are basically the same[10]. That is, normal pollination can be achieved when daily average temperature is ≥20 ℃. As daily average temperature drops to 15 ℃, pollination is affected. If it persists for more than 7 d, it will seriously affect pollination. Pollination cannot be carried out when daily average temperature decreases to 12 ℃.

Table 4 Favorable meteorological conditions during the pollination period of Mangoes[9]

Index level	Influence on the natural pollination of mangoes	Meteorological condition
1	Very beneficial	Daily average temperature ≥20 ℃, no precipitation
2	Beneficial	Daily average temperature≥20 ℃, daily precipitation <10 mm, and the number of consecutive precipitation days ≤3 d, or 15 ℃≤daily average temperature <20 ℃, no precipitation

The climatic conditions during the flowering and pollination period of mangoes in Jingdong and three other production areas inYunnan Province are shown in Table 5. During the flowering and pollination period of mangoes at Jingdong station (from February to March), monthly sunshine duration was 218.5 h (*i.e.* 7.3 h/d), which was lower than that of Yongren and Huaping and comparable to that of Yuanjiang. Monthly rainfall was 20.1 mm, with many sunny days and almost no continuous cold and rainy weather. During this period, the average temperature at Jingdong station was 15.8 ℃, and average maximum temperature was 25.9 ℃, which was the lowest among the four stations. However, the daily temperature range at Jingdong station was up to 16.9 ℃, and was the largest among the four stations. Comparative analysis shows that the overall heat conditions in Jingdong during this period were the worst. However, the highest temperature was close to 26 ℃, and daily temperature range was relatively large. At the same time, sunshine duration was still acceptable, indicating that the light and heat conditions during the day could basically meet the requirements for flowering and pollination. During the flowering and pollination period, the average temperature and sunshine duration in Jingdong were relatively low, so that 20 cm ground temperature was significantly lower. This indicates that in some years in the area, the heat and sunshine duration during this period were insufficient, which was not conducive to the flowering and pollination ofmangoes.

Table 5 Comparison of meteorological conditions during the flowering and pollination period of mangoes in Jingdong and three other production areas in Yunnan Province

Station	Altitude//m	Flowering and pollination period	Average temperature ℃	Average maximum temperature//℃	Daily temperature range//℃	20 cm ground temperature//℃	Monthly sunshine duration//h/d	Monthly average rainfall//mm
Jingdong	1 165.4	From February to March	15.8	25.9	16.9	17.9	7.3	20.1
Yongren	1 531.0	From March to April	18.6	26.9	16.6	21.2	8.6	11.8
Yuanjiang	400.6	From January to March	19.7	27.8	13.5	22.0	7.1	21.5
Huaping	1 245.0	From February to April	19.4	28.3	16.5	20.3	8.6	7.8

2.2.3 Development and maturation period of fruits. According to the observation of the phenological periods of mature mango trees by the Jingdong Meteorological Bureau, the fruit development period of late-maturing mangoes in Jingdong County is mostly from April to August. The final yield of mangoes depends on the quality of fruits. After mangoes set fruit, they generally need to go through two physiological fruit drop periods. If the young fruit stage encounters a long period of low-temperature and rainy weath-

er, the tree body will lack nutrients, often resulting in fruit drop. If a wind of force 7 or above occurs, fruits will drop severely. Meanwhile, the mechanical damage caused by a gale to the fruits is prone to lead to pests and diseases[6].

The climatic conditions during the development and maturation period of fruits in Jingdong and other three production areas in Yunnan Province were compared, as shown in Table 6. The average temperature at Jingdong station was 23.0 ℃, 1.7 – 5.1 ℃ lower than that of Huaping and Yuanjiang and comparable to that of Yongren. The average maximum temperature was slightly higher than that of Yongren. The monthly rainfall at Jingdong station was 144.2 mm, which was more than that of Yongren and Yuanjiang but less than that of Huaping. The sunshine duration at Jingdong station was 5.5 h/d, less than that of the other three stations. The average wind speed at Jingdong station was 0.9 m/s, and the frequency of wind speed ≥10 m/s was 0.1 times per month, both lower than those of the other three stations. In Jingdong County, rainstorm mainly occurred from June to September. The monthly average number of rainstorm days (daily precipitation ≥50.0 mm) from June to September was 0.5 d. The frequency of rainstorm from April to August was 1.6 times per month, which was higher than that of the other three stations.

As shown in Table 6, the average temperature at Jingdong station was the lowest, and its average maximum temperature was slightly higher than that of Yongren. However, its sunshine duration was significantly less than that of the other three places, and there was more rainfall during the same period (due to the large heat capacity of water), so that 20 cm ground temperature was significantly lower. This indicates that during the development and maturation period of fruits (lasting for several months), the total heat (accumulated temperature) in Jingdong was significantly insufficient (only the temperature intensity in the afternoon was still basically sufficient), which was the main reason for the late ripening of mangoes in Jingdong. At the same time, it shows that the light and heat conditions during the development and maturation period of fruits are a key factor affecting mango yield. In other respects, the wind speed in Jingdong during this growth period was relatively low, which was beneficial for increasing the leaf surface temperature. The frequency of rainstorm and other heavy precipitation was relatively high, and it can cause fruit drop, so it is an unfavorable factor. However, these effects were limited.

Table 6 Comparison of meteorological conditions during the the development and maturation period of fruits in Jingdong and three other production areas in Yunnan Province

Station	Development period of fruits	Wind speed m/s	Monthly frequency of wind speed ≥10 m/s	Monthly frequency of rainstorm	Monthly average rainfall//mm	Average temperature ℃	Average maximum temperature//℃	20 cm ground temperature ℃	Monthly sunshine duration//h/d
Jingdong	From April to August	0.9	0.1	1.6	144.2	23.0	29.6	25.2	5.5
Yongren	From May to June	2.5	1.9	0.3	106.0	23.1	29.1	26.0	6.9
Yuanjiang	From April to August	2.1	1.6	0.2	104.2	28.1	34.7	30.5	6.4
Huaping	From May to August	1.5	2.3	0.6	189.5	24.7	31.1	26.6	6.1

2.3 Main differences in climatic conditions between high-yield years and low-yield years According to the data provided by the Jingdong Bureau of Statistics, the production area of late-maturing mangoes in Jingdong tended to increase from 2016 to 2024. The R^2 value of the linear regression equation for the historical change of the yield per unit area was relatively small, that is, its linear trend was not significant at 0.05 level. As shown in Fig. 1, the yield per unit area only in 2018 and 2020 deviated significantly from the trend line, and was respectively higher and lower than the trend yield, revealing that 2018 was a high-yield year, and 2020 was a low-yield year. The differences in climatic conditions between these two typical years were analyzed (Fig. 2).

In the flower bud differentiation period of mangoes (Fig. 2), there was no big difference in average temperature, average maximum temperature, 20 cm ground temperature, daily temperature range and sunshine duration between 2018 and 2020, while the precipitation and average relative humidity in 2020 were significantly higher than those in 2018.

In the flowering and pollination period, all three temperature indicators in 2020 were slightly higher than those in 2018. There was no obvious difference in sunshine duration and average relative humidity between the two years, while the precipitation in 2018 was slightly more than that in 2020 (Fig. 2).

In the development and maturation period of fruits (from April to August) (Fig. 2), there was no big difference in the three temperature indicators and daily temperature range in the two years, but there was an obvious difference between the two years in climatic conditions. Firstly, although the precipitation in 2018 was 13.9% more than that in 2020, the sunshine duration in 2018 was significantly more than that in 2020, and the difference in the average relative humidity between the two years was exactly the opposite. Secondly, during the development period of fruits from July to September, the sunshine duration in 2018 was 140 h (namely an average of 1.5 h/d) more than that in 2020, while the monthly average temperature in the two years remained almost the same. Finally, since the development and maturation period of mango fruits in Jingdong extends from the late dry season to the middle and late rainy season, it is necessary to compare the beginning period of the rainy season and the degree of drought from March to May in the two years (Fig. 3). The rainy season began on May 28, 2018. The cumulative rainfall from March to May was 183.4 mm (15.1% more than that in the same period in previous

years). In 2020, the rainy season started on July 4 (36 d later than 2018), and the cumulative rainfall from March to May was only 83.1 mm (47.9% less than that in the same period in previous years and 54.7% less than that in the same period in 2018). It is obvious that the spring drought during the development period of fruits in 2020 was severe, while the impact of spring drought in 2018 was small (the precipitation in May was 106.7 mm more than that in the same period in 2020). Although the total heat during the period in 2020 was slightly better than that in 2018, the yield reduced because of severe spring drought and insufficient sunlight during the period. The yield was high in 2018 because spring drought had a minor impact and the light and heat conditions during the maturation period of fruits were favorable.

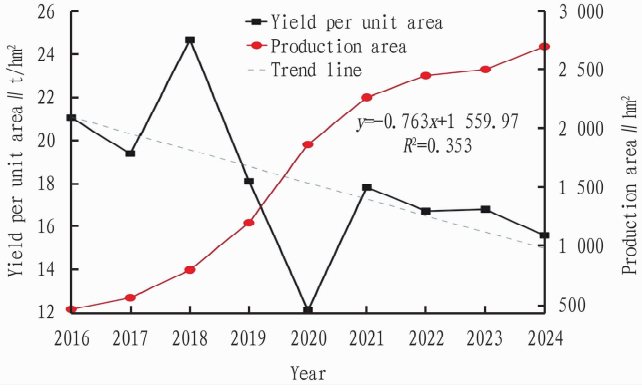
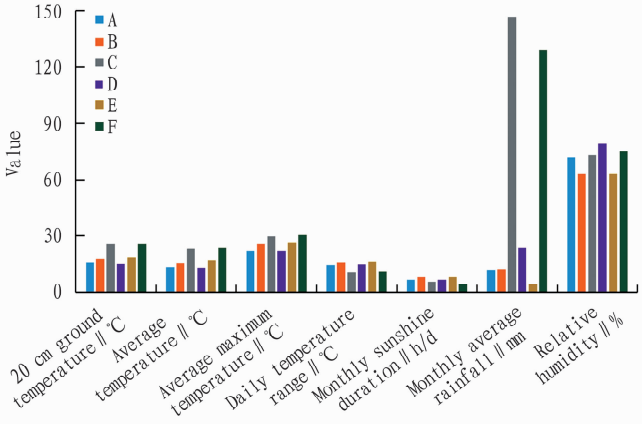


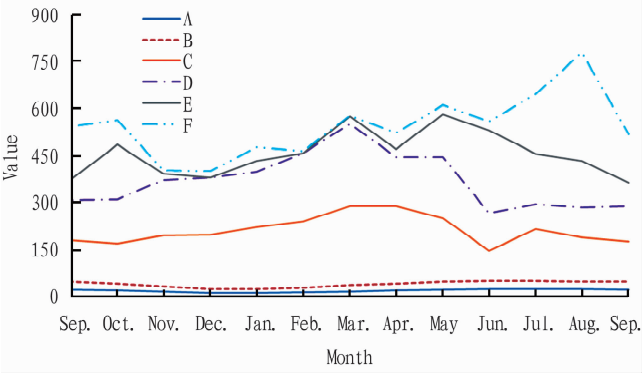
Fig. 1 Annual changes in the production area and per unit area yield of late-maturing mangoes in Jingdong over the years



Note: A. Flower bud differentiation period (December 2017 – February 2018); B. Flowering and pollination period in 2018 (February – March); C. Development period of fruits in 2018 (April – August); D. Flower bud differentiation period (December 2019 – February 2020); E. Flowering and pollination period in 2020 (February – March); F. Development period of fruits in 2020 (April – August).

Fig. 2 Climatic conditions in the three growth periods of mangoes in Jingdong County in 2018 and 2020

Comparative analysis shows that the difference in climatic conditions in the high-yield year (2018) and the low-yield year (2020) of mangoes in Jingdong affected mango yield mainly during the development and maturation period of fruits. The sunshine duration from July to September during the maturation period of fruits was relatively long, and the impact of spring drought during the young fruit period was small, which is conducive to the increase in mango yield.



Note: A. Average temperature (Sept. 2017 – Sept. 2018); B. Average temperature (Sept. 2019 – Sept. 2020); C. Sunshine duration (Sept. 2017 – Sept. 2018); D. Sunshine duration (Sept. 2019 – Sept. 2020); E. Precipitation (Sept. 2017 – Sept. 2018); F. Precipitation (Sept. 2019 – Sept. 2020). The unit of average temperature, sunshine duration and precipitation is ℃, h/d, and mm, respectively.

Fig. 3 Monthly variations in average temperature, sunshine duration and precipitation in high-yield and low-yield years

3 Conclusions

(1) Compared with the three main mango production areas in Yunnan, the overwintering heat conditions of mangoes at Jingdong station were better than those at Yongren and Huaping stations. During the growing season, climate humidity was relatively high, and the damage caused by high temperatures was small, and temperature effectiveness was high. During the vigorous growth period (from June to September), heat intensity was insufficient. There were obvious differences in the growing climate of mangoes during their various growth periods. During the development and maturation period of fruits and the flowering and pollination period, average temperature was significantly lower, and sunshine duration was less. During the flower bud differentiation period, average temperature was higher than that in Yongren and comparable to that in Huaping, but sunshine duration was significantly less.

(2) Jingdong County is in the middle and low altitude areas, where winter was dry and relatively warm, and summer was not extremely hot; the dry and wet seasons were distinct, and rain and heat weather occurred simultaneously; there was abundant sunshine in the winter half year. These climatic characteristics are an important basis for mango cultivation. The main climatic advantages for local mango cultivation are relatively favorable overwintering light and temperature conditions, moderate sunshine duration and air humidity during the flower bud differentiation period, abundant annual heat meeting the growth and development needs of mangoes, and abundant rainfall during the fruit ripening period.

(3) Insufficient light and heat intensity during the maturation

period of fruits, susceptibility to spring drought during the young fruit stage, and relatively low temperatures during the flowering and pollination period in some years are the main climatic factors affecting the formation of mango yield in Jingdong County and causing significant annual fluctuations. The insufficient light and heat intensity during the development and maturation period of fruits is the main reason for the late ripening of mangoes. At the same time, it indicates that in Jingdong County, medium and low altitude areas (<1 400 m) are only suitable for growing mangoes.

(4) The results of this study have practical guiding significance. In the meteorological services for mango production, it is necessary to focus on light and heat intensity during the maturation period of fruits (from June to September), the impact of spring drought (rainfall at the beginning of the rainy season and from March to May), and light and heat intensity during the flowering and pollination period, which can great help improve the prediction level of mango yield in Jingdong County.

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(From page 85)

ficant at 0.05 level in May and July. The significant positive correlation between NDVI and precipitation was mainly concentrated in the early stage. There was a significant lag in the response of vegetation to precipitation (the figure is omitted).

The snow on the grassland of Siziwang Banner in winter melts in spring, ensuring that the soil moisture can meet the needs of grass turning green again. Therefore, the impact of insufficient water on vegetation was mainly reflected in the middle and later stages of forage growth.

3 Conclusions

(1) From 2000 to 2021, the NDVI of grassland in Siziwang Banner showed an overall upward trend, with the average tendency rate of 0.05/10 a. The improvement of vegetation environment was quite obvious.

(2) The annual variation of NDVI in the grassland of Siziwang Banner was mainly driven by precipitation, and the correlation with temperature was relatively small.

(3) During the growing season, the temperature in May was positively correlated with NDVI. The heat conditions had certain restrictive effects during the greening period and the early stages of forage growth. Subsequently, the correlation between NDVI and temperature gradually became negative. NDVI was generally positively correlated with precipitation, but the response of NDVI to precipitation had a lag effect.

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