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CLIMATE-BASED ZONATION WITH GIS FOR DRIED-FRUITS AND NUT TREES IN BEIJING

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Abstract

Beijing has a dried fruit and nut tree cultivation area of 64.7 thousand hectares, accounting for 48% of the total fruit tree planting area. Though it involves a total of 121,000 households, the income per ha is only 7555 yuan. Scientific planning for the cultivation of popular dried-fruit and nut trees is essential for the rational allocation, efficient utilization and sustainable development of agricultural resources available in Beijing. By collecting the basic data regarding climate, ecology, and soil, and correlating them with the climatic and ecological adaptabilities of the crops, a fine zonation for each of the four most important dried-fruits and nuts produced in Beijing (100 m × 100 m) using GIS technology was developed. Each zonation identified the most favorable, favorable, general, unfavorable, and the most unfavorable areas. Further, we suggested ideal producing areas for the main dried fruits and nuts industries, providing a theoretical basis for the optimal layout of dried fruit and nut production facilities are suggested.

Introduction

In 2015, the area under fruit tree cultivation in Beijing was 136 thousand hectares among which the dried-fruits and nut tree planting area were 64.7 thousand hectares, reaching 48% of the total area under fruit tree cultivation. Among these, the chestnut tree occupies the largest planting area, 40.5 thousand hectares, and produces an output value of 487.21 million yuan. Chestnut trees are primarily distributed in Miyun (19.3 thousand hectares), Huairou (14.4 thousand hectares) and Changping (2.7 thousand hectares). There are 14 thousand hectares walnut trees, mainly distributed in Pinggu (4.5 thousand hectares), Miyun (2.7 thousand hectares), Fangshan (2.3 thousand hectares), and Changping (1.4 thousand hectares). There are 121,000 households with plant dried-fruit and nut trees, and the average annual household income reaches 4,027 yuan. The fruit industry plays a significant role in boosting the income of suburban Beijing farmers, and is the leading contributor to the incomes of orchard farmers especially those in the mountains. However, in general, the dried-fruit and nut cultivation industry has the issues of low yield per area, low efficiency and poor management. It has a lot to catch up with in order to meet the modernization requirements of transforming Beijing into a world-class, harmonious, and livable metropolis. An important part of this modernization proposal is the development of eco-business initiatives in mountainous areas, making full use of the barren hills and wastelands, and paying particular attention to woody grain and oil species such as chestnuts, walnuts, almonds, apricots, and hazelnuts which have strong adaptability, good resistance to drought and barrenness, and serve as protectors of the local ecology, to create a "furrow economy" that can improve the environment while securing the grain and oil supply. The climate and environmental conditions of Beijing make it particularly important to modernize the fruit industry and to optimize the distribution. A promising step in this direction is the adoption of GIS technology to carry out a detailed, climate-based agricultural zonation of the main dried-fruit and nut trees (Chen *et al*. 1988, Huang *et al*. 1998, Wu *et al*. 2008).

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Materials and Methods

The climate data were obtained primarily from the meteorological stations in Beijing city and the surrounding districts and counties, as well as the Beijing Meteorological Information. The geographic data include 1 : 250,000 basic geographic background data provided by the National Geomatics Center of China. Two most popular geographic information systems, ArcGIS 10.210 by Esri and ENVI 5.2, were used for data processing and analysis. The data were stored as split maps, and each map contained 14 layers of data such as the administrative boundaries, contour lines, and water information. The geographic information required for the zonation, including the administrative boundary of Beijing, the digital elevation model (DEM), and the geographical locations of the meteorological stations was extracted with ArcGIS 10.210. The soil pH was computed based on the geological features of Beijing. The relevant zonation indicators were set up taking into consideration the climatic and ecological requirements of each type of tree. After the raster map for each indicator was drawn. The grid calculator tool in ArcGIS10.2 was used to add the scores from all the indicators, taking into account their weights, to obtain a total score raster map. According to the total scores, five grades were set up, with the most favorable area being accorded the highest score and the most unfavorable idea, the lowest. Therefore, in the order of the highest to the lowest scores they are: the most favorable, favorable, general, unfavorable and the most unfavorable areas.

Results and Discussion

Beijing is in the North Temperate Zone, which has a semi-humid continental monsoon climate with hot and rainy summers, cold and dry winters, and short springs and autumns. The average annual temperature is 11-13°C in the plains, and 9 - 11°C in areas with an elevation below 800 m. The annual frost-free period is 180 - 200 days, which is shorter in the western mountainous areas. The average annual sunshine duration is approximately 2400 hrs and the average annual rainfall is 483.9 mm, which makes it one of the areas in North China recording the most rainfall.

The average annual temperature in Beijing is 11.8°C. As shown in Fig. 1, the average annual temperature is lower in the western and northern Beijing areas, while it is higher in the central, southern and eastern areas. Since Beijing is not a very large city in terms of its area, the difference in temperature is caused primarily by the differences in elevation. In general, the temperature decreases by 6°C for each 1000-meter increase in elevation. The temperature in piedmont plain areas is higher, with an average annual temperature of 11 - 13°C. The average annual temperature is 8°C for Yanqing basin, and only 2°C for Ling Mountain, Mentougou, and Dahaituo Mountain, Yanqing. The distribution of the average annual temperature is the most important factor that determines the ideal distribution of fruit tree plantations. For example, the average annual temperature of the Yanqing area in Beijing is approximately 8.5°C, and the extreme temperature is −27°C in winter. Fruit trees, in general, find it difficult to thrive in this climate but it is favored by almond and apricot trees. The period from June to September is ideal for the growth of fruit trees and their accumulation of photosynthetic products, and so, the highest temperature in this period would affect the accumulation of photosynthetic products and the fruit quality. The distribution of highest temperatures in Beijing from June to September is shown in Fig. 2, and it can be seen that the highest temperatures are mostly distributed in the urban areas and Southeast Beijing.

All fruit trees require certain amount of accumulated temperature to form and develop buds and produce mature fruits during their growing season. The accumulated temperature distribution in Beijing is shown in Fig. 3. The accumulated temperature in Yanqing is 3,252.6°C when the temperature is ≥10°C. The required accumulated temperature for ripening is 1,327°C for chestnuts, and 649°C for apricot. It can be seen that even relatively cold regions like Yanqing

exhibit sufficient accumulated temperature for nuts like chestnut. The frost-free period in Beijing lasts up to six months or 180 - 200 days approximately. The distribution of frost-free period in Beijing over the course of a year is shown in Fig. 4. The calculated annual duration of sunshine is 2500 - 2700 hrs. The distribution of sunshine duration in each region is shown in Fig. 5. The sunshine duration does not vary much from region to region but is longest in the Yanqing valley, which has a high elevation and considerable difference in temperature between day and night. All these factors make it an ideal area for the cultivation of high-quality fruits.

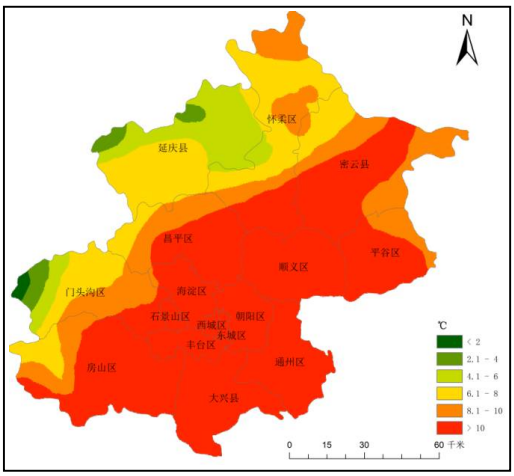

Fig. 1. Average annual temperature distribution in Beijing.

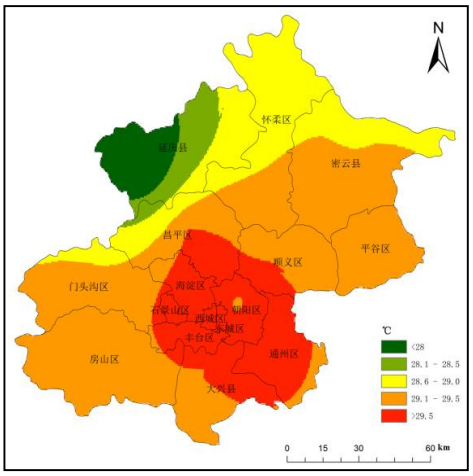

Fig. 2. Average high temperature distribution in Beijing for June to September.

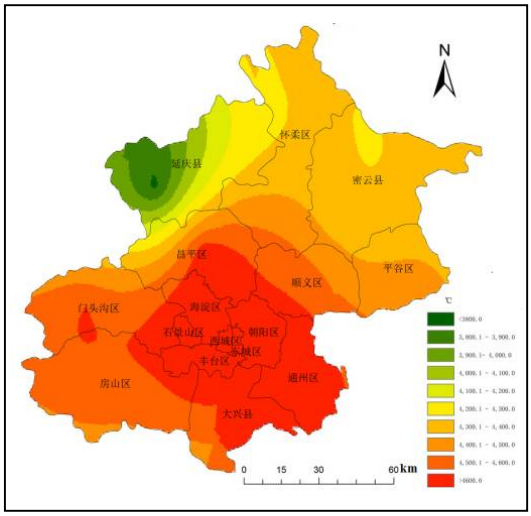

Fig. 3. Distribution of accumulated temperature greater than 10 degrees in Beijing.

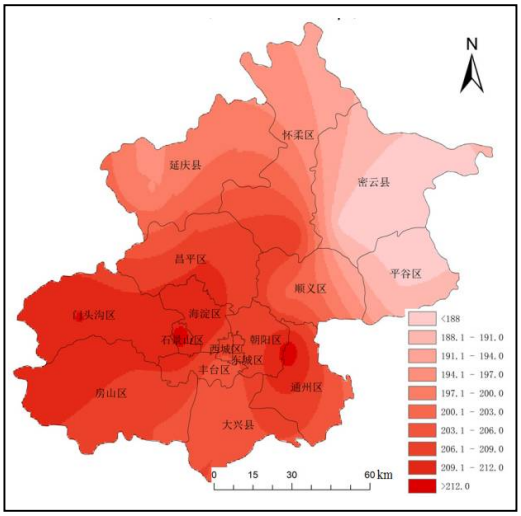

Fig. 4. Distribution of frost-free period in Beijing.

The distribution of precipitation in Beijing is shown in Fig. 6. The difference in precipitation is primarily related to the terrain of the mountains, with precipitation being concentrated on the windward slopes and the leeward slopes receiving significantly less precipitation. The southeastern part of Beijing is a plain with a low elevation and an average annual precipitation of approximately 600 mm. While the mountainous areas of the Yanqing basin, Zhaitang and the Qingshui river valley, and Mentougou are on the leeward slopes subjected to summer monsoons, the average annual precipitation is much reduced and is less than 500 mm. On the other hand, corresponding locations on the windward slopes receive considerably more precipitation. For example, the average annual precipitations in the Badao River region in Huairou, the Manshui River, and Fozizhuang in Fangshan, and Jiangjunguan in Pinggu are all more than 700 mm, among them Badao River region has recorded the highest precipitation of 820 mm.

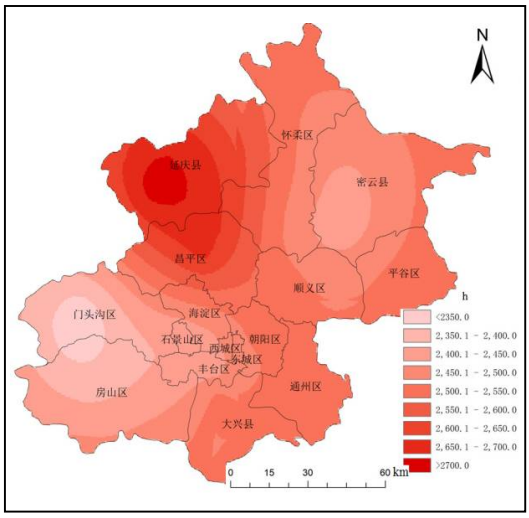

Fig. 5. Distribution of sunshine duration in Beijing.

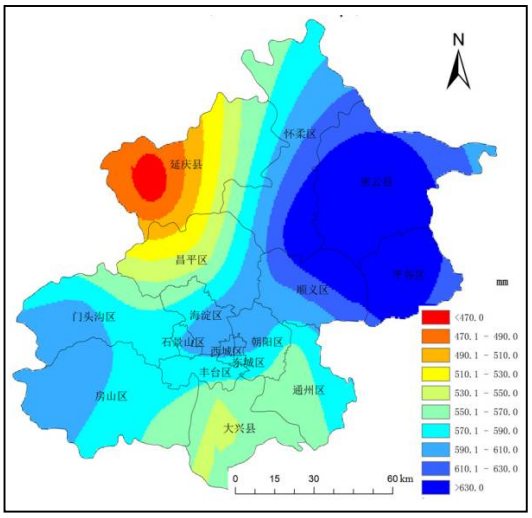

Fig. 6. Distribution of multi-year average rainfall in Beijing.

Chestnut trees can tolerate a wide range of temperatures and precipitation (Huang *et al.* 1998). They thrive best with an average annual temperature of 8 - 12°C; the ideal average temperature during the growing season from April to October is 18 - 20°C. A lowest temperature that is > -24°C in winter, a highest temperature that is ≤ 40°C, and an annual precipitation of 400 - 800 mm are also required. Chestnut is a heliophilous species and therefore, has a high requirement for sunshine; ideally, the annual sunshine duration should be 2000 - 2800 hrs. Chestnut is quite selective regarding the soil texture, preferring soil with good aeration and drainage. The ideal soils for chestnut are deep, sandy loams having a soil pH of 5.5 - 6.5. The soil in Beijing is primarily alkaline, and therefore, most areas are not favorable for the cultivation of chestnut (Guo *et al.* 2004). According to the required climatic conditions and current practices in chestnut production in Beijing, several zonation indicators were selected. Based on which the favorable areas for cultivating chestnut trees for commercial production was determined.

The specific indicators and scoring criteria are listed in Table 1. In addition, the soil pH was assigned a larger weight, with acidic soil scoring 65, moderately-acidic soil 50, mildly acidic soil 30, neutral soil 15, and alkaline soil 0. GIS technology was used to simulate and predict the

meteorological data pertaining to non-station areas to obtain high-resolution weather gridded data. Based on these fine-gridded meteorological data and the zonation indicators, the climate-based planting zonation was determined. Though the span of Beijing is small, there is considerable variation in elevations due to the presence of mountains. A variety of environmental factors are strongly affected by the topographic factors, including elevation, topography, slope, and slope direction. Therefore, in the present simulation, it focused on macroscopic factors such as climate

Table 1. Zonation indicators and scoring criteria for main dried fruits and nuts in Beijing.

Zonation indicator	Criteria	Persimmon score	Chestnut score	Walnut score	Almond-apricot score
Average annual temperature/℃	> = 11	30	25	30	20
	9 ~ 11	20	25	20	20
	7 ~ 8	15	15	15	15
	< 6 ~ 7	5	10	5	5
	< 6	0	0	0	0
Average maximum temperature from June to September/℃	> = 29.5	5	5	5	5
	29.0 ~ 29.5	10	10	10	5
	28.6 ~ 29.0	15	5	15	5
	< = 28.6	0	0	5	0
Frost-free period/d	> = 180	15	10	20	20
	160 ~ 180	10	10	10	15
	140 ~ 160	5	5	5	10
	< = 140	0	0	0	0
Sunshine duration/hr	> = 2,700	20	15	15	30
	2,550 - 2,700	15	10	10	25
	2,400 - 2,550	5	5	5	15
	< = 2,400	0	0	0	0
Elevation/m	> = 500	0	0	0	0
	300 - 500	10	10	10	10
	60 ~ 300	15	15	15	15
	0 ~ 60	5	5	5	5
Slope	> = 20	0	0	0	0
	12 ~ 20	5	5	5	5
	6 ~ 12	15	15	15	15
	0 ~ 6	20	20	15	15
Annual precipitation /mm	> = 650	15	15	20	15
	400 ~ 650	20	15	15	20
	350 ~ 400	15	10	10	15
	< = 350	0	5	0	5

Relevant data are cited from "Beijing Fruit Tree Production Area Planning Survey Report", China Agricultural University, February 2017.

and elevation. Further, GIS technology was used to plot the meteorological factors on a fine-gridded map with a spatial resolution of 100 m × 100 m. Moreover, experts evaluated the results and assigned scores to make the fine zonation maps accurate to the village level. Then, the spatial overlay function in GIS was used to superimpose the raster maps for all the indicators, obtaining the comprehensive climate score raster map. Eventually, the actual distribution of

chestnut plantations in Beijing was considered, and the final comprehensive scores were determined. On the basis of these, Beijing was divided into five zones: the most favorable, favorable, general, unfavorable and most unfavorable zones.

It can be seen from Fig. 7 that the extent of area favorable for chestnut cultivation in Beijing is small. The ideal zone is mainly around Nanbeigou, Huairou and the Miyun Reservoirs. Most of the areas of Beijing are located in the Yanshan settlement belt and are mostly composed of sedimentary rocks with no deterioration, with alkaline soil. In Yanqing - Changping active fault zone, including West Huairou, there are large areas of acid rocks that form acidic soils. In addition to the numerous deep and shallow intrusive rocks, there are large amounts of exposed Archean metamorphic rocks in the Mihuai rising fault zone. The soils so-formed are weakly acidic, and therefore, the best locations for chestnut cultivation in Beijing are concentrated in this zone.

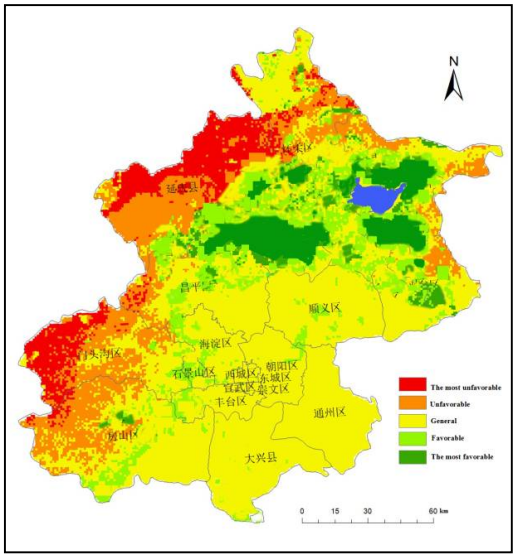

Fig. 7. Distribution of areas favorable for growing chestnut trees in Beijing.

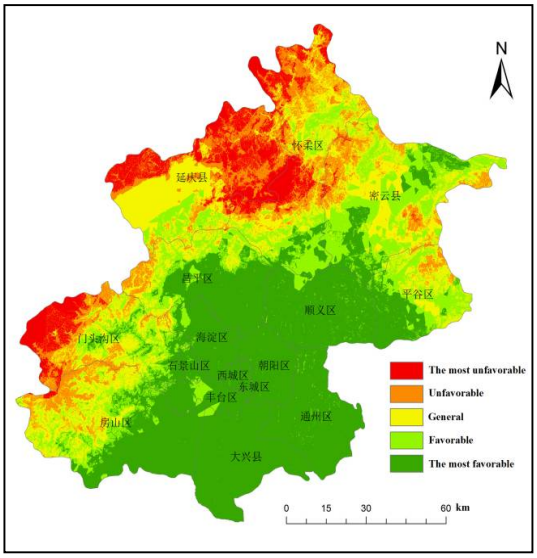

Fig. 8. Distribution of areas favorable for growing walnut trees in Beijing.

Currently, the total area of chestnut plantations in the city has exceeded 40 thousand hectares, accounting for 30% of the city's total area of fruit trees, and is the fruit species with the largest planting area. The chestnut-producing areas of Nanbeigou, Huairou, and the Miyun Reservoir account for 84% of the total area of chestnut plantations in the city. Chestnut production in Beijing is primarily concentrated in the following areas: (1) The Nanbeigou, Huairou area, which is the traditional chestnut producing area in Beijing. It is concentrated in Bohai Town, Jiudu River Town and Qiaozi Town. They have a total area of nearly 14.7 thousand hectares, and together, account for more than 60% of the total yield as well as exports from the city. The main cultivars include the local grafted chestnut Huaihuang and Huaijiu, as well as Yanhong, Yanchang and Yanfeng. (2) Areas surrounding the Miyun Reservoir. The extent of plantation here has reached 20 thousand hectares, which is nearly half of the total area of chestnut cultivation in Beijing. It is mainly distributed among the ten towns located at the east, west and north shores of the Miyun Reservoir, including Bulaotun, Dachengzi, Gaoling and Shicheng. There are 45,000 households planting chestnuts here, accounting for 60% of the fruit farmers in the whole county. The traditional cultivars here include Yanhong, Yanchang, Yinfeng and Yanshanzaofeng. (3) Other scattered

areas. They are mainly distributed in Yanqing, Changping, and Pinggu, with a cultivation area exceeding 6 thousand hectares, accounting for only 15% of the total area of chestnut plantations in the city. The major cultivars are Yanhong, Yanchang, and Yinfeng..

Walnut prefers sunlight and moisture, but not high temperature (Chen *et al.* 1992). It is cold-resistant and requires a warm and humid environment. The appropriate conditions for the optimum growth and development of walnut include an average annual temperature of 11~13°C, an accumulated temperature of > 2,500°C•day before the beginning of September (≥ 10°C); and a frost-free period of >180 days. It has relatively strict requirements of sunlight and moisture. With reduced moisture, the flowering differentiation would be poor, and it will directly impact the yield and quality, while rainy days during the maturity period cause rotten and bitter taste. The ideal annual precipitation for walnut trees is 600 ~ 800 mm.

According to the climate and soil conditions of different regions, the selection of appropriate walnut cultivars and optimization of cultivation operations to ensure proper development and maturing of the crops are necessary prerequisites for profitable production of walnuts. Based on the above points about the climatic and environmental requirements of walnut trees, along with relevant research and field investigation results, the zonation indicators and scoring criteria for walnuts in Beijing were arrived at.

As shown in Fig. 8, there are a lot of areas favorable for walnut plantations in Beijing, mainly because the walnut originated in the north and fits well in the ecological conditions of Beijing. The plains, hills, mountains and valleys of Beijing are the most favorable areas for the plantation of walnut trees. The unfavorable areas are the mountainous areas with high altitudes (Luo *et al*. 2008). It is difficult for walnut trees to thrive in areas in Beijing having an elevation greater than 800 m. Although the most favorable areas for growing walnut are the plains, owing to the strategy of not competing with grain cultivation areas, walnut cultivation in Beijing is mainly limited to the low mountains, hills, piedmonts, and some low-altitude mountainous areas. They can be divided into four producing areas: (1) The eastern low mountainous producing area - the Pinggu area. The main towns include Jinhai Lake (1.8 thousand hectares), Nandule River (1.07 thousand hectares) and Zhenluoying (0.53 thousand hectares). (2) The northern mountainous producing area, North Changping and the low mountainous areas in Huairou. The main towns include Changling Town (1.13 thousand hectares), Liuchun Town (0.87 thousand hectares), Ming Tombs Town (0.33 thousand hectares), and Bohai Town (0.27 thousand hectares). (3) Areas surrounding the Miyun Reservoir, including Bulaotun town and Dongshaoqu town. (4) Th western mountainous producing area. Since this area is mountainous, the dried-fruit and nut producing areas are mainly concentrated in the valleys and low mountain areas. They are generally small-scale and scattered. The main towns include Xiayunling village (0.47 thousand hectares), Tantu temple town (0.27 thousand hectares) and Qingshui town (0.27 thousand hectares).

Persimmon favors a warm climate, an average annual temperature of 9 - 14°C, a maturity temperature of 18-19°C and can tolerate a short period of low temperatures of −18 ~ −20°C (Li *et al*. 2009, Fan *et al*. 1998). It prefers an average annual precipitation of 450 - 650 mm. During the ripening period, persimmon prefers dry and sunny days, with an appropriate temperature. The ideal soil for persimmon is thick, well-drained loam which can maintain considerable humidity and is moderately rich in humus.

In general, Beijing is favored by persimmon trees. Based on the climatic conditions and the actual production of persimmons in Beijing, the zonation indicators were selected. On the basis of these indicators, the planting areas favorable for the cultivation of persimmon trees have been determined. The major ecological factors and scoring criteria that affect the growth and quality of persimmons in Beijing are listed in Table 1. According to the determined comprehensive

evaluation scores, the planting areas were divided into the following five grades sequentially, the most favorable, favorable, general, unfavorable and most unfavorable one. It can be seen from Fig. 9 that the most favorable areas for the persimmon cultivation in Beijing are plain areas, low mountains and hilly areas. However, due to the strong adaptability and low price of persimmon, in the past, it was mainly developed in the low mountains, valleys, and basins, the favorable and general areas.

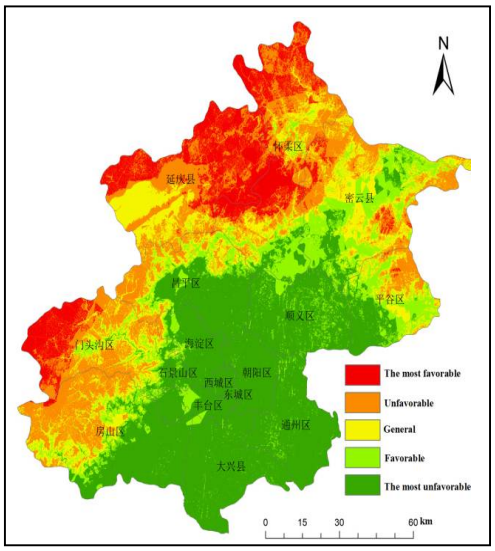

Fig. 9. Distribution of areas favorable for growing persimmon trees in Beijing.

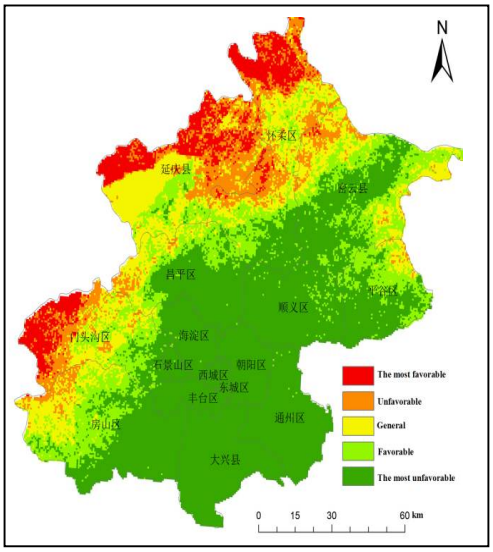

Fig. 10. Distribution of areas favorable for growing almond-apricot trees in Beijing.

Persimmon tree is a traditional fruit tree species in Beijing. Currently, there are 8.9 thousand hectares preserved cultivation area, accounting for 6.5% of the city's fruit trees cultivation areas. The total income is 0.9 billion per year, accounting for 2.1% of all fruit income. However, the current consumers have some misunderstandings regarding persimmon, causing difficulties in its selling and very low price. In the mountains, a lot of persimmon trees are actually in a laissez-faire state, and numerous persimmon trees died. To restore the persimmon industry in the future, the city should pay more attention to the persimmon marketing and new product development, so that consumers may understand the nutritional value of persimmon. The persimmon distribution in Beijing is mainly concentrated in three producing areas: (1) Southwest Beijing persimmon producing areas. These areas are mainly located in the piedmont warm areas of Northwest Beijing, including Zhangfang town, Shidu town, Qinglonghu town, and Fozizhuang, Fangshan, with a cultivation area of 2.7 thousand hectares, accounting for 34% of the total area of persimmon planting in the city. The main cultivar is Mopan persimmon. (2) East Beijing persimmon producing areas. They are primarily located in the low mountains and hills of East Beijing, are basically in the most favorable and favorable zones of persimmon, with a cultivation area of > 3.3 thousand hectares, accounting for 34% of the total area of the city's persimmon cultivation. (3) North Beijing low mountain persimmon producing areas. They are mainly distributed in Changling town, Ming tombs town, and Liuchun town, Changping, with a total area greater than 1.3 thousand hectares. They also fall in zones denoted as most favorable and favorable.

Almond-apricot is an important woody grain and oil resource. Almonds are one of China's traditional native products that gives a high exchange rate, and they can be used to make products like almond oil and almond drinks. The apricot tree has strong adaptability, is cold- and drought-tolerant, and resistant to thin soils. Thus, it can be planted in plains, mountains, or even sandy deserts. The cultivation of almond-apricot trees is helpful in the conservation of soil and water, revive barren hills and slopes, and restore the ecological balance in mountainous areas, generating huge ecological benefits. As a cold-resistant species, the apricot tree can tolerate low temperatures of −25 ~ −30 ℃ during the dormant period (Cheng *et al*. 2001). It tolerates high temperatures too and can grow normally and produce fruits even at temperatures as high as 43.9℃. However, the flowers and young fruits of apricots are very sensitive to low temperatures as temperature as low as −2 ~ −30℃ may freeze flowers while temperatures of 0℃ may cause frostbites to the young fruits. Continuous rain, cold and windy weather can affect the pollination of apricot flowers by insects, causing poor pollination and a sharp drop in yield. Apricot is strongly resistant to drought and can grow normally and produce fruits in areas with an annual rainfall of 300 ~ 600 mm (Li *et al*. 2015). But it is sensitive to moisture. A flood of even three days in an apricot orchard would lead to yellow leaves and dead roots, eventually killing the whole plant. Apricot is a strongly heliophilous species and can only grow and develop well under sufficient sunshine.

According to the above analysis and the actual cultivation pattern of almond-apricot production in Beijing, seven indicators including the average annual temperature were selected as zonation factors, with the corresponding criteria being listed in Table 1. Based on the analysis of results the comprehensive evaluation scores were determined, and the planting areas were divided into five grades as for the previous crops: the most favorable, favorable, general, unfavorable and most unfavorable areas. As shown in Fig. 10, the most favorable areas for almond-apricot in Beijing are mainly distributed in the mid-west piedmont and plain areas, the east plain areas, a small area of the Miyun basin, and part of the Yanqing valley. The vast mountainous areas in Beijing are not suitable for apricot planting due to the low temperatures and thin soil, while low-altitude areas such as the valleys of the Yongding and Dashihe rivers are favorable for apricot planting.

The mountainous areas in Beijing are generally not suited for cultivation due to low temperature and thin soil layers. However, almond-apricot plantations are primarily for dried fruits and nuts, and in accordance with the strategy of developing mountains and beaches, the main cultivation sites are the mountainous areas, most of which fall in the category of favorable and general areas.

Acknowledgements

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