Model for Predicting Climatic Yield of Sugarcane in Nanning City

Zhanggui LAN[1], Guanghai LI[1], Yulian LIANG[1*], Yuhong YANG[1], Xiaoping LI[2]

1. Nanning Municipal Bureau of Meteorology, Nanning 530028, China; 2. Bureau of Meteorology of Yongning District, Nanning 530200, China

Abstract According to spatial distribution of climate disasters in Nanning City and physiological and ecological indicator demands of sugarcane, with the aid of HJ - 1 CCD satellite remote sensing images, basic meteorological data and geographic information data, this paper established the model for predicting climatic yield of sugarcane in Nanning City, to predict total yield of sugarcane in Nanning City. Results indicated that the distribution of sugarcane in Nanning City is greatly influenced by drought. In 2010, regions suffered from drought had sugarcane planting area of 346.20 km², accounting for 18.88% of the total sugarcane planting area. The influence of frost disaster on distribution of sugarcane in Nanning City is limited. Regions suffered from frost had sugarcane planting area of only 67.1 km², taking up 3.75% of the total sugarcane planting area. In 2010, the climatic yield of sugarcane in Nanning City was 8.8446 million tons. It proved that the prediction accuracy of the model is up to 90%.

Key words Sugarcane, Climatic yield, Prediction model

1 Introduction

Guangxi Zhuang Autonomous Region is the largest sugarcane production area in China and also the key region for ensuring supply of sugarcane in China. Nanning City, situated in south of Guangxi, belongs to sub-tropical monsoon climate zone, has rich sub-tropical monsoon climate resources, and is one of major regions of sugarcane planting in Guangxi. Reasonably current situations of local distribution of sugarcane and climatic influence factors and predicting yield of sugarcane will be of great significance for planning supply and demand of sugarcane in China and stabilizing income of sugarcane farmers. Sugarcane growth is closely connected with climate. Climatic conditions are major factors restricting growth cycle of a certain crop. Especially, more than 90% sugarcane of China is planted in dry land, sloping fields and hilly areas without irrigation conditions. Thus, the influence of extreme climate is enormous. The interannual variation yield resulted from climatic factors is called climatic yield. We adopted remote sense monitoring, sampling survey and statistical regression simulation methods to obtain total planting area of sugarcane in the study area. According to remote sense monitoring of sugarcane growth, combining meteorological factor influencing sugarcane growth vigor and development[1-4] and their influence on sugarcane yield and spatial distribution[5], we determined proportion of sugarcane with different growth condition and built model for predicting climatic yield of sugarcane in Nanning City. This model breaks away from simulation of pure historic experience, and uses objective data to increase accuracy rate of prediction. Since the meteorological factors have been incorporated in the trend yield, meteorological yield only needs considering future climatic conditions. This prediction model features convenient data acquisition and low human

resource cost, so it is highly operational.

2 Building model for predicting climatic yield of sugarcane in Nanning City

2.1 Method for extracting distribution of sugarcane planting in Nanning City Using HJ - 1 satellite remote sensing data of 2010, we analyzed spectrum character changes in many sugarcane sample training areas with different growth vigor and terrain, and built the sugarcane remote sensing interpretation model. Through extracting remote sensing data of sugarcane planting area in Nanning City, we obtained distribution of sugarcane planting area of Nanning City in 2010[6].

2.2 Model for predicting climatic yield of sugarcane Through remote sense monitoring, we obtained total planting area of sugarcane in the study area, and determined proportion of sugarcane with different growth vigor according to remote sense monitoring results. Through sampling survey, we obtained situations of levels of sugarcane growth, including effective stems, plant height, stalk cross-sectional area, stalk length, specific gravity factor, and single stalk weight, as well practical data about plant diseases and insect pests, droughts, and frost damage. We used data obtained from remote sense monitoring and sampling survey to predict the trend yield of study area by the prediction model. Getting rid of traditional model that considers pure historic experience, this model incorporates influence of meteorological disasters on the yield, and uses current objective data, so it increases rate of prediction accuracy. The prediction model for total climatic yield of raw sugarcane is as follows:

$$Y_w = S_{sum} \times y_{ideal} \times \prod_{i=1}^{n} D_i \times \quad (1)$$

where Y_w signifies total yield of raw material, y_ideal refers to per unit area yield of sugarcane in ideal meteorological condition, S_{sum} is planting area of sugarcane, D_i stands for the rate of sugarcane growing to ideal state in certain meteorological disaster, and n is the type of meteorological disaster included in the calculation.

The per unit area yield is calculated by following formula:

y_i = Number of effective stems per unit area × Single stalk weight (2)

Single stalk weight (kg) = Stalk cross − sectional area (cm^2) × Stalk length (cm) × Specific gravity factor K

K = 0.785 − 0.835(g/cm^3) (3)

Through sampling measurement of sugarcane, we selected five 20 m × 20 m good, medium and bad sample lands respectively, surveyed number of sugarcane plants, plant height, stalk diameter and stalk length, established the regression equation, and reserved 10% as regression verification data. We obtained the equation of per unit area yield of raw sugarcanes in good, medium and bad lands (listed in Table 1), and took the equation for per unit area yield of sugarcane with good growth vigor as the equation for per unit area yield of sugarcane in ideal meteorological condition (*i. e.* y_{ideal} = y1):

Table 1 Equation for per unit area yield of raw sugarcane in different growth vigor

Growth vigor of sugarcane	Equation for per unit area yield//kg/m^2	Regression coefficient
Good	y_1 = 5.95 × 1.258 × 0.835	0.912
Medium	y_2 = 5.55 × 1.196 × 0.805	0.951
Bad	y_3 = 6.90 × 0.882 × 0.785	0.896

The value of D_i is determined according to seriousness of meteorological disaster and its influencing area:

$$D_i = \frac{\sum_{i=1}^{3} S_i y_i}{S_{sum} y_{ideal}}$$ (4)

where S_j signifies sugarcane planting area under light, medium and serious influence of meteorological disaster, y_i refers to the per unit area equation corresponding to the disaster level, namely, the per unit area equation of sugarcane with good growth vigor.

2.3 Determination of sugarcane distribution area at different levels of meteorological disasters Water and heat conditions are the most important meteorological factors restricting plant growth, and drought and frost are major meteorological disasters influencing growth and development of sugarcane in Nanning City[7]. In this study, we incorporated these two meteorological disasters into calculation.

For drought data, we adopted continuous days without available precipitation (daily precipitation Pr <3mm), and took continuous drought days Dr ⩾10 d as a drought process. For the sequence composed of data of continuous drought days from 146 automatic stations and 9 national standard meteorological stations in 2006 − 2010, we calculated the critical drought days of the 98 − th, the 95 − th, the 90 − th, the 80 − th and the 60 − th percentile of this sequence by the percentile method (listed in Table 2). According to different percentiles, we classified the drought into 5 categories. On the principle of higher level of drought leading to more seriousness of drought disasters, we determined weight of each drought category by the analytic hierarchy process (AHP). According to critical drought index preliminarily determined for

each category, we counted times of droughts in each station separately. Then, multiplying the weight of respective category, we obtained the drought value of each station.

Table 2 Critical value and weight of critical drought days

Level of critical drought	5	4	3	2	1
Percentile interval//%	⩾98	95 − 98	90 − 95	80 − 90	60 − 80
Days of critical drought	77	61	51	34	22
Weight of level of critical drought disaster	5/15	4/15	3/15	2/15	1/15

$$\overline{Dr_i} = \sum_{j=1}^{5} A_j B_j$$ (5)

where $\overline{Dr_i}$ is the drought value of each station, A_j is weight of each level drought, and B_j is times of droughts of the respective level. After obtaining the drought value, in ArcGIS, we interpolated the drought value of each station to the domain level of entire Nanning City with 1 km × 1 km cell. Then, using the natural breakpoint method inbuilt in ArcGIS, we divided values of each cell into light, medium and severe levels, and then it is able to obtain spatial distribution of drought categories in Nanning City. Finally, we conducted superposition analysis on sugarcane distribution and drought category distribution extracted from remote sensing images, and extracted sugarcane planting area under influence of each drought category (shown in the left of Fig. 1).

Similarly, we adopted extreme minimum temperature $T_{min} < 4$ ℃ of each station to form extreme minimum temperature sequence, and calculated the critical disaster minimum temperature of the 98 − th, the 95 − th, the 90 − th, the 80 − th and the 60 − th percentile of this sequence by the percentile method (Table 3). According to critical drought index preliminarily determined for each category, we counted times of frosts in each station separately, and finally obtained frost value of each station. In ArcGIS, combining remote sensing distribution map of sugarcane planting area, we obtained distribution results of sugarcane planting area suffered from light, medium and serious frost.

$$\overline{Fr_i} = \sum_{j=1}^{5} A_j B_j$$ (6)

where $\overline{Fr_i}$ is the frost value of each station, A_j is weight of each level frost, and B_j is times of frosts of the respective level.

Table 3 Critical value and weight of frost disaster

Level of critical drought	5	4	3	2	1
Percentile interval//%	⩾98	95 − 98	90 − 95	80 − 90	60 − 80
The critical minimum temperature of frost disaster (4 ℃)	− 0.2	0.0	0.3	2.1	4
Weight of level of critical frost disaster	5/15	4/15	3/15	2/15	1/15

The calculated Dr and Fr values are normal average annual climatic values. To predict climatic yield of sugarcane in a certain yield, we should determine the difference between temperature and precipitation of current year and average annual value. This difference can be described by the anomaly of annual precipitation

and average minimum temperature of current year:

$$D_{dr} = \overline{Dr_i} \times (1 - \frac{Pr_x - \overline{Pr}}{\overline{Pr}}) \tag{7}$$

$$D_{fr} = \overline{Df_i} \times (1 + \frac{T_{min} - \overline{T_{min}}}{\overline{T_{min}}}) \tag{8}$$

where D_{dr} and D_{fr} signify drought influence index and frost influence index of a certain year, $\overline{Dr_i}$ and $\overline{Df_i}$ are normal climatic values of drought influence index and frost influence index. Pr_x and T_{minx} are the annual precipitation and average annual minimum temperature of this year, while $\overline{Pr}$ and $\overline{T_{min}}$ are average values of annual precipitation and average annual minimum temperature.

3 Prediction results of climatic yield of sugarcane in Nanning City

3.1 Spatial distribution of sugarcane planting and meteorological disasters
The distribution of sugarcanes is not only restricted by meteorological conditions, but also influenced by regional terrain and other non-natural factors. Through superposition analysis on total sugarcane planting area of Nanning City obtained from remote sensing classification and the sugarcane distribution (Table 4) determined by equations (5) and (6), we obtained superposition analysis results of sugarcane distribution and meteorological disasters in annual normal state of climate (Fig. 1). From the distribution of entire sugarcane planting areas, it can be known that sugarcane planting of Nanning City is mainly centralized in Binyang County, Wuming County, Heng County, Yongning District and Jiangnan District, while in Shanglin County, Mashan

County and Long'an County, there is little sugarcane planting. From the distribution of drought disasters (the left of Fig. 1), it can be seen that serious droughts occur mainly in Jiangnan District, Xixiangtang District, Xingning District, Qingxiu District, Long'an County and Heng County. Except Jiangnan District having large area of sugarcane planting, other areas have little sugarcane planting. In regions suffered from serious drought, the total sugarcane planting area is 346.20 km², accounting for 18.88% of total sugarcane area; most sugarcane areas of Wuming County, Heng County and Yongning District are situated in medium drought areas, and this level of sugarcane planting area takes up 55.76% of total sugarcane planting area. In Binyang and Shanglin counties, due to sufficient river irrigation and rich rainfall, sugarcane areas are situated in light drought areas and the sugarcane area influenced by light droughts takes up 25.36% of the total sugarcane area. From distribution of frost disaster (the right of Fig. 2), it can be seen that most regions of Nanning City are situated to the south of Tropic of Cancer, so the frequency and influence of extreme minimum temperature are local; apart from Daming Mountain area situated in serious frost disaster area due to high elevation and low temperature, some sugarcane areas of Binyang County also suffer from serious frost. In Heng County and Qingxiu District, there are also serious frosts, but they are not main sugarcane planting areas, thus the influence on sugarcane planting is small, only 67.1 km² sugarcane planting area is influenced by serious frost, accounting for 3.75% of total sugarcane planting area; most areas of the rest are slightly influenced by light frost disasters.
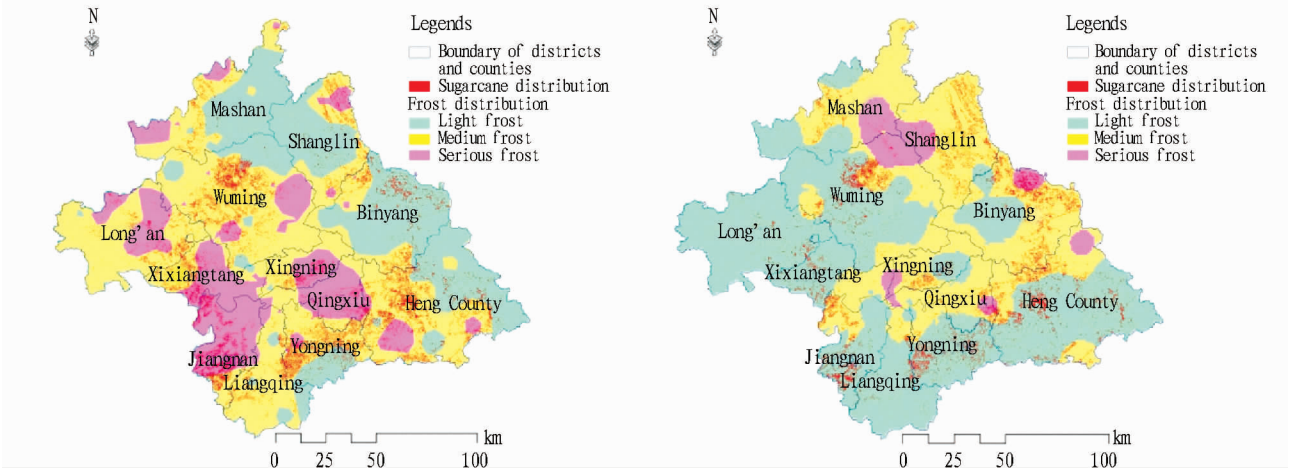

Fig. 1 Drought (left) and frost (right) distribution and sugarcane distribution in Nanning City

Table 4 Distribution of sugarcane planting in Nanning City

Sugarcane planting area // km²	Light	Medium	Serious	Total
Drought	453.22	978.04	356.20	1 787.46
Frost	1 055.1	575.26	67.1	

3.2 Prediction results and verification of climatic yield of sugarcane
Substituting sugarcane areas influenced by various meteorological disasters to equation (2) and equation (4), we

can obtain the value Di of drought and frost in normal climate is 0.82 and 0.94 respectively. Using average value of the minimum temperature and precipitation in 9 standard meteorological stations of Nanning City, we calculated the anomaly of precipitation and minimum temperature between 2010 and 2006 – 2010. According to equation (7) and (8), the Di value of drought and frost in 2010 is 0.87 and 0.91 separately. Finally, substituting Di to equation (1), we finally obtained the climatic yield of sugarcane of Nanning City in 2010 was 8.8446 million tons. In the study ar-

ea, we selected sugarcane areas of Nanning Sugar Industry Company and compared the actual yield data in 2010/2011 season without prediction value, and found that the prediction accuracy is up to 90.2%. This indicates that our prediction model for climatic yield can reach the prediction accuracy above 90%.

4　Conclusions

The prediction model of climatic yield of sugarcane is based on superposition and analysis of spatial distribution of climatic disasters and distribution of sugarcane planting areas. For the sugarcane yield of a certain year, it is feasible to make prediction according to current climatic prediction data provided by the meteorological authority and sugarcane growth vigor. Therefore, it is recommended to properly arrange grinding season according to distribution of rainfall in the same year, to facilitate increasing sugar content in the grinding season. Besides, it should make proper arrangement of sugarcane harvesting and transport works. For areas vulnerable to frost disasters annually, it is proposed to give priority to harvesting and transport, so as to reduce losses due to frost disasters. Finally, sugarcane farmers should make proper adjustment of sugarcane harvesting, transport and grinding season according to actual

growth of sugarcane and prediction results of the yield.

References

[1] CHEN H, LIN TZ. Relationship between seasonal yield of sugacane colony growth and meteorological factors[J]. Sugarcane, 1994(4): 12 –15. (in Chinese).

[2] HE Y, TAN ZK, DING MH, *et al.* Study on key meteorological factors restricting Guangxi sugarcane yields and sucrose content[J]. Journal of Anhui Agricultural Sciences, 2008, 36(8): 3181 –3184. (in Chinese).

[3] JIANG JS, XIE GS, LIN LF, *et al.* Relationship between meteorological factors and sugarcane growth and the establishment of its prediction model [J]. Sugarcane, 1991(4): 1 –5. (in Chinese).

[4] OU ZR, TAN ZK, MO XH, *et al.* Study on the climate condition of sugarcane yield in Guangdong[J]. Sugar Crops of China, 2008(4): 45 –47, 51. (in Chinese).

[5] SU YX, LI Z, SUN H. Climate division of sugarcane planting based on GIS in Guangxi[J]. Chinese Journal of Agrometeorology, 2006, 27(3): 252 –255. (in Chinese).

[6] DING MH, TAN ZK, LI H, *et al.* Survey methods of sugarcane plant area based on HJ-1 CCD data[J]. Chinese Journal of Agrometeorology, 2012, 33 (2): 265 –270. (in Chinese).

[7] TAN ZK, OU ZR, HE Y. Analysis of the major meteorological calamity and the research on optimum layout of cane sugar production in Guangxi[J]. Sugarcane and Canesugar, 2006(1): 17 –21, 33. (in Chinese).

cultivation systems. At the same time, using LCA method, we evaluate the impact of various cultivation systems on environment. The results show that in terms of input-output ratio, the direct seeding cultivation of beet is superior to transplant cultivation, and the load of direct seeding cultivation on environment tends to decline.

References

[1] Hokkaido Sugar Beet Association. Sugar beet yearbook[M]. Sapporo: Nikosha Co., Ltd., 2005: 9.

[2] Agriculture & Livestock Industries Corporation[J]. Sugar Information, 2006 (17): 1 –20, 56 –64.

[3] Bassam N. Energy plant species[M]. Sapporo: Nikosha Co., Ltd,. 1998: 81 –84.

[4] Ogata N, Tanaka M. Possibility of breeding sugar and fodder beets for ethanol production[J]. Proceedings of the Japanese Society of Sugar Beet Technology, 1998(40): 41 –49.

[5] Tomioka E. Hokkaido soil[M]. Sapporo: Nikosha Co., Ltd., 1985: 33.

[6] Hokkaido. Association of Japanese Society of Soil Science and Plant Nutrition. Hokkaido agriculture & soil and fertilizer[M]. Sapporo: Nikosha Co., Ltd., 1999: 342.

[7] Hokkaido. Prefectural Tokachi Agricultural Experiment Station, Improvement of technology for direct planting of sugar beets[M]. Sapporo: Nikosha Co., Ltd., 2003: 27.

[8] Social Organizations, Journal of the Japan Institute of Energy(Editor). Biomass handbook[M]. Marvelous AQL, 2005: 2 –6, 369.

[9] NANZHAI GJ, SENKOU YY, DONG YD. On endangered species considering environmental loads[M]. Marvelous AQL, 2002: 80 –91.

[10] Koga N, Tsuruta H, Tsuji H, *et al.* Fuel consumption-derived CO_2 emissions under conventional and reduced tillage cropping systems in Northern Japan[J]. Agriculture Ecosystems & Environment, 2005(99): 213 –219.

[11] Nakatsu S, Higashida S. Effects of minimum tillage on upland soil and crop yields[J]. Hokunou, 2006, 73(2): 134 –141.

[12] Hokkaido. Government Agriculture Department, Agricultural Working Integration in Hokkaido II(in Japanese)[M]. Sapporo: Nikosha Co., Ltd, 2000: 48 –51, 76, 387 –393.

[13] Koga N. Use of LCA for assessing environmental impacts of arable crop production in the Tokachi Region of Hokkaido[J]. Hokunou, 2004, 71 (1): 8 –16.

[14] Nansai K, Moriguchi Y, Tohno S. Embodied energy and emission intensity data for Japan using input-output tables (3EID)[M]. Inventory Data for LCA. National Institute for Environmental Studies, Japan, 2002.

[15] Society of Hokkaido Agricultural Machine Industry. An agricultural machinery designated sales price list[M]. Sapporo: Nikosha Co., Ltd., 2005: 30 –33.

[16] Okamura T. The basics of agriculture mechanization[M]. Sapporo: Nikosha Co., Ltd., 1991: 353 –379.

[17] Hakoyama S, Katagi I, Kawaguchi K, *et al.* Effect of amino N and sodium in sugar beet root biomass on conversion of sugar into alcohol[J]. Proceedings of the Japanese Society of Sugar Beet Technology, 1993(35): 110 –116.

[18] Ogata N, Tanaka M. Evaluation of ethanol conversion efficiency of *B. vulgaris* L. in an anaerobic fermentor[J]. Proceedings of Hokkaido Crop Breeding Society, Biomass and Bioenergy, 1997(38): 86 –87.

[19] Venturi P, Venturi G. Analysis of energy comparison for crops in European agricultural systems[J]. Biomass and Bioenergy, 2003(25): 235 –255.