THE STATISTICAL ANALYSIS OF ARTIFICIAL SNOW AUGMENTATION EFFECT ON FREEZE INJURY OF THE WINTER WHEAT

Jia Zhaomao[a] and Gao Ziyi[b]

[a] Weather Modification Office of Kuitun Co. of Xinjiang Production And Construction Group Co., Kuitun, Xinjiang 833200, China

[b]Xinjiang Meteorological Bureau, Urumqi, Xinjiang 830002, China

Abstract. Since 1978, artificial snow augmentation by aircraft silver iodide seeding to the winter stratiform clouds, have been conducted continuously along Tianshan mountains in northern Xinjiang, China. The freeze injury comparison of the winter wheat was made between the 18-unseeded years and 17-seeded years. The result has showed that the average annual freeze injury area has been decreased over 80% during seeding period in the present study. Three main factors affected wheat freeze injury which include wheat seed improvement and wintertide temperature increase as well as artificial snow augmentation have been analysised. The obtained results suggest that the cloud seeding is a primary factor. Its main effect on freeze injury of winter wheat were found to be that, during critical period of December for wheat through winter, the snow cover depth was increased 2.2 centimeters and the first day of stable snow cover of five centimeters was advanced 5-7days.

1. INTRODUCTION

Since wintertide 1978, an operational winter snowpack augmentation program was conducted continuously along the northern foot of Tianshan Mountain that is a major wheat-growing area in Xinjiang, China. The target area is nearly parallel to Tiansan mountains oriented west-east. The extensive measurements of the cloud and the precipitation, which included aircraft, radar, radiosonde and ground-based precipitation physics observations, have been done simultaneously. The operational goal was to increase ground snow depth to protect the winter wheat through winter. Seeding operations focus on winter stratiform clouds, generally from the beginning of November through the beginning of January(60-70 days). The seeding project included the treatment of all suitable synoptic systems with no randomization. Some 7-15 seeding missions every year have been conducted, and they account for approximately 1/2-2/3 of all snow events. Main seeding mode was to use one aircraft fitted E-16 airborn AgI generator made in the United States. Airbore generator delivered silver iodide at rate of approximately 154 grams per hour from each of two silver iodide-potassium iodide solution burners. One individual seeding mission lasted 2-3 hours and AgI of 500-800 grams was dispersed typically. The crystal forming effectiveness is up to 10^{15} per gram AgI at -10℃ temperature.

The cloud physics studies have shown that the organnized winter cloud systems, which are responsible for most of the precipitation in northern Xinjiang during the winter, almost always form under the synoptic situations of the upper-level low pressure control and the surface cold front passage, and have quite offen a multi-level strcture consisted of 2-3 cloud levels. The precipitation elements in the cloud system grow mainly within the boundary layer below 1500 metres above sea level, the precipitation from the regions of the cloud above 3000 metres only account for approximately 5-30% of the total the precipitation. Hence, cloud seeding operations were undertaken on top of low-level cloud where the cloud temperatures are mostly warmer than -20^0C .

In the present paper, Kuitun Co. of Xinjiang Production and Construction Group Co., that is located at the centre of cloud seeding area, is selected for the effect evalution (see Fig.1). Its area was about 2000 Km^2, the winter wheat of around 13500 hectares was seeded yearly in this region. Three main factors affected wheat freeze injury which include wheat seed improvement and wintertide temperature increase as well as artificial snow augmentation, have been analysised. The results shown that cloud seeding is a major factor.

2. STATISTICAL ANALYSIS OF FREEZE INJURY AREA DECREASE OF WINTER WHEAT

A comparative analysis for the wheat freeze injury between 18-unseeding years (from 1960 to 1977) and 17-seeding years (from 1978 to 1994) was done. Before cloud seeding, cumulative and annual mean freezed areas were 539000 hectares and 3000 hectares respectively, that account for approximately 22.2% of total seed area. However, after cloud seeding, cumulative and annual mean freezed areas were 6500 hectares and 380 hectares respectively which only account for

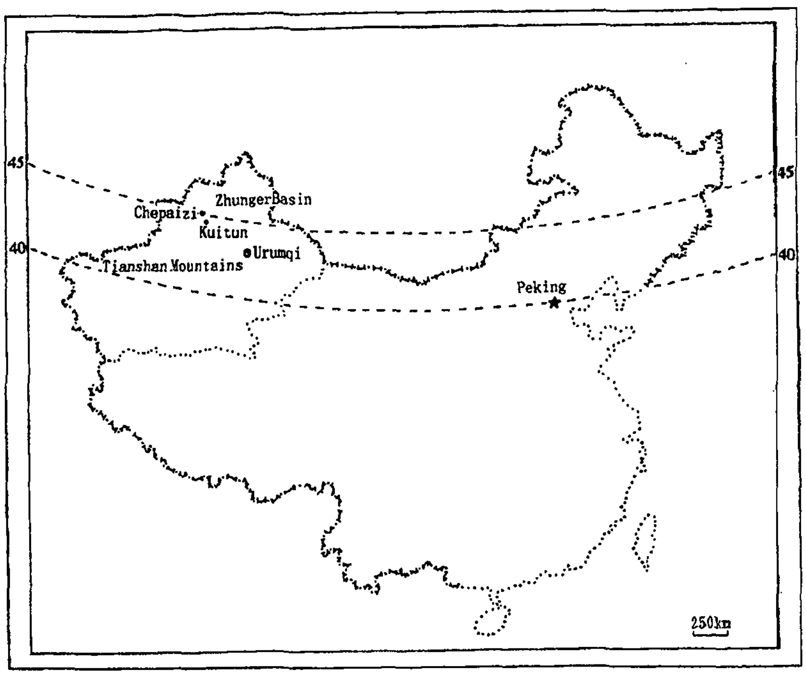

Fig.1. Map of snow augmentation experiment area

approximately 2.5% of total seed area. The decrease of freezed area was 88.7%. Using rank-sum test (W-M-W test), statistical significance of percentage freezed area decrease was estimated. It is showed that freezed area has been decreased significantly during cloud seeding period, with an attendant statistical significance of better than 0.0005.

3. STATISTICAL ANALYSIS OF TEMPERATURE CHANGE

Two meteorological stations, namely Kuitun and Chepaizi, were selected to analyse the temperature change during the wintertide. The Kuitun is situated in middle freezed region of the winter wheat, and the Chepaizi is situated in heavy freezed region. Table 1 and Table 2 summarize the results obtained from Historical Serial Test (T-test) for two sites respectively. The results shown that in Kuitun station the temperatures were increase significantly in December and January, among them monthly mean temperature increased values were 2.1℃ and 2.0℃ respectively. However, in Chepaizi except monthly mean temperature was increase significantly in January (increased value was 1.3℃), the temperature changes (increased or decreased) were not significant during other two months.

Table 1. The statistical test of the temperature change in Kuitun(℃)

Item	Monthly average	Monthly average minimum	Monthly Extreme minimum
Month	11 12 1	11 12 1	11 12 1
Historical average μ_0	-2.3 -12.4 -16.5	-5.9 -16.3 -21.6	-14.3 -26.5 -28.5
Seeding average X	-1.5 -10.3 -14.5	-4.1 -13.1 -18.8	-14.3 -21.9 -26.3
$X-\mu_0$	0.8 2.1 2.0	1.8 3.2 2.8	0.0 4.6 2.2
Standard deviation S	2.79 4.28 1.96	4.14 4.69 2.19	 5.12 2.88
$t=(X-\mu_0)*n\text{^}0.5/s$	2.182 2.023 4.082	1.793 2.813 5.114	 3.704 3.056
Whether significant	No Yes Yes	Yes Yes Yes	 Yes Yes
Significance level	 0.025 0.0005	0.05 0.005 0.0005	 0.001 0.0005

Note: One side test, taking significance level $\alpha=0.05$

Table 2. The statistical test of the temperature change in Chepaizi(℃)

Item	Monthly average	Monthly average minimum	Monthly Extreme minimum
Month	11 12 1	11 12 1	11 12 1
Historical average μ_0	-2.8 -13.3 -18.2	-6.6 -17.0 -22.0	-15.6 -27.7 -30.2
Seeding average X	-3.1 -11.9 -16.9	-6.5 -15.6 -21.0	-16.0 -25.2 -30.0
$X-\mu_0$	-0.3 1.4 1.3	0.1 1.4 1.0	-0.4 2.5 0.2
Standard deviation S	3.27 4.47 2.53	2.65 5.29 2.73	7.10 6.19 3.39
$t=(X-\mu_0)*n\text{^}0.5/s$	-0.378 1.291 2.055	0.155 1.091 1.465	-0.232 1.665 0.236
Whether significant	No No Yes	No No No	No No No
Significance level	 0.025		

Note: One side test, taking significance level $\alpha=0.0$

4. STATISTICAL ANALYSIS OF SNOW COVER DEPTH CHANGE

The snow depth changes based on T-test were shown below in Table 3 and 4 for Kuitun and Chepaizi respectively. From Table 3, we can find that during critical period of December for wheat through winter ground snow depths were increased significantly in Kuitun, average and maximum as well as minimum all were 2.2cm. In Chepaizi (see Table 4), though average snow depth of December did not change, but maximum and minimum snow depths were increased significantly , and they account up to 2.7cm and 1.7cm respectively.

According to the studies on freeze injury of winter wheat, if 5-cm stable snow cover can be formed in December, winter wheat safely lives through the wintertide under the lower temperatures ranging from -24 ℃ to -30 ℃. Therefore, the first days of 5 -cm stable snow over before and after cloud seeding were analysed. The results indicated that during seeding period from 1978 to 1994, mean first days were advanced by 9-days and 5-days in Kuitun and Chepaizi respectively.The correlation anylyses of historical data from 1960/61 to 1977/78 shown that, the relationship between temperature and freeze injury did not existed(correlation coefficient was only 0.0741). The relationship between temperature and snow cover also very pool (correation coefficient was only 0.0667), namely warmer winters did not corresponded with more snow. However high inverse correlation between snow cover and freeze injury was found, correation coefficient achieved to –7.791, with a statistical significance at better than 0.001. This led to the conclusion that snow

Table3. The statistical test of the snow depth change in Kuitun(cm)

Item	Monthly average	Monthly maximum	Monthly minimum
Month	11 12 1	11 12 1	11 12 1
Historical average μ_0	0.8 4.8 11.2	3.9 8.4 13.6	1.5 1.8 8.3
Seeding average X	0.4 7.0 11.4	4.1 10.6 15.4	0.3 4.0 7.6
$X-\mu_0$	-0.4 2.2 0.2	0.2 2.2 1.8	-1.2 2.2 -0.7
Standard deviation S	1.06 4.11 4.11	6.18 4.91 5.77	0.99 3.46 3.16
$t=(X-\mu_0)*n\hat{}0.5/s$	-1.400 2.207 0.195	0.133 1.847 1.248	-5.039 2.622 -0.886
Whether significant	No Yes No	No Yes No	Yes Yes No
Significance level	0.025	0.05	0.0005 0.001

Note: One side test, taking significance level α =0.05

Table4. The statistical test of the snow depth change in Chepaizi(cm)

Item	Monthly average	Monthly maximum	Monthly minimum
Month	11 12 1	11 12 1	11 12 1
Historical average μ_0	1.2 5.2 10.4	2.1 8.8 14.6	0.8 1.6 6.6
Seeding average X	1.3 5.2 12.2	4.3 11.5 17.1	0.9 3.3 9.4
$X-\mu_0$	0.1 0.0 1.8	2.2 2.7 2.5	0.1 1.7 2.8
Standard deviation S	1.68 1.208	5.03 6.73 7.96	1.41 3.82 6.90
$t=(X-\mu_0)*n\hat{}0.5/s$	0.245	1.803 1.654 1.256	0.292 1.835 1.623
Whether significant	No No	Yes Yes No	No Yes No
Significance level		0.05 0.05	0.05

Note: One side test, taking significance level α =0.05

cover has more important effect than temperature on freeze injury. The snow cover was increased only in December because stable snow cover had not been formed in November under the warmer surface temoerature, and there was not cloud seeding or had few operations in January.

5. ANALYSIS OF WINTER WHEAT SEEDS CHANGE

The winter wheat seeds have been divided into such three categories as strong, middle and weak based on the cold resistance of the varieties. Before and after cloud seeding, Kuitun Co. all have adopted seeds with strong or middle cold resistances that can bear the temperatures lower than -17℃.Hence, the change of winter wheat seed has not important effect on freezed area decrease.

6. CONCLUSIONS

Some of the conclusions that can be drawn from above analyses include:

1) During cloud seeding period, average annual freeze injury area of winter wheat has been decreased over 80%, with a statistical significance of better than 0.0005.

2) During cloud seeding period, temperature increased significantly in middle freezed region, average increased values were 2.1℃ and 2.0℃ in December and January respectively. However, in heavy freezed region except average temperature increase was significant (1.3 ℃) in January, the temperature changes of November and December have not significant.

3) After cloud seeding, ground snow depths were increased significantly during critical period of December for the wheat through winter, ranging from 1.7cm to 2.7cm. At same time, the first days of 5-cm stable snow cover were advanced by 5-9days.

4) The change of winter wheat seed has not important effect on freezed area decrase.

5) Among the factors that caused considerable decrease in freezed area of winter wheat, artificial snow augmentation has more important effect than temperature increase of winterwide.

6) However, this does not suggest that the changes in snow cover was attributed entirely cloud seeding, and partly was due to natural increase in winter precipitation which occured in Xinjiang area since 1980s.

7. REFERENCES

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