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Original scientific paper

Effects of Straw Mulching on Soil Temperature and Maize Growth in Northeast China

Shaodong LIU, Shujuan YI*, Yongcai MA

Abstract: In China, corn is growing in large quantities, and a large amount of straw is produced each year. Improper straw treatment may cause environmental problems. Covering the fields after straw crushing can prevent soil erosion and increase soil fertility, which has become a recommended method of straw treatment. The effects of straw mulching on soil water content, soil temperature and maize growth traits were analyzed through comparative experiments. The results showed that straw mulching had heat insulation effect. In May and June, when the average temperature was low, straw mulching kept the ground temperature at a low value, resulting in late emergence of crops and poor growth in the nutritional stage. In July and August when the temperature is higher, the higher ground temperature is maintained, which makes the crop grow better in reproductive growth stage and yield higher. In addition, straw mulching makes the soil water content higher and has a positive effect on Maize Cultivation in northeastern China for Rain-fed agriculture.

Keywords: ground temperature; soil moisture content; straw returning; yield

1 INTRODUCTION

In China, the planting area and yield of corn are in the first place [1]. Straw is the main by-product of corn planting. A large amount of corn straw is produced in China every year. It is estimated that the annual output of corn straw in China is 240 million tons [2]. Straw is the biological transformation product of a large number of water, fertilizer, light, gas, heat and other resources. About 50% of agricultural input factors are converted into crop straw, but only 10% of straw in China returns to farmland, and 21% of straw is discarded and burned [3]. This is a serious waste of resources, which will cause environmental pollution problems such as haze and smoke. Straw returning is an effective way to solve this problem. The practical experience in the United States and Europe shows that straw mulching can effectively reduce wind and water erosion and soil erosion [4]. Straw is the biotransformation of water, fertilizer, air and heat resources in the process of crop growth, which is rich in carbon, nitrogen, phosphorus, potassium and all kinds of trace elements. After returning to the field for decomposition, it is beneficial to achieve the balance of soil nutrients, improve the soil structure and fertility, and realize the sustainable development of agriculture [5].

Northeast China is the suitable planting area and the largest main production area of corn in China [6]. Corn planting area accounts for more than 30% of the total corn planting area in China, and spring corn production accounts for 29% of the total corn production in China [7]. This area is located in the high latitude area, which mainly belongs to the temperate monsoon climate. It is cold and long in winter, warm and short in summer. The area is dominated by black soil with fertile soil. In the long-term agricultural production, the region has formed a relatively fixed corn planting mode. Due to the unclear understanding of straw decomposition law under cold and dry natural conditions, straw returning has not formed a unified way. It is a key technology to popularize in Northeast China that straw is crushed and directly returned to the field to achieve the purpose of water storage and soil moisture conservation, increase of surface accumulated temperature and soil fertility [8]. The main method is to smash and throw the straw into the field during the corn harvest, and bury it in the ground when plowing [9]. The results show that the method has higher requirements for the degree of straw fragmentation and the depth of turnover [10]. As a response to soil, erosion in Northeast China, straw mulching is being advocated [11]. In this paper, based on the climate and soil conditions of Northeast China, the effects of straw mulching on soil moisture, soil temperature and corn growth characteristics are analyzed, which will help to explore a reasonable way of straw mulching in this area.

2 TEST CONDITIONS AND METHODS

2.1 Test Conditions

The test was carried out from May to October 2019. The test field is located in Zhaozhou County, Daqing City, Heilongjiang Province, China. Longitude: 125.08 latitude: 45.52, the effective accumulated temperature of the year in this area is 2950 °C, the rainfall is 258 mm. The trial maize variety was Heyu 89, which was sown in May and harvested in October. There was no irrigation measure during this period, and the water demand of crops was realized by precipitation. The area of the experimental field is 1800 m^2, of which 900 m^2 of straw mulch is returned to the field. As the experimental group (marked as EG), 900 m^2 of conventional planting is used as the control group (marked as CG), and the experimental group and the control group are adjacent. In October 2018, after the corn harvest of the EG plot was completed, the straw was thrown back to the field in full amount, with a length of about 8 cm and a return amount of 6000 kg/ha. The stubble height was 10 cm, and the depth of subsoiling was 35 cm. In the CG, the surface straw was cleared after harvest, and the cultivation method was the same as that of the EG. The cultivated layer soil of 0 - 30 cm depth was excavated and the soil quality was tested as follows: organic matter content was 21.4 g/kg, alkali hydrolyzed nitrogen content was 290.3 mg/kg, available phosphorus content was 17.4 mg/kg, available potassium content was 255.4 mg/kg, and pH value was 7.21.

2.2 Test Instruments

Oven (model: y-hx, Suzhou Taiyu oven equipment Co., Ltd.), electronic scale (model: gh-9018, Guangzhou guangheng electronic scale Co., Ltd.), geothermometer (model: hy-01, Wuqiang County Ocean instrument factory).

2.3 Test Items and Methods

Soil moisture content. At 8 o'clock every day, the soil at 10 cm is taken from three measuring points, and the soil moisture content is measured by drying method, and the average value is taken as the soil moisture content of that day. The average value of soil water content in each day of each month is used to analyze the change of water content in each month during corn planting.

Decomposition rate of straw. On the 15th day of each month in the experimental field, three 4 m^2 areas were selected to collect the straw in the area, weigh the weight after drying, and calculate the decomposition rate after average area. The decomposition rate of straw is calculated by Eq. (1) [12]. The specific formula is:

$$R_d = \frac{W_i - W_f}{W_i} \times 100\% \qquad (1)$$

where: R_d - decomposition rate of straw; W_i - initial dry weight of straw; W_f - dry weight of decomposed residues of straw.

The average decomposition rate of the three regions was taken as the monthly decomposition rate value for analysis.

Soil temperature measurement. In the EG plot and the CG plot, three points are arranged diagonally. The geo thermos meters are installed at depths of 0 cm, 5 cm, 10 cm and 15 cm, respectively. Geothermal data were recorded at 8:00, 11:00, 14:00, 17:00 and 20:00 daily, and the values of the three measured points were averaged for analysis.

Growth traits of maize. In the center of the test plot and the control plot, 25 m^2 area was selected to record the parameters of maize growth period and yield in the area for comparative analysis.

3 TEST RESULTS AND ANALYSIS

3.1 Decomposition Rate of Straw and Soil Water Content

The straw was returned to the field after maize harvest in autumn. Since the soil in Northeast China was nearly frozen at this time, the rate of straw decomposition was slow and sampling was difficult, the sampling experiment of straw decomposition rate was carried out from April next year. The change of straw decomposition rate from April to October is shown in Fig. 1.

From Fig. 1 it can be seen that the decomposition rate of straw is only 5% in April, and it increases with time. From October to April of the previous year, during the period of land freezing in Northeast China, the degradation of straw almost stopped, the decomposition rate in 6 months was only 5%, and the inhibition of soil temperature on the decomposition of straw was obvious. From the slope of the curve, we can see that the decomposition rate increased slowly in April, May and June, increased rapidly in July and August, and began to decrease again in September. The decomposition speed of straw is faster at higher temperature and water content [13, 14]. In July and August, the annual rainfall and temperature in the experimental area were the highest values throughout the year, so the decomposition rate of straw was the highest in these two months. By September, the decomposition rate of straw was over 80%, at which time only a small amount of fragile residue remained.

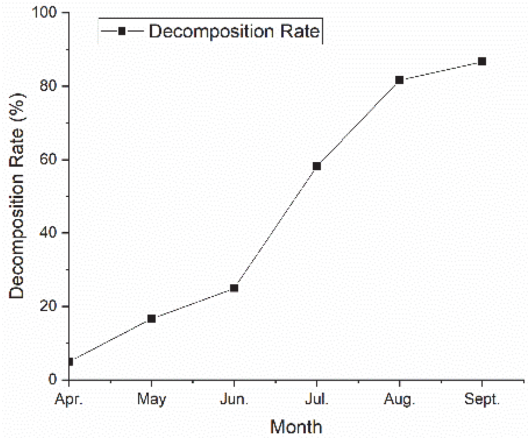

Figure 1 Trend of straw decomposition rate

The monthly soil moisture content of the experimental and control plots are shown in Fig. 2. It can be seen from the graph that there is only one peak of soil water content in both the test group and the control group. The peak of soil water content in the test group occurs in July, and that in the control group occurs in August. These two months are also the highest rainfall months in the region. Comparing the curve of soil water content change between the two plots, the soil water content of the test group was higher than that of the control group. Obviously, straw mulching can improve soil moisture content.

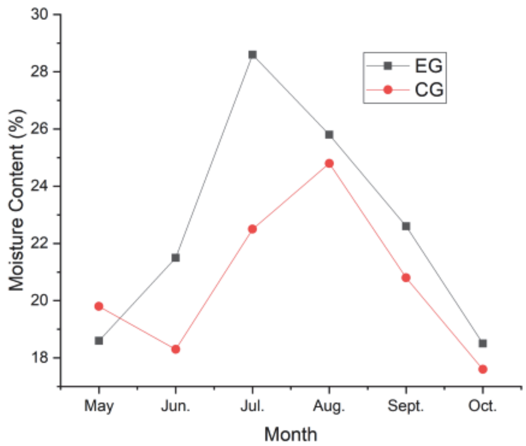

Figure 2 Variables of soil water content

The difference in soil water content for each month is listed in Tab. 1.The difference of soil water content in Tab. 1 is the difference between the EG and the CG in each month in Fig. 2.

Table 1 Soil moisture difference

	May	June	July	August	September	October
Difference	−1.2%	3.2%	6.1%	1%	1.8%	0.9%

From Tab. 1, it can be seen that months with large difference in water content occur in June and July, and the decomposition rate of straw is relatively low in these two months, and there is more residual, which can play a better role in the continuous precipitation. By August, although rainfall was high at this time, the decomposition rate of straw was high, and the ability of residual straw to inhibit evaporation was weak. The soil moisture content of experimental plot and control group was close. Therefore, straw mulching has a positive effect on increasing soil water content. The larger the residual amount of straw, the stronger the effect. This is extremely advantageous to the corn planting areas in Northeast China, which mainly depend on rain-fed agriculture.

3.2 Soil Temperature

Soil temperature varies with time and depth. To compare soil temperature between test and control fields, a three-dimensional column chart of soil temperature over time and depth was drawn for each month, as shown in Fig. 3 to Fig. 8.

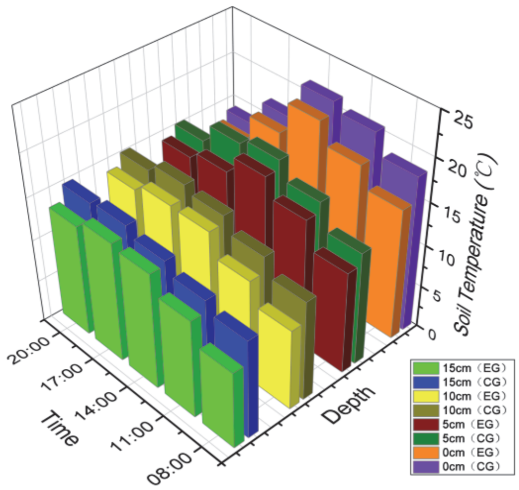

Figure 3 Daily variation of soil temperature at depths in May

Fig. 3 shows the diurnal variation of soil temperature at each depth in May. The average daily minimum and maximum temperatures in May are 11 °C and 22 °C. From the change of daytime temperature, the maximum daytime temperature of soils at different depths was at 14:00, when the light intensity and ground temperature are in a higher stage. According to the temperature fluctuation of different depths, the temperature fluctuation of 0 cm soil is the largest, while that of 15 cm soil is weak. At the depths of 0 cm, 5 cm, 10 cm and 15 cm, the ground temperature of EG was lower than that of CG, indicating that straw mulching significantly reduced soil temperature.

Fig. 4 shows the daily variation of soil temperature at different depths in June. The average daily minimum and maximum temperatures in June are 17 °C and 28 °C. The overall temperature of each soil layer in June is higher than that in May. From the extent of change, the shallow soil temperature fluctuates greatly during each period of the day, which is caused by the large diurnal temperature difference in June in this area. The geo temperature of deep soil (15 cm) is relatively constant and its variation is gentle. Compared with the CG, the soil temperature of 10 cm and 15 cm in the EG was lower than that in the CG. At depths of 0 cm and 5 cm, the starting temperature of the EG was lower at 8:00 a day, the rising speed was slower, and the temperature decreased slowly after reaching the peak value. In the CG, the starting temperature was higher at 8:00 a day, and the temperature increased rapidly. After reaching the peak, the temperature decreased rapidly. Straw mulching delayed the rate of ground temperature rise and the rate of ground temperature decrease after the peak.

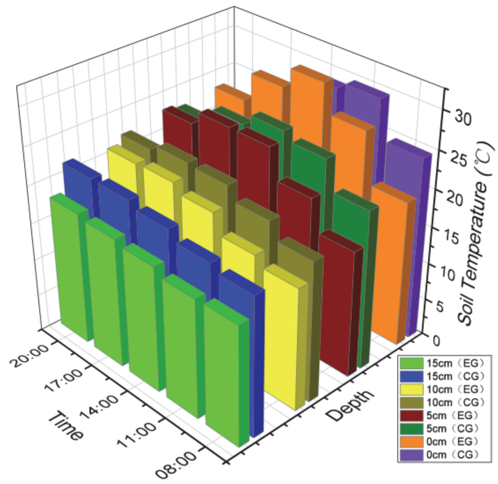

Figure 4 Daily variation of soil temperature at depths in June

Fig. 5 shows a column chart of July geo temperature variations. The monthly mean minimum and maximum daily temperatures are 20 °C and 29 °C, respectively, which are the months with the highest average temperatures in the region. Comparing with June, the soil temperature at 15 cm and 10 cm depth in the EG was always higher than that in the CG. At depths of 0 cm and 5 cm, soil temperature in the EG increased rapidly and decreased slowly. The soil temperature in the EG was slightly lower than that in the CG and increased simultaneously at 8:00. After reaching the peak, the ground temperature decreased slowly in the EG and rapidly in the control group.

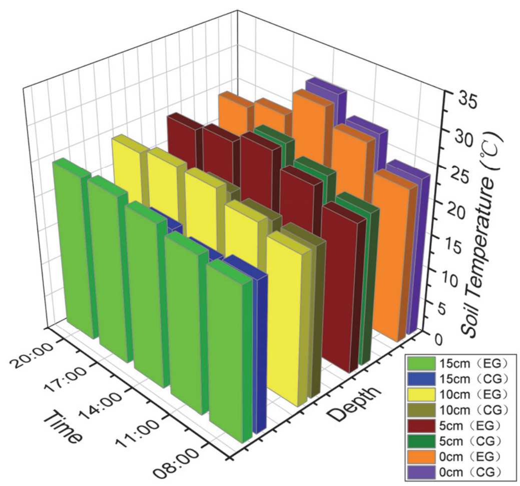

Figure 5 Daily variation of soil temperature at depths in July

Fig. 6 shows soil temperature variations at various depths in August. The average daily minimum and maximum temperatures in August are 19 °C and 27 °C, slightly lower than the ground temperature in July, but the difference between day and night is small. Reflected in the geo temperature, from the soil temperature as a whole is lower than July, the temperature of each soil layer is relatively constant, and the geo temperature at different depths is very close. The soil temperature at 15 cm and

10 cm depths was relatively constant, and it was higher in the EG than in the CG. At 0 cm and 5 cm, the ground temperature of the EG and the CG is close, and the pattern of intraday changes is also similar. This is because the decomposition rate of straw has reached more than 80%, and the effect of soil temperature regulation has decreased.

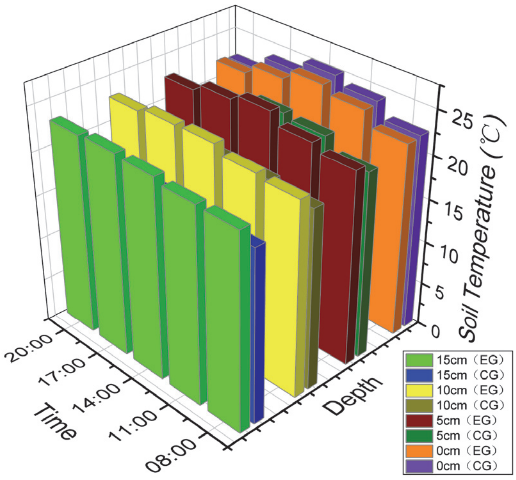

Figure 6 Daily variation of soil temperature at depths in August

Fig. 7 is a column chart of the geo temperature variations in September. In September, the average daily minimum and maximum temperatures were 12 °C and 22 °C. The temperature began to decrease rapidly and the difference between day and night became larger. From the comparison of ground temperature of each soil layer, the temperature of deep layer is significantly lower than that of shallow layer, and the difference of intra day temperature change is more obvious. At depths of 15 cm and 10 cm, the variations of ground temperature in the EG were similar to that in the CG. At depths of 0 cm and 5 cm, the soil temperature in the EG increased slowly, and after reaching its peak, the temperature of the two groups decreased at a similar rate.

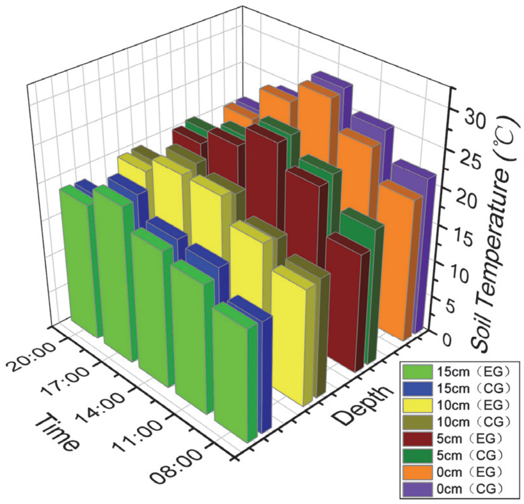

Figure 7 Daily variation of soil temperature at depths in September

Compared with Fig. 3 to Fig. 7, straw mulching has a greater effect on soil temperature. When the residual amount of straw was large, the ground temperature of the EG was significantly different from that of the CG. In May and June, the temperature of soil layers in different depths of the EG and the CG was significantly different. In July, August and September, the difference was significantly reduced. Straw has the effect of constant geo temperature. In May and June, when the temperature is lower, straw mulching keeps the geo temperature low. From July to August when the air temperature is higher, straw mulching keeps the ground temperature at a higher value. Especially for deep soil temperature, this effect is more obvious.

3.3 Growth Traits of Maize

The difference of maize plant growth traits can reflect the effect of straw mulching. The data of plant height, stem diameter and yield are shown in Tab. 2.

Table 2 Plant traits

	Seedling	Jointing		Heading		Grain Filling		Yield / kg/ha
	Emerging	Plant height	Stem diameter	Plant height	Stem diameter	Plant height	Stem diameter	
EG	May 21st	124.4 cm	2.6 cm	259.2 cm	3.2 cm	265.7 cm	3.4 cm	10716.0
CG	May 17th	131.7 cm	2.8 cm	236.6 cm	3.1 cm	261.4 cm	3.2 cm	10522.5

It has been explained in the previous paper that the soil moisture content of the EG is higher than that of the CG at each growth period. However, as shown in Tab. 2, the plant height and stem thickness of the EG at seedling and jointing stages were weaker than those of the CG. However, the EG was higher than the CG during the Heading and filling stages. The emergence date of EG was May 21, CG was May 17, and EG was 3 days later than CG. As shown in Fig. 3, the ground temperature of each layer of EG was lower than that of CG in that month. It can be inferred that straw mulching reduced the ground temperature and delayed the emergence time. At the jointing stage, the plant height and stem diameter of the experimental plot were 124.4 cm and 2.6 cm respectively, which were lower than 131.7 cm and 2.8 cm of the control plot. The jointing stage of maize is in the middle of June. As shown in Fig. 4, except for a few periods of topsoil, the overall ground temperature of the test plot is lower than that of the control plot, and the lower ground temperature has an inhibitory effect on the growth of maize, making the growth index of EG maize weaker than CG. After the tasseling stage, the plant height and diameter of the experimental plot were 259.2 cm and 3.2 cm respectively, which were 236.6 cm and 3.1 cm of the control plot. From the point of view of soil temperature, tasseling silking period is in July. Due to the influence of straw mulching, e.g. soil temperature is significantly higher than CG. Higher soil temperature makes maize grow rapidly in this growth stage, and the growth index exceeds CG. In the filling stage, the same pattern was also observed. At the filling stage, the plant quality of EG was still better than that of CG, and the soil temperature of EG was higher than that of CG in August, which promoted the growth of plants. It can be seen that there is a high correlation between the growth of maize plants and ground temperature. Straw mulching makes the ground temperature lower in May and June, which has an adverse effect on plant growth. E.g., growth index is weaker than CG growth index. However, in July and August, straw mulching maintained high ground temperature and promoted plant growth, and the e.g. growth traits were reversed.

In terms of crop yield, the yield of the experimental group was 714.4 kg, which was higher than 701.5 of the control group. EG was higher than CG. The seedling stage and jointing stage belong to the vegetative growth stage, and straw mulching has an adverse effect on it. The tasseling silking stage and filling stage belong to the reproductive growth stage. The growth of the plant determines the yield at this stage. Straw mulching maintains a higher ground temperature, which promotes the growth of maize and improves the yield of crops.

4 DISCUSSION ON THE EFFECT OF STRAW MULCHING

Straw mulching had a positive effect on soil moisture improvement. Using the method of straw mulching, the soil moisture content was greatly improved, and enough water was ensured during the maize growth, especially in the stage of heading and grain filling. The greater the residual amount of straw, the more the soil water content will increase, and the difference in water content can reach up to 6.1%. Compared with the CG, the effect of straw residue on soil water content is also reduced.

The decomposition speed of straw was positively correlated with air temperature and soil water content. When the air temperature is low, the water content is low and the decomposition rate of straw is low. The decomposition rate of straw grows with the increase of air temperature and soil water content. From October of the previous year, after straw mulching was returned to the field, the decomposition rate of straw could exceed 80% until September of the next year.

The effect of straw decomposition on the geo temperature is more direct. The residual amount of straw was large, and the ground temperature of the test group was significantly different from that of the control group. In May and June, the temperature was low and the ground temperature remained low under straw mulching. In July and August, the temperature is higher, the straw plays a good role in keeping warm, and the ground temperature is kept at a higher value. The effect of straw mulching on maize growth is mainly reflected by the ground temperature. May and June are the stage of maize nutritional growth. Low ground temperature has a negative impact on plant growth. Maize emerges late, and plant height and stem thickness are small. July and August are the reproductive growth stages of maize. Straw mulching maintains high ground temperature, promotes crop growth and increases crop yield.

The decomposition of straw has a direct effect on the ground temperature. The residual amount of straw was large, and the ground temperature of the EG was significantly different from that of the CG. In May and June, the temperature was low and the ground temperature remained low under straw mulching. In July and August, the temperature is higher, the straw plays a good role in keeping warm, and the ground temperature is kept at a higher value. The effect of straw mulching on maize growth is mainly reflected by the ground temperature. May and June are the stage of maize nutritional growth. Low ground temperature has a negative impact on plant growth. Maize emerges late, and plant height and stem thickness are small. During the reproductive growth stage of positive Maize in July and August, straw mulching maintained high ground temperature, promoted the growth of crops, and increased the yield of crops.

5 CONCLUSIONS

With the rapid development of agricultural economy in Northeast China, the total amount of crop straw resources will continue to increase. At present, there are more discussions on straw returning methods in Northeast China, and the practice of different straw returning methods is also in progress, but no consensus has been reached. From the comprehensive point of view, straw mulching can make the soil maintain a high water content, can make that maize reproductive growth stage has better temperature and water conditions, can improve corn yield. In Northeast China, straw mulching can avoid the environmental pollution caused by straw burning and reduce the cost of straw treatment, which is a beneficial attempt of straw returning.

Acknowledgments

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Contact information:

Shaodong LIU
(1) College of Civil Engineering and Water Conservancy,
Heilongjiang Bayi Agricultural University,
Daqing Heilongjiang 163319, China
(2) Research Center of Rice Ecological Seedling Raising Device and Mechanization of Planting Process Engineering Technology of Heilongjiang Province

Shujuan YI
(Corresponding author)
(1) College of Engineering,
Heilongjiang Bayi Agricultural University,
Daqing Heilongjiang 163319, China
(2) Research Center of Rice Ecological Seedling Raising Device and Mechanization of Planting Process Engineering Technology of Heilongjiang Province
E-mail: yishujuan_2005@yeah.net

Yongcai MA
College of Engineering,
Heilongjiang Bayi Agricultural University,
Daqing Heilongjiang 163319, China