INVESTIGATION OF THE DECOMPOSITION PATTERN OF CORN STRAW IN COLD LAND UNDER DIFFERENT FIELD RETURN METHODS
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寒地玉米秸秆腐解规律的探究

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ABSTRACT
In order to explore the best parameters for the decomposition of corn straw for return to the field under extremely cold temperature conditions in northeast China, an orthogonal test was used to test the decomposition of corn straw and to analyse the effects of factors such as straw return depth, straw return amount, straw stalk part and decomposer concentration on the decomposition efficiency of corn straw. The results showed that the most significant effect on the decomposition efficiency of cold land corn straw was the amount of straw returned to the field, followed by the concentration of decomposer and the depth of straw returned to the field, and the least effect was the straw part. Among them, the amount of straw returned to the field showed a negative correlation on the decomposition efficiency of cold land corn straw; the concentration of decomposer, the depth of straw returned to the field and the straw part showed a positive correlation on the decomposition efficiency of cold land corn straw.

摘要
为了探索中国东北地区在极寒温度条件下玉米秸秆腐解还田的最佳工作方式，采用正交试验法对玉米秸秆进行腐解试验，分析了秸秆还田深度、秸秆还田量、秸秆茎部位、腐解剂浓度等因素对玉米秸秆腐解率的影响。结果表明，对寒地玉米秸秆腐解率的影响最为显著的是秸秆还田量，其次是腐解剂浓度、翻埋深度，影响最小的是秸秆部位。其中秸秆还田量对寒地玉米秸秆腐解率呈现负相关关系；腐解剂浓度、翻埋深度、秸秆部位对寒地玉米秸秆腐解率呈现正相关关系。

INTRODUCTION
The Three Rivers Plain is located in the northeast border of China and is an important part of the Northeast Plain, one of the three major black soil areas in the world. The climate is mild and humid in summer and cold and dry in winter, with large temperature differences throughout the year (*Liang et al., 2022*). At the same time, Heilongjiang is also a major corn producing region in China, with large amounts of corn straw and abundant corn straw resources after the autumn harvest. In the past, farmers burned corn straw in their fields, with the attendant air pollution problems and fire risks, causing this disposal method to be banned (*Sun, 2015*). Under these conditions, straw return to the field has become the main disposal method and has had an important impact on farm production. In addition, straw returns play an important role in maintaining soil fertility and improving the amount of humus in the soil. It was found that corn straw is rich in nitrogen, phosphorus, potassium and other nutrients for crop growth (*Wang et al., 2013*). In order to improve the efficiency of the use of straw and reduce the waste of resources, a series of methods for the comprehensive use of straw have been proposed, of which straw fertilization is currently the most rapidly developing straw utilization (*Li et al., 2021*). It was found that by controlling the amount of corn straw returned to the field at 4500 KG per hectare and applying a decomposer, the straw decomposed at a higher rate and the following year's corn yield increased more（*Yang et al., 2013*）.

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Rapid decomposition of cold land corn straw is closely related to crop protection tillage, and there have been studies on the decomposition law and mechanism of cold land straw in China, but there are few studies on the decomposition characteristics of cold land corn straw with additional application of decomposer, and there is also a lack of studies on the decomposition efficiency of corn straw. An orthogonal test design was used to study the decay effect of corn straw decay under different combinations of factors, using the decomposition efficiency of corn straw as the analysis index, to analyze the decomposition efficiency of corn straw and to provide technical and management theoretical guidance for the decomposition of corn straw in cold areas.

MATERIALS AND METHODS

OVERVIEW OF THE TEST AREA

The test was conducted at the Experimental Center of Jiamusi University (130°22'08 "E, 46°48'35 "N, 81.2 m above sea level), which is the hinterland of the Three Rivers Plain formed by the confluence of the Songhua, Heilong and Ussuri rivers, with a climate type belonging to typical temperate continental monsoon climate with high winds and low precipitation in spring, warm and rainy summer, cool climate in autumn and cold and long winter (*Liu et al., 2022*). The soil of the area is black, that is homogeneous humus, a clayey soil with good properties and high fertility. Soil capacity is the ratio of the mass of a unit volume of soil to the mass of the same volume of water in the field in its natural basal state, with clayey soils having a capacity of 1.0~1.5 g/cm^3. The lower the soil capacity and the higher the organic matter content, the better the structural properties. The soil capacity of the test area was 1.25~1.35 g/cm^3.

Table 1

Test environmental factors

Meteorological factors	Oct. 2021	Nov. 2021	Soil freezing period				Apr. 2022	May. 2022
			Dec. 2021	Jan. 2022	Feb. 2022	Mar. 2022		
Average max temperature [K]	286.15	274.15	261.15	261.15	266.15	277.15	287.15	294.15
Average min temperature [K]	272.15	264.15	250.15	249.15	253.15	265.15	274.15	280.15
Average wind velocity [m/s]	2.33	2.83	2.11	1.89	2.53	2.22	3.08	2.25
Total rainfall [mm]	13.82	68.41	6.05	4.39	10.21	13.68	74.69	4.7
Average relative humidity [%]	52.84	77.20	64.26	66.35	65.96	61.97	44.97	54.45

Methods

Multi-factor orthogonal experimental design

In this test, an orthogonal test design method using Design-Expert V8.0.6 software was used to comprehensively analyze the factors affecting the effectiveness of straw decomposition and return to the field (*Qi et al., 2021*). The survey showed that the amount of straw used for straw return should be controlled at about 3750-4500 kg of fresh straw and 1500-3000 kg of dry straw per 1 ha area of field; the amount of fresh straw can be increased to about 6000-6750 kg for plots with good soil fertility level; the amount of fresh straw should be reduced to about 3000-3750 kg for plots with poor soil fertility level (*Yao, 2014*).

The amount of straw used to return to the field is too large and affected the normal growth of the crop seedlings. In combination with the size of the test plots, which were each 0.25 m x 0.25 m, the amount of straw was set at three levels of 30 g, 40 g and 50 g. The corn straws with a more consistent length of corn stalks were selected, and roots and leaves were removed. The treated straws were divided into five equal parts from the top to the roots and represented by numbers 1 to 5 in the upper (top), upper middle, middle, lower middle and lower part (roots) (*Yu et al., 2012*), and three levels were selected 2, 3 and 4.

The organic material ferment produced by Shandong Junde Biotechnology Co., Ltd. was chosen as the straw decomposer, which contains a variety of beneficial microorganisms such as Bacillus, Bacillus, Actinomyces, Saccharomyces, Xylella, Lactobacillus and Photosynthetic bacteria to promote the decomposition of straw; the decomposition agent concentration was set at three levels of 7.5%, 10% and 15%. The straw return depth was set to 0.1 m, 0.15 m and 0.2 m. With the decomposition efficiency of corn straw as the objective of the experimental study, the $L_9(3^4)$ orthogonal test factor level was selected, as shown in Tables 2 and 3.

Table 2

Factor levels of orthogonal tests

Level	Test factors			
	A. Straw amount	B. Straw stalk part	C. Decomposer concentration	D. Straw return depth
	[g]		[%]	[m]
Ⅰ	30	2	15%	0.1
Ⅱ	40	3	10%	0.15
Ⅲ	50	4	7.5%	0.2

Table 3

Orthogonal test design table $L_9(3^4)$

Test treatment	Test factors			
	A. Straw amount	B. Straw stalk part	C. Decomposer concentration	D. Straw return depth
	[g]		[%]	[m]
1	Ⅰ（30）	Ⅰ（2）	Ⅰ（15%）	Ⅰ（0.1）
2	Ⅰ（30）	Ⅱ（3）	Ⅱ（10%）	Ⅱ（0.15）
3	Ⅰ（30）	Ⅲ（4）	Ⅲ（7.5%）	Ⅲ（0.2）
4	Ⅱ（40）	Ⅰ（2）	Ⅱ（10%）	Ⅲ（0.2）
5	Ⅱ（40）	Ⅱ（3）	Ⅲ（7.5%）	Ⅰ（0.1）
6	Ⅱ（40）	Ⅲ（4）	Ⅰ（15%）	Ⅱ（0.15）
7	Ⅲ（50）	Ⅰ（2）	Ⅲ（7.5%）	Ⅱ（0.15）
8	Ⅲ（50）	Ⅱ（3）	Ⅰ（15%）	Ⅲ（0.2）
9	Ⅲ（50）	Ⅲ（4）	Ⅱ（10%）	Ⅰ（0.1）

Measurement index

The nylon mesh bag method was used to determine the decomposition efficiency as follows: the length of straw was fixed at 0.1~0.12m, and the straw was packed into 40 mesh nylon mesh bags (size 0.3 m×0.2 m) and numbered according to the arrangement in Table 3, and six replicate tests were conducted for each group, and buried at a predetermined depth according to the preset in the test program, as shown in Figure 1. Spraying different concentrations of organic material decomposer for the nylon mesh bag before burial according to the test program was performed to ensure full contact between straw and organic material decomposer. The nylon mesh bags were sprayed with different concentrations of organic matter maturing agent prior to burial in accordance with the trial protocol to ensure that the straw was in full contact with the organic matter maturing agent and buried in the ground for 8 months. In addition, each test plot was spaced greater than 0.15 m apart to avoid interference between the two test groups, which could affect the test results.

a Depth of straw return 0.1m **b Depth of straw return 0.2m**

Fig. 1 - Return depth limit

a Electric blast dryer **b Drying straw number**

Fig. 2 - Thermostatic drying

The straw decomposition efficiency was tested by removing the nylon mesh bag, separating the soil from the straw residue, rinsing the straw residue, drying it with an electric blast dryer, at a constant temperature of 358.15 K, cooling it to room temperature and then weighing it, and calculating the straw decomposition rate R_d using the weight loss method (*Yu et al., 2015; Wang et al., 2020*). The specific calculation formula is:

$$R_d = (W_i - W_f)/W_i \times 100\% \tag{1}$$

where: W_i - initial dry weight of straw;

W_f - dry weight of straw decay residue.

Data processing

The orthogonal test was performed using the visual analysis method with the following steps:

$$k_i = K_i/s \tag{2}$$

Where:

K_i- the sum of the test results corresponding to the level number i on any column;

k_i- the arithmetic mean of the test results obtained at level i for any of the upper column factors

S - the number of occurrences of each level on any column was taken as 3.

$$R = max\{k_1, k_2, k_3\} - min\{k_1, k_2, k_3\} \tag{3}$$

Where:

R - the extreme difference

If each test factor has no effect on the test index, the values of k_i under each factor should be equal; on the contrary, the presence of a certain difference in the value of k_i under each factor indicates that the test factor has an effect on the test index. The magnitude of the value of k_i is used to determine the degree of influence of each test factor level on the test index, and the magnitude of the R value is an important basis for determining the degree of influence of factors on the test index (Yang et al., 2021).

RESULTS AND ANALYSIS

In Table 4, the decomposition efficiency data presented in the test results are the average values of decomposition efficiencies for six replicate tests (six bags buried simultaneously under the same conditions to ensure the same replicate test conditions).

Analysis of extreme differences

The extreme difference values were calculated for each level of each factor (see Table 4). It can be seen that the extreme difference R_A of straw return amount is 28, the extreme difference R_B of straw part is 3.14, the extreme difference R_C of decomposer concentration is 13.63, and the extreme difference R_D of straw return depth is 6.4. The larger the extreme difference value of the factor, the greater the effect of the level change of the factor on the test results. Among the factors selected in this experiment, the extreme difference values of straw return amount were much higher than those of the other factors, i.e., straw return amount had the greatest effect on the degree of straw decay. Straw part had the least effect on straw decomposition efficiency, decomposer concentration had the second highest effect on straw decomposition efficiency, and straw return depth had the third highest effect on straw decomposition efficiency. Numerically, the main order of the factors was: straw return amount > decomposer concentration > straw return depth > straw part.

Table 4

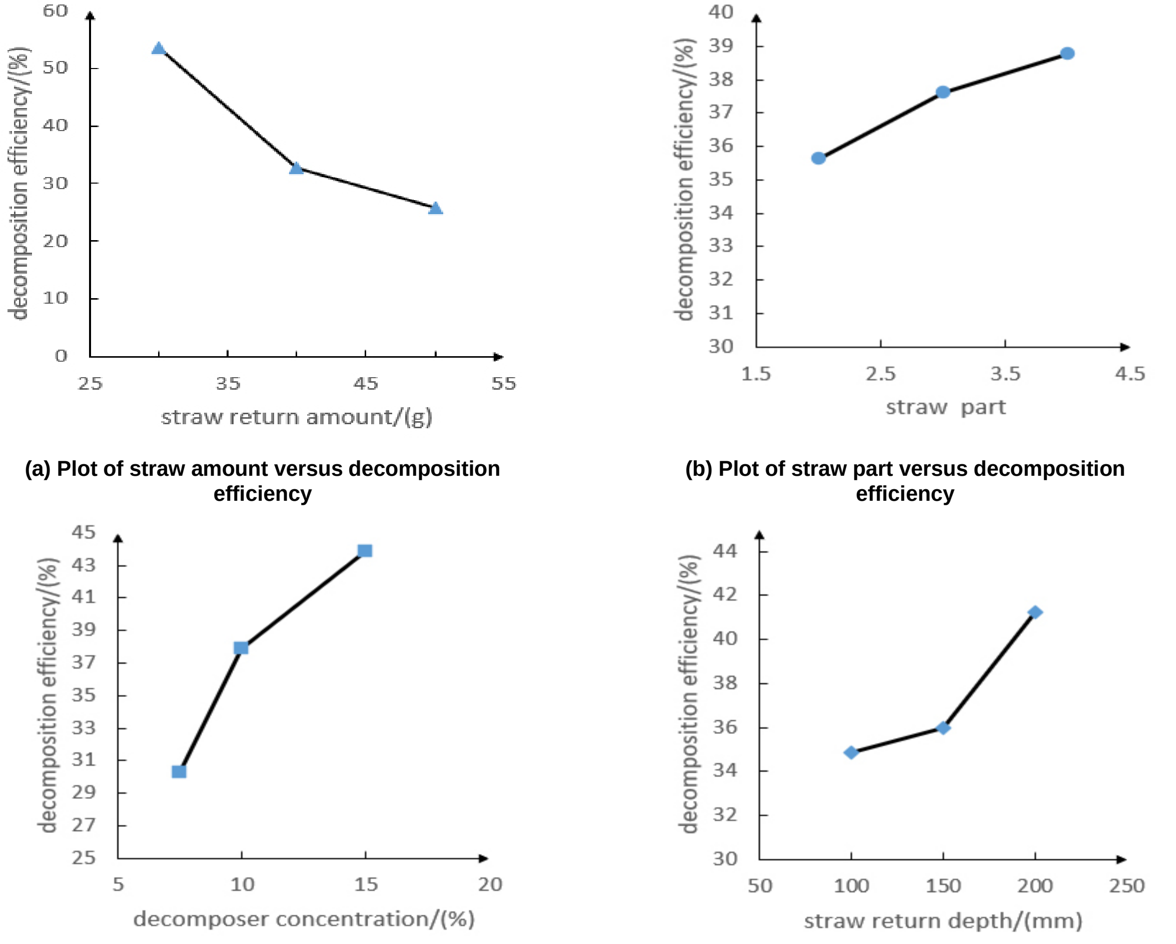
Results of orthogonal test

Test treatment	Test factors				decomposition efficiency
	A. Straw amount	B. Straw stalk part	C. Decomposer concentration	D. Straw return depth	
	[g]		[%]	[m]	[%]
1	Ⅰ（30）	Ⅰ（2）	Ⅰ（15%）	Ⅰ（0.1）	56
2	Ⅰ（30）	Ⅱ（3）	Ⅱ（10%）	Ⅱ（0.15）	53.1
3	Ⅰ（30）	Ⅲ（4）	Ⅲ（7.5%）	Ⅲ（0.2）	51.9
4	Ⅱ（40）	Ⅰ（2）	Ⅱ（10%）	Ⅲ（0.2）	35.4
5	Ⅱ（40）	Ⅱ（3）	Ⅲ（7.5%）	Ⅰ（0.1）	23.4
6	Ⅱ（40）	Ⅲ（4）	Ⅰ（15%）	Ⅱ（0.15）	39.3
7	Ⅲ（50）	Ⅰ（2）	Ⅲ（7.5%）	Ⅱ（0.15）	15.5
8	Ⅲ（50）	Ⅱ（3）	Ⅰ（15%）	Ⅲ（0.2）	36.4
9	Ⅲ（50）	Ⅲ（4）	Ⅱ（10%）	Ⅰ（0.1）	25.1
K_1	161	106.9	131.7	104.5	
K_2	98.1	112.9	113.6	107.9	

Test treatment	Test factors				decomposition efficiency
	A. Straw amount	B. Straw stalk part	C. Decomposer concentration	D. Straw return depth	
	[g]		[%]	[m]	[%]
K_3	77.0	116.3	90.8	123.7	
k_1	53.67	35.63	43.9	34.83	
k_2	32.7	37.63	37.87	35.97	
k_3	25.67	38.77	30.27	41.23	
R	28.0	3.14	13.63	6.4	
Order of factors	A>C>D>B				
Optimal condition combination	$A_1B_3C_1D_3$				65.5

Influence analysis of factors

According to the characteristic of "balanced and dispersed, neat and comparable" of the orthogonal test, the trend curves of each factor on the decomposition efficiency of straw are plotted as follows.



(a) Plot of straw amount versus decomposition efficiency

(b) Plot of straw part versus decomposition efficiency

(c) Plot of decomposer concentration versus decomposition efficiency

(d) Plot of straw return depth versus decomposition efficiency

Fig. 3 - Factor-indicator relationship curve

From Fig. 3-(a) it can be seen that: the overall trend of straw decomposition efficiency decreased with the increase of straw return amount. This is because straw decomposition is mainly through the decomposition of microbial colonies in the soil, and with the increase in the amount of straw, the amount of remaining straw after decomposition increases, making the soil more porous and affecting the subsequent crop planting. This suggests that straw decomposition is not favored when the amount of straw is high. In terms of the rate of change, the straw decomposition efficiency showed a decreasing trend with the increase in the amount of straw.

The decomposition efficiency decreased by 20.97% from 53.67% to 32.7% when the amount of straw changed from 30 g to 40 g, which is a significant decrease; and when the amount of straw changed from 40 g to 50 g, the decomposition efficiency decreased from 32.7% to 25.67%, which is a 7.03% decrease and a slower decrease. *Wang Hanpeng et al., (2018*), analyzed that the decomposition efficiency of returned straw decreased with the increase of returned straw at different straw return amounts.

From the trend of the curve in Fig. 3-(a), it can be inferred that there is also an optimum amount of straw required for straw decomposition in black soil. The curve path of straw decomposition efficiency with straw amount cannot be clearly given due to the number of straw amount levels in this experiment; however, it can be inferred that the peak decomposition efficiency may occur near the straw amount of 30 g, that is around 4800 kg of straw per hectare of land returned to the field. In view of the significance of the effect of straw amount on the effect of straw decomposition, and considering that the environmental factors and climatic factors in Northeast China differ greatly from those in other regions, the range of suitable straw amount for straw decomposition can be further studied.

From Fig. 3-(b) it can be seen that: With the change of straw part, the closer the straw part is to the root, the higher the moisture content of the straw and the straw decay rate shows an increasing trend, but the trend is slower. The straw decomposition efficiency increased by 2% from 35.63% to 37.63% when the straw parts were shifted down from the middle to the middle, with a slow upward trend; The straw decomposition efficiency increased by 1.14% from 37.63% to 38.77% when the straw parts were shifted down from the middle to the lower middle, with a slower increasing trend. *Cai Lijun et al., (2019),* analyzed the decomposition pattern of different parts of corn straw, and the overall decomposition efficiency of different parts of straw was highest in leaves, followed by stalks, and the rachis was the most difficult to decompose. From the trend of the curve in Fig. 3-(b), it can be inferred that: the decomposition efficiency of corn straw showed an increasing trend as the straw parts became closer to the roots and the water content of the straw became higher (*Yu et al., 2012*). Therefore, considering the characteristics of rainfall in Northeast China, corn straw should be returned to the field for decomposition as early as possible after the corn harvest to ensure a high decomposition efficiency.

From Fig. 3-(c) it can be seen that: the decomposition efficiency of corn straw showed an increasing trend with the increase of decomposer concentration. The decomposition efficiency of corn straw increased from 30.27% to 37.87% when the concentration of decomposer increased from 7.5% to 10%, an increase of 7.6% and an obvious upward trend; when the decomposer concentration increased from 10% to 15%, the decomposition efficiency of corn straw increased from 37.87% to 43.9%, an increase of 6.03%, and the increasing trend became slower. *Fan Zuowei et al., (2021)*, experimentally analyzed that inoculation of corn straw with microbial decomposition solution could effectively promote the rate of straw humification and rapid accumulation of effective nutrients in the soil. From the trend of the curve in Fig. 3-(c), the effect of different decomposer concentrations on the increase of straw decomposition efficiency was significant. However, when the concentration of decomposer is too high, it will increase the number of remaining colonies in the soil and root burn will occur, which will affect the subsequent crop planting. Therefore, the concentration and dosage of the decomposer should be controlled in the straw decomposition and return operation.

From Fig. 3-(d) it can be seen that: the change of straw decomposition efficiency showed an increasing trend with the increase of straw return depth. *Wang Jinwu et al., (2017),* summarized and analyzed that the depth of corn straw returned to the field should be greater than 0.18 m to basically meet the straw decay degradation requirements. From the decomposition change amplitude, the straw decomposition efficiency increased from 34.83% to 35.97% when the return depth was increased from 0.1 m to 0.15 m, up 1.14%, with a slow rising trend; the straw decomposition efficiency increased by 5.26% from 35.97% to 41.23% when the return depth was increased from 0.15 m to 0.2 m, which was a significant increase. The straw decomposition efficiency was 41.23% at a return depth of 0.2 m. It can be inferred from the rate of change of the curve: when the return depth is less than 0.1 m, the straw decomposition efficiency is influenced by the environment and the decomposition rate is low. It is speculated that the highest straw decomposition efficiency of corn straw may occur in the range of 0.15~0.2 m tillage depth.

Experimental validation

To validate the results of the optimal design, the optimal combination of factor parameters was averaged in repeated tests to derive the error between the derived and optimal solution. The results of the validation tests are shown in Table 5.

Table 5

Test validation results

Test number	**Test conditions**		**Decomposition efficiency [%]**
1	straw return amount A_1 : straw stalk part B_3 : decomposer concentration C_1 : straw return depth D_3 :	30g Lower Middle 15% 0.2m	62.2
2			62.0
3			63.2
4			62.6
5			61.4
Average value			62.3
Percentage error			4.89%

The results of the validation tests show that: at a straw amount of 30 g, a straw part of the middle and lower part, a decomposer concentration of 15% and a turning depth of 0.2 m, the average decomposition rate of corn straw was 62.3%, with an error of 4.89% between the optimized result of 65.5%. The small error between the indicator validation test and the optimization results is less than 5%, indicating that the results obtained from the target optimization design are reliable.

CONCLUSIONS

1) The amount of straw had the most significant effect on the straw decomposition efficiency. In the range of straw amount set in this experiment, the decomposition efficiency of straw was negatively correlated with the amount of straw, which was 53.67% when the amount of straw was 30 g, and 25.67% when the amount of straw was 50 g. When carrying out the return operation, it is important to keep the amount of straw returned to the field to around 3500 kg per hectare of land in order to achieve the best possible replacement.

2) Under the incubation conditions, the concentration of decomposer has an important effect on straw decay. The decomposition efficiency of straw showed a positive correlation with the increase of decomposer concentration, when the decomposer concentration was 7.5%, the decomposition efficiency was 30.27%; when the decomposer concentration was 15%, the decomposition efficiency was 43.9%. In this test, the test material is straw stalks, which are difficult to decompose. In field practice, the actual degree of decomposition of the straw is higher than the test data because the straw leaves and stalks are mixed and deeply broken by machinery. When returning the straw to the field, the concentration of the decomposer and the amount of spraying can be increased according to the crushing of the straw in order to achieve a better decomposition effect.

3) In the combination of factors and levels selected in this experiment, the effect of straw return depth on straw decomposition efficiency showed a positive correlation, when the return depth was 0.1 m, the decomposition efficiency was 34.83%; when the return depth was 0.2 m, the decomposition efficiency was 41.23%. Therefore, the straw return depth should be controlled within the range of 0.15 m to 0.2 m. The return depth can be adjusted according to the conditions in the field to achieve good decomposition.

4) In this experiment, the straw part had the least effect on straw decomposition efficiency. Under the level of straw part set in this experiment, the straw decomposition efficiency showed a positive correlation with the straw part, when the straw part was the upper middle part, the straw decomposition efficiency was 35.63%; when the straw part was the lower middle part, the straw decomposition efficiency was 38.77%. Therefore, straw return should be done as early as possible after the corn harvest. The straw return operation should be carried out as early as possible after the maize harvest, when the straw has a high water content, which helps it to decompose.

Discussion

Corn is grown in all the planting area of the Heilongjiang Reclamation Region, in the first, second, third, fourth and fifth cumulus zones (*Zhang et al., 2014*), spread over 12 locations in the east and west of Heilongjiang Province, with marked differences in soil properties between the regions (*Liu et al., 2019*). In addition, the timing of the corn harvest and the form of straw return vary from region to region, with differences in straw decomposition time, degree of shredding and depth of turning and burying. Considering that all of the above factors can affect the effect of straw decomposition and return to the field, it should be applied and promoted in a reasonable manner, taking into account all the local influencing factors, and establishing a straw decomposition and return model that is appropriate to the local situation.

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