Experimental study on baling rice straw silage

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Abstract: For resolving harvesting technology of fresh rice straw silage and plugging of the round steel-roll baler in China, experimental researches were carried out. For harvesting technology, baling silage and chopping silage were experimented. For the round baler, three kinds of feeding rolls equipped for enhancing feeding capability were experimented separately by reliability. Experimental results indicate: harvesting technology of baling fresh rice straw as silage is practicable; slicing-disc feeding rolls can be used to the baler to resolve plugging in straw-baling course. And through further experiments by reliability and density, optimal structure of the feeding roll is obtained: big and small slicing-discs arranged in interval and inclination, distance between slicing-discs being 30–40 mm.

Keywords: silage harvesting, rice straw, round baler, feeding mechanism

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1 Introduction

Great progress has been made in producing dairy in China, which has become the third biggest nation in milk production now. Feeding straw is a basic strategy for realizing sustainable development in agriculture. China produces about 640 million tons (1 ton=10^3 kg) of straw every year, which include about 190 million tons of rice straw[1]. However, only fifteen percent of the rice straw is fed to ruminants; the rest is burnt or buried in the field, such treatment brings environmental pollution or waste.

Dry rice straw is not a suitable feed for ruminant animals because of poor quality, therefore, suitable treatment for rice straw is necessary. In China, rice straw is approximately 65% moisture when rice is harvested by combines; this makes it suitable for storage as silage. Thus, the study of rice straw silage technology is not only beneficial to resolve shortage of coarse fodders in China, but also help to effectively improve environmental pollution due to burning or inappropriate processing. So far, there have been researches regarding rice straw as feed in China and abroad[2-3], but research for harvesting technology of fresh rice straw silage has just begun.

The experiments are aimed at researching reasonable silage-harvesting technology and equipment for fresh rice straw, therefore resolving the harvesting problem in scale for fresh rice straw as silage, so that feeding of rice straw can be promoted in countryside of China.

Baling is a convenient method for packaging alfalfa and straw both as dry fodder and for silage[4-6]; however, with fresh intact rice straw, current round baling technology results in excessive plugging[7]. Chopping is an alternative harvest method, but baling can provide advantages of high productivity and low cost. The objectives of this work were to:

1) Compare chopping to baling for making rice straw silage;

2) Compare feed roll configurations of a round baler baling fresh rice straw;

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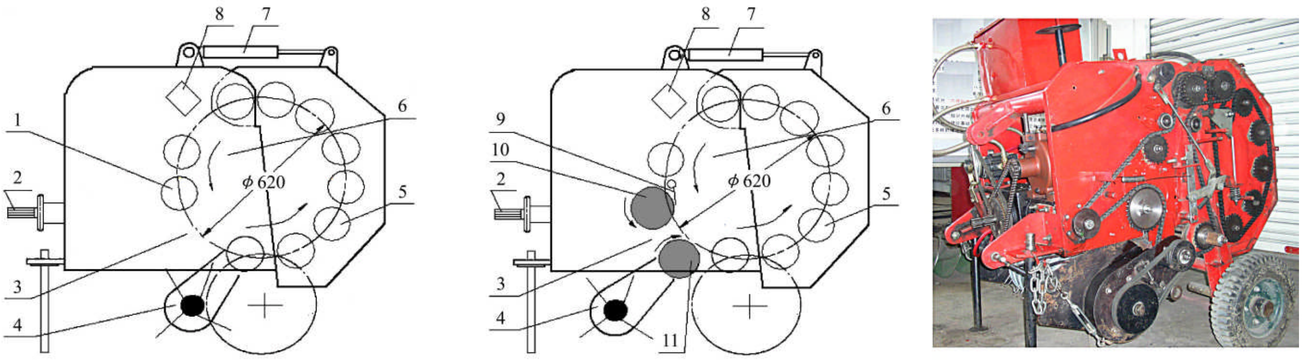
3) Refine feed roll design for a round baler for fresh rice straw.

2 Materials and procedures

2.1 Chopping versus baling

Equipments used were: Taihu 4 LBZ-145 head-feed combine, 4 ZTL-1 800 threshing combine prior to cutting，9 RZ-50 crop straw chopper, YK 7 050 round steel-roll baler. YK 7 050 steel-roll round baler is shown in Figure 1.



Conventional type Improved type

1.Steel roll at feeding entrance 2.Main shaft 3.Feeding entrance of rice straw 4.Pick-up 5.Steel roll 6.bale chamber 7.Hydraulic gate-lift system 8.Rope-wrapping system 9.Protection plate 10.Upper roll 11.Bottom roll

Figure 1 Configuration of the round steel-roll baler

Fresh intact rice straw (dongnong 03 rice) was baled with moisture content ranging from 65% to 75% and with particle lengths of 650 mm to 750 mm. When making baling-silage, the round steel-roll baler was used to pick up and bale intact rice straw in the field, feeding volume of rice straw was 1.5 kg/s to 2.5 kg/s while rotating speeds of steel rolls and bottom feeding roll were 200 r/min and 185 r/min, respectively. When making chopping-silage, fresh rice straw bale was transported to storing site from the field and chopped by the chopper.

For baling silage, the head-feed combine or threshing combine was used to harvest rice grains at the fundamental ripe stage; the round steel-roll baler is utilized to bale fresh rice straw in nominal 30 kg packages which were then placed in plastic bags, sealing and storing at room temperature. Two layers of bags were used to seal the baling silage in 2006-2007 (Figure 2), whereas in 2007-2008 inside bag was for sealing the baling silage and outside bag was for transportation (Figure 3).

Rice straw silage was stored in the laboratory (Figure 2) at room temperature for 45 days prior to chemical composition analysis and pH value determination.

Figure 2 Baled silage stored in laboratory in 2006-2007

Figure 3 Baled silage stored in the barn in 2007-2008

For chopping silage, the head-feed combine or threshing combine was used to harvest rice grains at the fundamental ripe stage; then baling and transporting them to storing site, chopping rice straw to particle length of 40 mm to 60 mm; and compacting them in plastic bags, which was approximately 30 kg in size.

They were stored in two-layers of plastic bags at room temperature for 45 days prior to sample analysis. Chopped silage and the chopper were shown in Figure 4.

Figure 4 Chopped silage stored in laboratory and the chopper used in 2006-2007

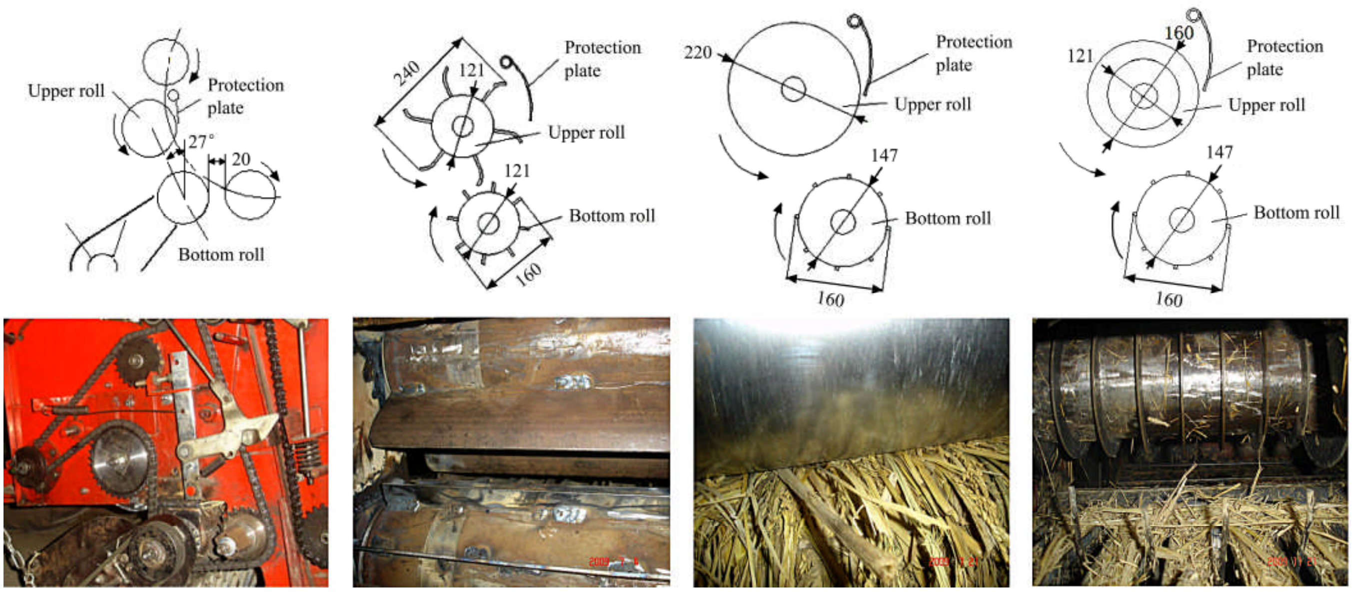
2.2 Feed roll configuration

In China, many types of balers have been developed and utilized, but smaller round steel-roll balers are utilized broadly throughout countryside because of simpler structure and lower power requirements (13 to 20 kW); however, these balers easily plug during baling of fresh rice straw, thus the feeding roll mechanism was equipped and tested. For further deciding of detailed structure of feeding roll mechanism, three kinds of fundamental structures were designed and tested (Figures 1 and 5). Figure 5a illustrates the placement of the feeding rolls; Figures 5b, 5c, and 5d mainly illustrate alternative designs for the top roll. They are axial plates, smooth round roll, and slicing discs.

By Figure 5b, axial plates for grasping straw are welded on the upper roll (maximum diameter 240 mm) and bottom roll (maximum diameter 160 mm), which are corresponding to each other so as to enhance the feeding and processing capability for rice straw. The bottom roll rotational speed is 1.5 times that of the upper roll so that peripheral speeds are matched.

The second configuration (Figure 5c) has a nearly smooth upper roll (maximum diameter 220 mm); the bottom roll has some small rods （height 6.5 mm）welded on the surface; the speed ratio also remained constant.

A third configuration (Figure 5d) was designed to slice and grasp rice straw during feeding to reduce plugging in front of the upper roll, this is helpful with uneven feeding into the baler. In this configuration, slicing discs are welded on the upper roll along axial direction (diameter 160 mm, height 19.5 mm, distance 48 mm), there are some small rods （height 6.5 mm） welded on the bottom roll. The ratio of rotation for upper roll and bottom roll remained constant.



a. Feeding mechanism b. Axial-plate roll c. Smooth round roll d. Slicing-disc roll

Figure 5 Configuration of the feeding rolls

Comparisons were made based on lack of plugging and resulting bale density.

In all experiments, fresh intact rice straw of 66% moisture and nominal 750 mm length was fed at a rate of 1.5 kg/s to 2.5 kg/s. At least 10 full bales were formed with each configuration.

2.3 Feed roll design

For optimizing structure of the mechanism so as to realize continuous and steady feeding of intact rice straw, single-factor experiments were made for the arrangement of slicing discs on upper roll.

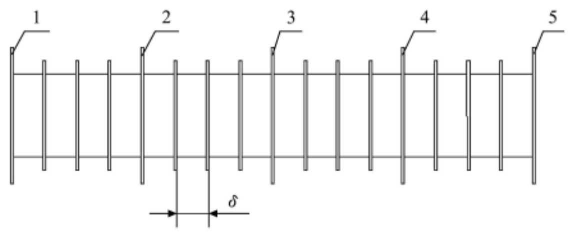
The description of many alternative arrangements are explained in Table 1.

Measurements made were reliability and density. The diameter of large and small slicing discs were 210 mm and 160 mm, respectively (Figure 6).

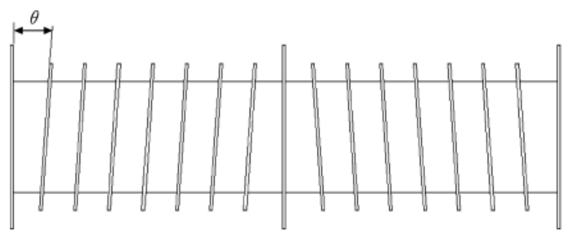
Table 1 Description of many arrangements of tested slicing discs

Parameters	Values															
Arrangement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number of large slicing discs* /pcs	0	1	2	3	4	5	3	3	3	3	3	3	3	3	3	3
Spacing between discs/mm	48	48	48	48	48	48	48	48	48	48	48	8	18	28	38	58
Angle of discs/degrees(°)	0	0	0	0	0	0	1	2	3	4	5	0	0	0	0	0

*With 1 disc, it was placed in the center (position 3, Figure 6a); with 2 discs, they were placed in positions 2,4; with 3 discs, they were placed in positions 1,3,5; with 4 discs, they were placed in positions 1,2,4,5.



a. Large and small slicing-discs



b. Angled slicing-discs

c. Experimental picture

Figure 6 Configuration of the slicing-disc feeding roll

3 Results and discussion

3.1 Chopping versus baling

One very good silage quality/stability indicator is pH[8-10]; pH values of lower than 3.8 are best, pH values of 3.8 to 4.2 are better while values of 4.2 to 4.7 are poor, yet acceptable. If pH exceeds 4.8, there is risk of lysteria, other mold, and poor stability when the silage is fed. The pH value of baled-silage averaged 4.33 in 2006-2007 (bale density lower) and 4.17 in 2007-2008 (bale density higher), especially the baled rice straw silage maintained good odor and green color in 2007-2008; chopped silage pH averaged 3.92 in 2006-2007. Although chopping resulted in a lower pH, both were acceptable.

Experimental result is illustrated in Figure 7 (three samples were duplicated).

For baling-silage of intact rice straw, the values of neutral detergent fiber（NDF）and dry matter（DM） are less than the values of NDF and DM in fresh rice straw (NDF decreased 5.89%, DM decreased 9.19%); but the values of acid detergent fiber (ADF) and crude protein (CP) are more than the values of ADF and CP in fresh rice straw (ADF increased 3.41%, CP increased 11.35%).

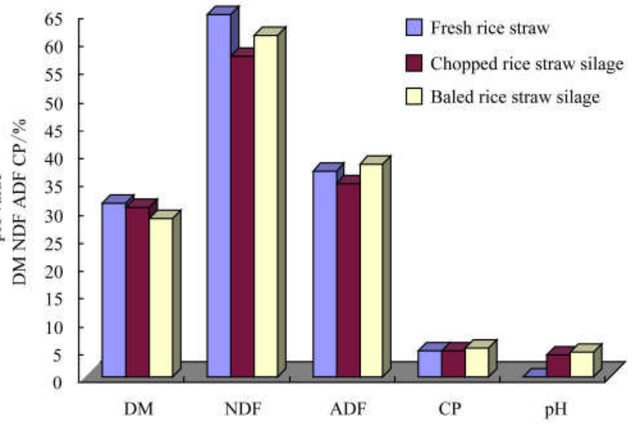


Figure 7 Chemical composition and pH value of fresh rice straw and the silage

For chopping-silage of fresh rice straw, the values of NDF, ADF and DM are less than the values of NDF, ADF and DM in fresh rice straw (NDF decreased 11.51%, ADF decreased 5.67%, DM decreased 2.47%); but the values of CP are not different.

There are not differences for DM, NDF and ADF, there are differences for CP and pH (p>0.01) between chopping-silage and baling-silage.

In summary, ensiling of fresh rice straw can yield a high quality ruminant feedstuff. Although the silage quality of chopped rice straw is slightly better than baled (lower pH, lower fiber), there are more processing procedures and high cost of labor, and more loss in transportation for this technology, therefore, the harvesting technology is more costly. Meanwhile, the quality of baled intact rice straw is also acceptable, especially because of high harvesting efficiency and low cost of processing, and broad adaptability to different rice combines, it makes harvesting technology of baling fresh rice straw as silage more suitable to be utilized in countryside in China.

3.2 Varied feed roll configurations

Of the feed roll configurations tested, only the slicing discs can be used to the baler (Table 2).

Table 2 Plugging percentage with varied feed roll designs

	Conventional	Steel-roll baler with feeding mechanism		
	steel-roll baler	Axial-plate roll	smooth roll	slicing-disc roll
Plugging percentage* /%	80	85	25	0

*10 bales per treatment if no plugging occurred; 30 bales per treatment if plugging occurred

For axial-plate roll, because the upper roll has deep grooves (59.5 mm), rice straw easily wrapped into the space between upper roll and protection plate when the bale was nearly full of baling chamber and not in rotating condition, thus easy to plug around upper roll. It was easier to produce plugging around bottom roll for axial-windrow rice straw to get into the baler, this is because axial-feeding rice straw is easy to plunge in the grooves (19.5 mm) on bottom roll.

For smooth roll, it was discovered that rice straw can be grasped and transported to baling chamber only when the distance between upper roll and bottom roll was full of rice straw. Because smooth upper roll possess less friction, rice straw is easy to plug in front of smooth roll when feeding volume increases suddenly.

For slicing-disc roll, it was discovered that the distance between upper roll and bottom roll can be designed according to smaller value (30–35 mm) because of big height of slicing discs (19.5 mm). The structural design, which is easier to grasp rice straw when rice straw contacts round slicing discs, enforces the feeding capability and avoid plugging because of axial-longitude arrangement between slicing discs on upper roll and rods on bottom roll, especially for fresh intact rice straw (mainly axial-windrow).

3.3 Feed roll design

For all arrangements in Table 1, there were no plugs during formation of 10 bales from each arrangement; however, arrangements 12 and 13 resulted in wrapping, which may eventually cause a plug; for this reason, larger spacing between discs seems advisable.

Density of the bales increased only slightly with number of big slicing discs increasing (Table 3). With too many large discs, however, the ability to handle temporary increases in feeding volume lowers since clearance between rolls is limited by diameter of large discs.

Density of the bale will increase with angle of slicing discs rising (Table 3), but only when the angle is no less than 5°, there are differences in baling density（p＞0.01）. It illustrates the structure is also beneficial to grasp and process rice straw continuously. This is because acting width of slicing discs increases when angle of slicing discs rises, which strengthen the processing capability of slicing discs on upper roll, meanwhile, the wrapping capability of rice straw on upper roll is also strengthened. Therefore, angle of slicing discs cannot be too big, which is better at 4°–5° in the experiment.

Table 3 Baling density for tested slicing discs

Parameters	Code and value															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Arrangement density/kg·m^{-3}	199.3	199.5	202.9	202.5	205.0	210.9	202.7	208.1	206.6	208.4	208.7	211.9	211.7	208.9	204.5	191.8

Note: 10 bales per arrangement.

4 Conclusions

1) Fresh rice straw can be made into silage. Baling-silage of fresh rice straw is applicable in countryside of China.

2) For solving the plugging problem, it is practicable to equip the feeding rolls in the round steel-roll baler, which improves the feeding capability and reliability. By the experiments, the feeding mechanism with slicing discs is adopted, that is, equipping slicing discs on upper roll and axial-plate on bottom roll.

3) From the experiments, optimal structure for the feeding roll with slicing discs is, the diameter of large slicing discs 210 mm, the diameter of slicing disc 160 mm, one piece of large slicing disc combining four pieces of slicing discs, angle of slicing discs 4°–5°, distance between slicing discs 30–40 mm.

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