STRAW HARVESTER FOR ANIMAL FEED[1)]

Sang Hun Kim*, Beom Soo Shin* and Sang Il Nam**

Introduction

Straw and other fibrous by-products are inevitably produced during cereal production and have traditionally been used for many purposes including feeding animals. The potential of these by-products as a feed resource for ruminants is being increasingly appreciated (FAO, 1977). In the future, the amount of cereals fed to farm animals will have to be reduced and livestock will have to rely more on by-products such as straw.

The method of animal production can be classified by the major portion of feed. One is animal forage and the other is grains. In Korea, livestock farmers normally depend more than 70% upon grains for the feed stuff. This livestock production system causes the unbalance of nutrition, and results in low productivity of animal farming.

In many livestock farms in Korea the rice straw is using as a major animal forage and the amount of rice straw fed takes 46% of total amount of required forages. Especially the rice straw is mainly using during spring, fall and winter season. However, there are still lots of problems to be solved such as harvesting cost, transportation between rice farm and livestock farm, and quality loss during drying and storage. Therefore the mechanization of straw harvesting is urgently needed to use the renewable agricultural by-products and to overcome the shortage of animal forage.

The objective of this research is to develope a straw harvester with new concept which can solve the problems of the quality loss and the labor cost during drying in a field, collecting, and storage. The developed straw harvester is self-propelled machine rebuilt by rice combine and equipped with the pick-up device, the macerater and the mat-forming device.

Design of Straw-Harvester

Straw left on the field after harvesting by rice combine is picked up by the pick-up device and fed into the macerater which can macerate and cut the straw to increase the efficiency of drying and feed. By passing through the mat-forming device the macerated straw are pressed and formed into a continuous mat. Such a thin and wide mat can be dried in a field within only one day. The overall view of straw harvester developed in this research is shown in Fig. 1.

1. Pick-up device

The function of the pick-up device is to pick the straw layed on field and convey it to a feeding belt for a macerater. It consists of the frame, the band-type conveyor and the tine. The frame of pick-up device is supported by the frame of rebuilt combine, and the up and

1) This research is funded by Ministry of Trade and Industry, KOREA.

* Professor and Assistant Professor, Dept. of Agricultural Machinery Engineering, Kangwon National University, Chunchon, 200-701, KOREA

** Director, Central Institute, DongYang Moolsan Co., Youngin, 449-870, KOREA

down movements are done by the hydraulic cylinder of combine cutter-bar. The width of flat rubber belt in the frame was determined to 750mm based on several preliminary experiments. The tine was made of music wire. The forward velocity of conveyor belt in the pick-up device should be at least same as the ground speed of straw harvester. Otherwise, straw will be piled up on the conveyor belt.

The proposed capacity of straw harvester is 1500 kg/hr when the working width is 0.7m and the ground speed of harvester is 1 m/sec.

2. Macerater

The maceration roll is made of long steel pipe with thickness of 4.8mm, length of 700mm, and diameters of 152mm and 203mm which has straight knurled surface. As shown in Fig. 2, three steel rolls with knurled surface are arranged in the triangular shape and an impact rotor is placed thereafter. Although this arrangement of three rolls enables the straw to pass twice between rolls, the maceration occurs only between the first two rolls because the only first two rolls have different relative surface velocity. The straw at the second pass is just pressed and fed into the impact rotor. The edge of the impact rotor is made of steel angles welded on the circumference of two circular plates. An guide plate is put in front of the impact rotor for easy crushing of straw. Only one belt is used to transmit the power to all rolls. The upper rolls and the impact rotor rotate in counter clockwise and the other rolls rotate in clockwise.

3. Mat-forming device

The mat-forming device, as shown in Fig. 3, is a press with a long conveyor belt for forming and pressurizing a straw-mat. For the role of mat forming, a rubber-coated steel roll driven by a hydraulic motor drives a main belt conveyor and another two rubber-coated steel rolls drive secondary belt conveyor. These two belt conveyors press the macerated straw and form the straw mat while the mat get through the conveyor belts to the outside. The two rubber-coated steel rolls are operated by the hydraulic cylinders on their both ends so that each roll can be pressed or unpressed independently. The capacity of water extraction and mat formation depends on the pressing forces between rubber-coated steel rolls and two conveyor belts.

Experimental Material and Method

1. Pick-up device

To evaluate the performance of the pick-up device, the operation of mechanism and the designated function were examined in a paddy field after rice harvesting.

2. Macerater

To produce good quality of straw as a forage, it is important to soften the agricultural by-product like rice straw, because the softness of straw is major factor for the intake of straw by cattle. To evaluate the softness of macerated straw quantitatively, density, deformation, and plastic deformation were measured. As the material becomes softer, the deformation as well as the plastic deformation gets bigger with force. Density was measured according to ASAE Standard(S269.4), and the deformation was measured by applying the dead load from 10kg upto 48kg. The plastic deformation was measured 10 minutes later after removing the load when the volume of material assumed to be steady state.

The performance of macerater could be evaluated by measuring the degree of maceration and the drying rate of macerated material. The degree of maceration was determined by deformation and plastic deformation after drying the macerated material in the oven dryer. Also the drying rate was determined by measuring the moisture content of macerated material according to the time in a oven dryer set at 110℃.

The test material was barley straw with the moisture content of 65%(w.b.) and fed into the macerater at constant rates from 327 kg/hr to 1,964 kg/hr. The clearance between rolls where the maceration occurred maintained 0.3mm and the clearance between the impact rotor and the guide plate was 2mm.

3. Mat-forming device

The performance of mat-forming device was evaluated by the drying rate and the strength of straw mat.

(1) drying rate

To investigate the effect of press on the drying performance, the drying rate was compared between the macerated and pressed material and the macerated and unpressed material. The control was the material treated nothing. Experimental condition and material were RR-1 in Table 1.

Effects of mat-forming pressure and pressing time on mat drying rate were tested by measuring the m.c. of the macerated and pressed materials with the conditions of pressures, 3.4 and 5.8 kg/cm^2, and belt speeds, 8cm/sec and 18cm/sec. Experimental condition and material were RR-2 in Table 1. Effect of thickness of straw mat also was investigated on the experimental condition of RR-2 by measuring the drying rates for two kinds of straw mat with different thickness. One is 2.5 times thicker than other.

(2) mat strength

Straw mat discharged from the straw harvester should be laid down between the stubbles to get enough space between mat and ground for good aeration. If the distance between two adjacent stubbles is too long, the mat will deflect and contact the ground surface which results in worse drying rate. Therefore, the maximum distance not to contact the ground surface is defined as the mat strength index of straw mat. A special device was constructed to measure the limit distance before the deflection occurs.

Effect of pressing time on the mat strength were investigated by measuring the strength index of mat formed at two different belt speeds with pressure of $3.4kg/cm^2$. The moisture content of macerated material was 68.5% and the feed rate was $0.4g/cm^2$.

The mat strength indices were measured by changing the pressure levels 3.4, 4.8 and $5.8kg/cm^2$ to investigate the effect of pressure on the mat strength and the effect of no of roll. The test material was macerated barley with the moisture content of 67.6%(w.b.) and the feed rate was $0.35g/cm^2$.

Results and Discussion

1. Pick-up device

The rice straw and barley straw was picked by the pick-up device with the efficiency of 80%. To increase the efficiency, the angle of pick-up band which was 50 ° could be decreased and at the upper end of the pick-up device, the spring tine should be submerged not to drag back the straw.

2. Macerating Device

The prototype macerater described above was tested to evaluate shredding performance. The deformation with pressure and plastic deformation was measured according to the feed rate(Table 2). Macerated material shows no difference of bulk density within tested feed rates. But the deformation of the macerated material increases with increase of the pressure. At the higher feed rate, the deformation with pressure and plastic deformation of the macerated material became bigger and also those values were 5% to 50% higher than the case of untreated material.

Table 3 shows the comparison of variation of m.c. between macerated and untreated barley straw in a dryer oven. For the macerated material, drying rates of the material conditioned with different feed rate shows no difference between each other. But the drying rate of the macerated material is quit higher than that of the untreated material. After two hour drying, the moisture content of macerated material dropped to 3% (w.b.), but that of untreated material was 13%(w.b.).

3. Mat forming device

1) Drying rate with forming pressure

The drying rate of macerated and pressed straw mat was compared with those of macerating only and untreated barley straw by sun drying in a field (Fig. 4). The drying rate of straw mat was 2.6 times higher than that of untreated straw after one hour and 1.8 times after two hours. The m.c. of straw mat was between 8 - 19% (w.b.) after four hours but m.c. of untreated straw and macerating only were 52%(w.b.) and 26%(w.b.) respectively.

The effects of mat forming pressure and pressing time (being changed by belt speed) on mat drying rate were shown in Fig 5. As the pressure and the pressing time increase, the drying rates increases. At pressure of 5.8 kg/cm^2, m.c. of the mat became 8%(w.b.).

Fig. 6 shows the drying rate of mat which is 2.5 times thicker than the thickness of previous mat (0.167g/cm^2). The m.c. of thick mat was 32%(w.b.) after four hours which is 20% points higher than the m.c. of thin mat. The mat thickness should be maintained appropriate level with compromised feed rate for the higher capacity of mat drying.

2) Mat strength

When the straw mat is deposited on the field stubble after formation, it must possess sufficient strength to allow it to span gaps in the stubble where no stems support it. Because the mat is wet, and the plant fibers are quite elastic, it has very little resistance to bending. Therefore, it supports itself due to tensile strength in the same manner a cable supports itself across a span.

Table 4 shows the mat strength measured by the test machine when the pressing time was changed by belt speed at a pressure of roll press, 3.4 kg/cm^2. The mat strength has a trend to increase with the increase of pressing time.

As shown in table 5, the mat strength also can be increased with the increase of pressure of roll press. The M.S.I. in table 5 is bigger than in table 4 at the same levels of factors, because the m.c. of material for the test of table 5(67%,w.b.) was lower than that of table 4. So the mat strength can be increased as m.c. of material decreases during harvest.

Table 6 shows the M.S.I. of mat produced by one and two roll press at two levels of pressures. At low roll pressure, no of roll did not changed the M.S.I. but at high roll pressure one roll is better than two rolls.

Conclusions

The mechanization of straw harvesting is needed to use the renewable agricultural by-products and to overcome the shortage of animal forage. The objective of this research is to develope a straw harvester which is self-propelled machine rebuilt by rice combine and equipped with the pick-up device, the macerater and the mat-forming device.

The developed machine works like these processes. The straw left on field after harvesting by combine harvester is picked up by the pick-up device and fed into the macerater which can macerate and cut the straw to increase the efficiency of drying and feed. By passing through the mat-forming device the macerated straw are pressed and formed into a continuous mat. Such a thin and wide mat can be dried in a field within only one day.

The test results are as follows;

1. The proposed capacity of straw harvester is 1500 kg/hr when the working width is 0.7m and the ground speed of harvester is 1 m/sec.

2. The deformation of the macerated material was upto 50% higher than that of untreated material.

3. The drying rate of straw mat was 2.6 times higher than that of untreated straw after one hour at a field. The m.c. of straw mat was between 8 - 19% (w.b.) after four hours but M.C. of untreated straw and macerating only were 52%(w.b.) and 26%(w.b.) respectively.

4. The mat strength increase with the increase of pressing time and the increase of pressure of roll press.

References

Ajibola, O., R, Koegel, and H. D. Bruhn. 1980. Radiant energy and its relation to forage drying. Trans ASAE 23(5):1297-1300.

Barrington, G. P. and H. D. Bruhn. 1970. Effect of mechanical forage harvesting device on field curing rates and relative harvesting losses. Trans ASAE 13(6):874-878.

Bruhn, H. D. 1955. Status of hay crushing development. J. Agr. Res. 36(3):165-170.

Dernedde, W. 1985. Vorwelken Von Gras. Halmgutertetechnik. VDI-Kolloquium Landtechnik Heft 2.

Feldman, M., E. Z. Jan. 1977. Gathering Cereal Straw and Chaff for Feed. Grain and Forage Harvesting : Proceedings first international grain and forage conference. ASAE.

Hall, C. W. 1957. Drying farm crops. Edwards Brothers, Ind., Ann Arbor, MI, 327 p.

Henderson, S. M. and Perry, R. L. 1966. Agricultural process engineering. The AVI Publishing company, Inc. Westport, CT.

Koegel, R. G., R. J. Straub, and R. P. Walgenbach. 1985. Quantification of mechanical losses in forage harvesting. Trans ASAE 28(4):1047-1051.

Krutz, P. J. and W. K. Bilanski. 1968. Mechanically treating hay for moisture removal. Can. Agr. Engr. 10:60.

Pedersen, T. T. and W. F. Buchele. 1960. Dyring rate of alfalfa hay. Agr. Engr. 41(2):86-89.

Risser, P. E., R. G. Koegel, K. J. Shinners, and G. P. Barrington. 1985. Factors affecting the wet strength of macerated forage mats. Trans ASAE 28(3):711-715, 721.

Savoie, P., C. A. Rotz, H. F. Buchltz, and R. C. Brook. 1982. Hay harvesting system losses and drying rates. Trans ASAE 25(3):581-585, 589.

Shinners, K. J., G. P. Barrington, R. J. Straub, and R. G. Koegel. 1985. Forming mats from macerated alfalfa to increase drying rates. Trans ASAE 28(2):374-377, 381.

Shinners, K. J., R. G. Koegel, and R. J. Straub. 1986. Drying rates of macerated alfalfa mats. ASAE Paper 86-1033.

Wolfgang Fritz. 1986. Redesign of the Macerater of an Experimental Mat Harvesting Machine. University of Wisconsin-Madison.

Shinners, K.J., R.G.Koegel and R.J.Straub. 1988. Design consideration and performance of a forage maceration device. Applied Engineering in Agriculture 4(1):13-18

T.J.Kraus, K.J.Shinners, R.G.Koegel, and R.J.Straub. 1993. Evaluation of a Crushing-Impact Forage Macerator. Trans ASAE 36(6):1541-1545.

Kim, S.H. 1993. Rectangular Baler for rice-straw.

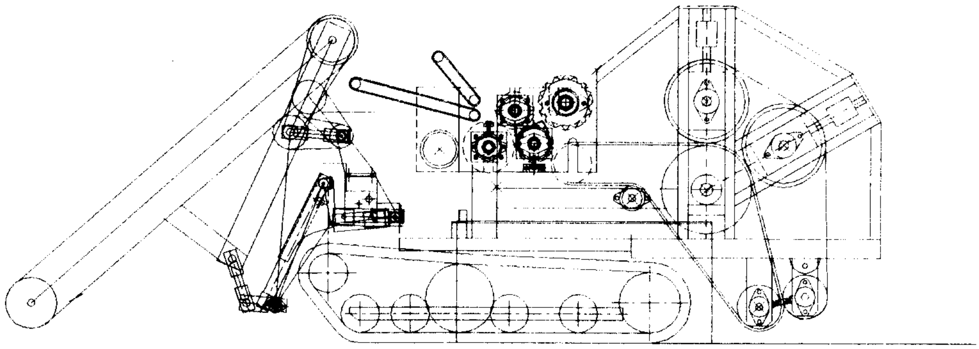

Fig. 1. Overall view of straw harvester

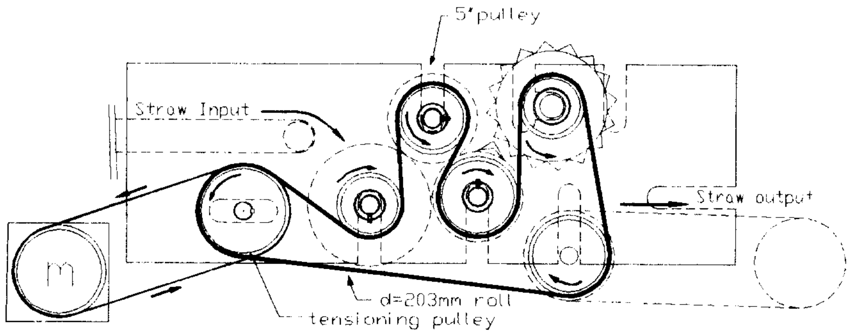

Fig. 2. Schematic diagram of Macerater

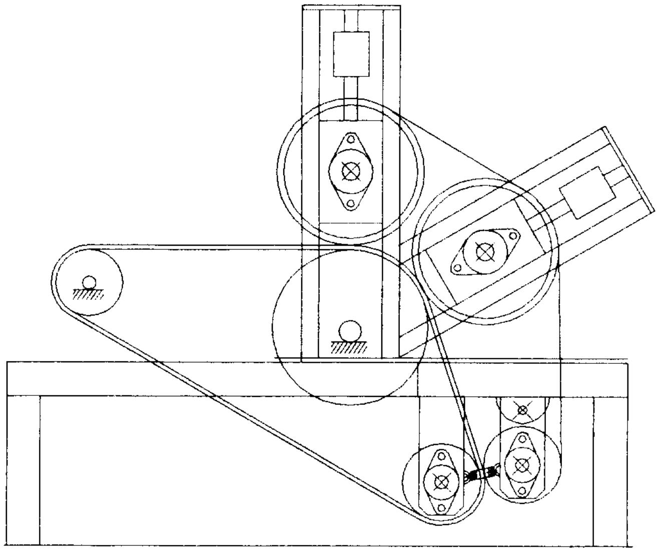

Fig. 3. Schematic diagram of Mat-forming device

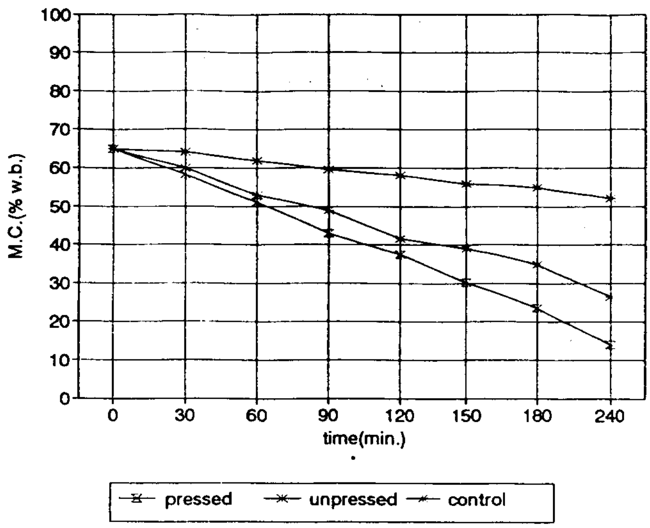

Fig. 4. Drying rate of straw mat in a field

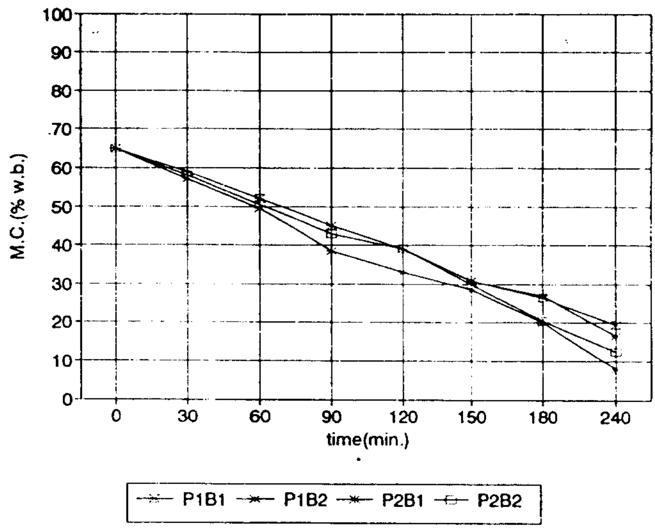

Fig. 5. Drying rate of straw mat according to the pressure and the pressing time

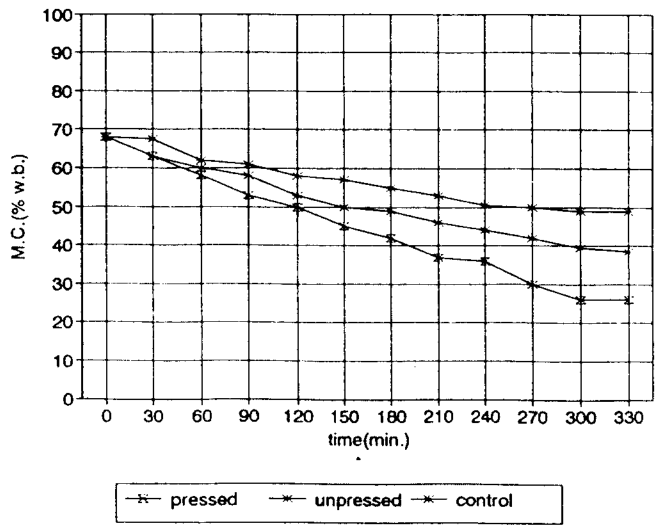

Fig. 6. Drying rate of thick straw mat

Table 1. Experimental methods and conditions for drying rate

Exp. No	Initial M.C. (% w.b.)	Pressure (kg/cm^2)	Drying method	Feed rate (g/cm^2)	Conveyor belt speed (cm/sec)	Remark
RR-1	66.8	4.8	Sun drying	0.165	8	pressed unpressed control
RR-2	65	3.4 5.8	Sun drying	0.165	8 18	pressed unpressed control

Table 2 Deformation of macerated barley straw

Feed rate (kg/hr)		327	655	982	1,309	1,636	1,946	control
Bulk density(g/ℓ)		22.2	22.5	21.5	19.7	23.2	20.2	30
Pressure (kg/cm^2)	0.11	0.71	0.69	0.72	0.74	0.72	0.74	0.66
	0.19	0.75	0.75	0.76	0.78	0.75	0.77	0.72
	0.27	0.78	0.77	0.78	0.79	0.78	0.79	0.77
	0.35	0.79	0.78	0.80	0.82	0.80	0.81	0.77
Plastic deformation		0.21	0.25	0.34	0.29	0.33	0.28	0.19

Table 3 M.C. of macerated and untreated barley straw in a dryer oven

Feed rate (kg/hr) / Time(hr)	327	635	982	control
0	0.747	0.697	0.697	0.61
0.5	-	0.413	0.357	0.50
1	0.217	0.187	0.207	0.40
1.5	0.067	0.087	0.083	0.31
2	0.027	0.030	0.027	0.13
3	0.010	0.013	0.007	0.094

Table 4 M.S.I. according to the belt speed

Belt speed (cm/sec)	M.S.I. (cm)
8	19.3
18	18.6

Table 5 M.S.I. according to the roll pressure

Pressure (kg/cm^2)	M.S.I. (cm)
3.4	21.3
4.8	21.5
5.8	22.8

Table 6 M.S.I. according to the no of roll

No. of rolls	Roll pressure (kg/cm^2)	
	3.4	5.8
1	24.2	24.3
2	24.7	21.2