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FIELD PERFORMANCE EVALUATION OF A STUBBLE CUTTING MACHINE COUPLED WITH A WINDROW GATHERING SYSTEM

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ABSTRACT: Stubble left in the field after harvest is a by-product in rice production systems. Presently, most of the stubble is burned in the field or mulched in the soil. In areas where the requirement for straw exceeds supply, stubble collection is carried out. With the height of stubble after harvesting of 25.3 cm, the available stubble yield is 3.1 ton/ha at a moisture content of 12%. In previous research, the use of a combine harvester to cut stubble simultaneously with harvesting was found to be inappropriate because of improperly designed equipment for this purpose. Thus, cutting and gathering stubble is still a challenge because of technological and economic reasons. In this study, the performance of a rice stubble cutting machine coupled with a windrow gathering system was evaluated along with an economic analysis of the use of the machine. We found that the machine performed well in the field with a capacity of 0.5 ha/h and the maximum rotary moment for driving the cutting disc was 168 N.m, corresponding to 14.1 HP at cutting speed of 52.3 m/s. At the cutting height of 4.9 cm, collected stubble yield was 2.0 ton/ha with the stubble loss in field of 7.3%. Using the machine for stubble cutting and gathering not only contributes to increasing rice farmers' income but has the added benefit of avoiding in-field burning of stubble that causes air pollution and greenhouse gas emissions.

Keywords: Stubble, Cutting machine, Windrow gathering, Performance evaluation

1. INTRODUCTION

Vietnam is a major rice producer with around 44.1 million tons of paddy harvested annually [1]. With the yield of straw and stubble per grain yield of, typically, 0.9 ÷ 1.1, a huge amount of straw and stubble is produced [2, 3]. Asides from the rice straw yield of 2.8 ton/ha [4], stubble left in the field after harvest is a by-product in a rice-based production system. At present, most of the stubble is burned in the field or mulched in the soil. In some provinces, such as Long An, Binh Thuan, etc., where the need of straw for soil covering is more than the supply, stubble collection at local rice fields is an attractive proposition. Such covering protects the soil from rain, sun, and wind. It increases soil moisture by allowing more water to sink into the ground and by reducing evaporation.

With the height of stubble after harvesting typically around 253 cm, the available stubble yield (excluding straw) is 3.1 ton/ha. The moisture content of stubble after harvest is around 12% which is equal to that of rice straw left in the field for a few days. In practice, the use of combine harvesters to cut stubble simultaneously with harvesting is inappropriate because of its improper design for this purpose. The cutting bar and thresher of the combine are overloaded due to low cutting height, which results in a high level of impurities such as mud and insects. Thus, cutting and gathering the stubble remains a technical challenge.

In this study, the performance of a rice stubble cutting machine coupled with a windrow gathering system was evaluated based on its cutting capacity, fuel consumption, stubble yield, and loss. In addition, the use of the machine was assessed in term of socio-economic and environmental impacts.

2. MATERIALS AND METHODS

2.1 Scope and Limitations

The field experiments were conducted in Long An (March 2017) and Tien Giang Provinces (April 2018) that located in Southern Vietnam. The area of the field site was 0.5 ha with the length of 100 m. The experiment was limited to the performance evaluation of the machine, together with a basic economic analysis.

2.2 Stubble Cutting Machine Description

The machine was designed with a cutting capacity of 4 ha per day. It was mounted at the back of a four-wheel tractor (46 HP at 2600 rpm) through a three-point linkage system. For the second test, it was matched with a 28-HP ISEKI tractor.

Fig. 1 Stubble cutting machine in action

Cutting disks with a diameter of 500 mm were driven by a Power-Take-Off shaft (PTO) of a tractor. Two-speed levels of PTO (540 and 750 rpm) were set up during the test. The windrow gathering system with four rake wheels was mounted at the back of the machine. Cut stubble was gathered in windrows based on the four self-rotary wheels with a diameter of 1 m. The angle of rake-wheels and forward direction was adjusted to the width of windrows after gathering.

2.3. The methodology of Data Collection and Calculation

Data collected during the test included ground speed of the machine, cutting speed, fuel consumption, cutting height, stubble loss in-field, stubble moisture content, and stubble yield.

The ground speed and working width of the machine are the basis for determination of its working capacity. The ground speed of the machine was calculated based on the measured working distance (50 m) and the time to pass. The data was recorded with 5 replications. It is computed as the following equation:

$$V_s = 3.6 * \frac{s}{t} \quad (1)$$

where: V_s = ground speed of the machine, km/h
s = measured working distance, m
t = time, s

Cutting speed was determined based on the speed and diameter of the cutting disks. It was tested with two-speed levels of PTO of 540 and 750 rpm and five replications for each level. It is computed as the following equation:

$$V_c = \frac{\pi * D * n}{60} \quad (2)$$

Where: V_c = cutting speed, m/s
D = diameter of cutting disc, m
n = revolution cutting disc, rpm

Speed and track of rake teeth were determined by the ground speed of the machine and rotary speed of the rake teeth. The rotary speed of the rake teeth was computed based on the revolution speed and its diameter. The ratio is used as an indicator to determine the working capacity of the gathering system. It is illustrated by the following ratio:

$$\lambda = \frac{V_o}{V_p}$$

where: λ = ratio between rotary speed and ground speed
V_o = rotary speed of rake teeth, m/s;
V_p = ground speed of the machine, m/s

The moisture content of the stubble was determined using a drying oven at 105°C for constant weight (about 24 hours) with 30-gram stubble samples [5]. Stubble samples were collected randomly in the field with five replications. It was calculated using the following formula:

$$MC = \frac{M_w - M_d}{M_w} * 100 \quad (3)$$

where: MC = moisture content, %
M_w = mass of wet stubble, g
M_d = mass of dry stubble, g

Available stubble yield was determined by cutting stubble in five 1-square-meter plots, scaling the collected amount of stubble, taking a sample for moisture content test, and converted to a moisture content of 12%.

Rice stubble loss in the field was calculated using the following equation [6]:

$$S_l = \frac{S_a - S_c}{S_a} * 100 \quad (4)$$

Where: S_l = rice stubble loss, %
S_a = weight of available stubble, ton/ha
S_c = weight of collected stubble after cutting, ton/ha

2.4. Pull Force and Torque Measurement

During the test, the pull force was measured using two tractors with the same specifications. Force measuring equipment was mounted between the two tractors. The first tractor was operated at the same speed that was determined during actual operation (Fig. 2).

Total power required for the machine include power for pulling on the field and power for driving the cutting disc. It was computed using the following formulas:

$$P = P_1 + P_2 \quad (5)$$

where: P = total power, HP
P_1 = pulling power, HP

Fig. 2 Pull force measuring

The torque for driving the cutting disc was determined using force measuring equipment mounted at the drive pulley (Fig. 3).

Fig. 3 Moment measuring

$$P_1 = \frac{N*v}{3600*0.75} \quad (6)$$

where: N = pull force, N

v = forward speed, km/h;

P_2 = rotary power, HP which is computed as following equation.

$$P_2 = \frac{M*2*\pi*\omega}{60*1000*0.75} \quad (7)$$

where: M = torque, N.m

ω is rotary speed, rpm

3. RESULTS AND DISCUSSION

3.1. In-field Performance of the Machine

The machine operated well in the field with a cutting capacity of 0.5 ha/h. The forward speed of the machine is 4.9 km/h, corresponding to 1.36 m/s. It is higher compared to straw chopper combine from 1.8 to 3.0 km/h [7]. During the test, average fuel consumption was 4.6 L/h.

The average cutting speed of the machine is 35.3 and 45.6 m/s, corresponding to speed levels of PTO of 540 and 750 rpm, respectively. According to Reznik [8], the optimum cutting speed for rice straw is 35 ÷ 40 m/s without a stationary bottom blade.

Rotary speed *[V_0]* and ground speed of rake teeth *[V]* depend on the ground speed of the machine and setting angle of the rake wheel *[β]* as follows:

$$V_0 = V_p * cos\theta = 0.96, \text{ m/s}$$

$$V = \sqrt{\left(V_p * cos\theta * sin\theta\right)^2 + V_p^2 * (1 - cos^2\theta)^2}$$

$$\beta = actg\frac{V_p * cos\theta * sin\theta}{V_p * (1 - cos^2\theta)}$$

With a constant ground speed, the rotary speed of rake teeth equals ground speed and zero when the setting angle is zero and 90^0, respectively (Fig. 4). It is recommended that the appropriate speed of the PTO is set at the speed of 750 rpm.

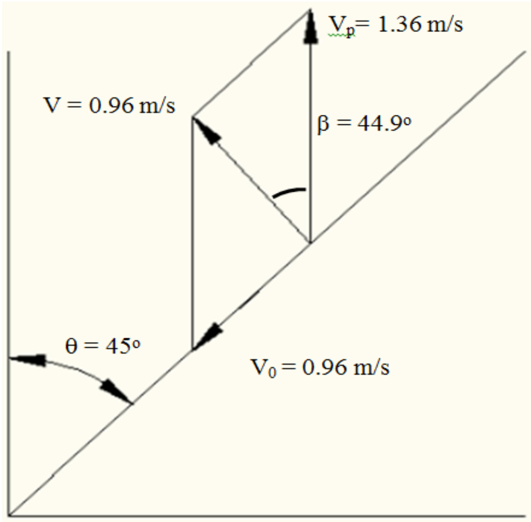

Fig. 4 Track of wheel rake teeth

For the in-field tests, with a diameter of 1 m, the rake wheels rotate at a speed of 17 rpm. Rotation speed depends on the ground speed of the machine, and angle setting of the rake wheels. For the first step in this study, the rake wheels were set at an angle *[θ]* of 45^0. With ground speed *[V_p]* of 1.36 m/s and rotary speed *[V_0]* of 0.89 m/s, the ratio of gathering speed *[λ]* is 0.65.

The track of rake teeth is parallel lines (Fig. 5) with the angle *[β]* of 44.90 and a speed *[V]* of 1.06 m/s. The cut stubble was gathered in windrow due to the force of rake teeth as shown in Fig. 8.

3.2. Pull Force and Moment

The maximum pull force and torque were 2914 N and 168 N.m, respectively (Fig. 6 & 7). Both pull force and torque fluctuated due to the difference in the field and remaining stubble conditions. With a forward speed of 4.9 km/h and the rotary speed of 600 rpm, the power for pulling the machine and power for driving the cutting disc was 5.3 HP and 14.1 HP, respectively. Thus, the total power required was 19.4 HP. It means that the designed machine would be matched with a 28-HP tractor, which was used in the test.

Fig. 5 Track of wheel rake teeth on the field

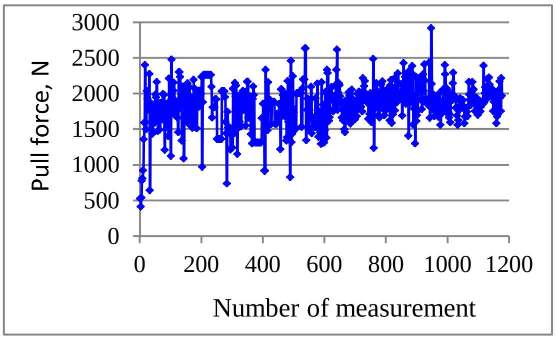

Fig. 6 Fluctuation of pull force

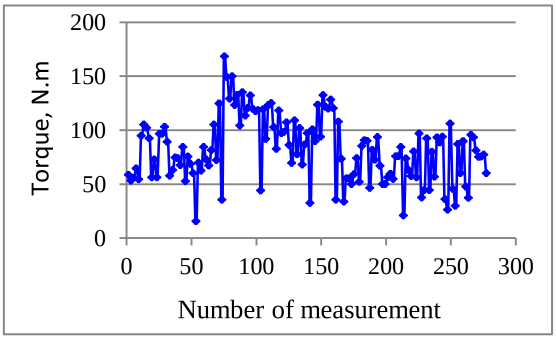

Fig. 7 Fluctuation of torque

3.3 Stubble Height and Loss after Cutting

The average height of stubble after cutting is 4.9 ± 0.8 cm with the sample size of 5 replications. The height is still greater than the requirement of farmers. However, it would be adjusted by changing the position of the lifting bars. For the existing machine commonly used by farmers, the cutting height is 6.6 ± 0.9 cm.

Stubble loss in the field varied from 4.5 to 9.9% with the average of 7.3 ± 2.2% and the sample size of 5 replications. The variation of value is due to the difference in lodging percentage of stubble after harvesting.

3.4 Windrow Gathering, Baling and Stubble Yield

The amount of stubble left in the field depends on the cutting height after harvest. With a cutting height of 15 to 37 cm, stubble yield varied from 1.3 to 4.4 ton/ha for converted moisture content of stubble of 10% (Fig. 8). Meanwhile, the straw yield is 2.8 and 4.5 ton/ha, corresponding to cutting height of 30 cm, and 15 cm, respectively.

The stubble cut is gathered into windrows with the width of 70 cm (Fig. 9), fitting with the operation of existing straw balers. During the test, a straw baler (MRB0855T) was used for collecting stubble in round bales with a dimension of 50-cm diameter, 70-cm length and about 29.0 ± 1.5 kg in mass.

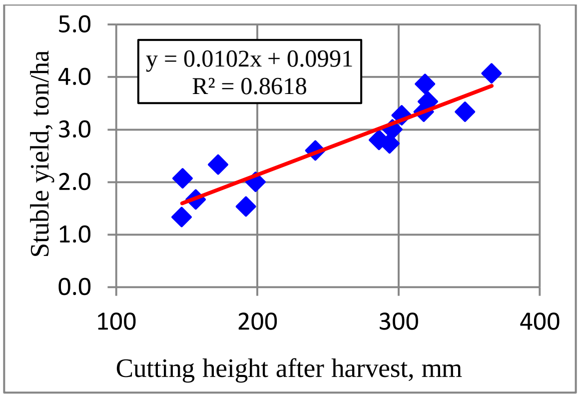

Fig. 8 Stubble yield depending on cutting height after harvest

Fig. 9 Row of stubble after cutting and gathering

With the stubble loss in field of 7.3%, the collected yield is 2.0 ton/ha at a moisture content of 12% which was converted from 53.1% of stubble right after harvest.

3.5 Economic Analysis

Economic aspect was analyzed based on the operation cost for stubble gathering and extra income from the sale of stubble. Cost of stubble collection includes costs of depreciation, repair, labor, fuel, renting of the tractor, and in-field stubble with the total of 10.0 $US/ton (Table 1 & Fig. 10), in which, the highest cost is for fuel consumption (3.4 $US/ton). With the investment cost of $US3100, and field working capacity of 0.5 ha/h, the pay-back period is 2.0 years, and internal rate of return is 27%.

Table 1. Input data for economic analysis

Investment cost, $US	3 100
Life-span, year	5
Repair ratio	1.2
Renting of the tractor, $US/day	22
Bank interest, %/year	12
Field capacity, ha/hr	0.5
Field capacity, ha/day	4
Working hour per day	8
Working day per crop	30
Crop per year	2
Labor cost for tractor driver, $US/day	17
Price of straw bale, $US/bale	0.7

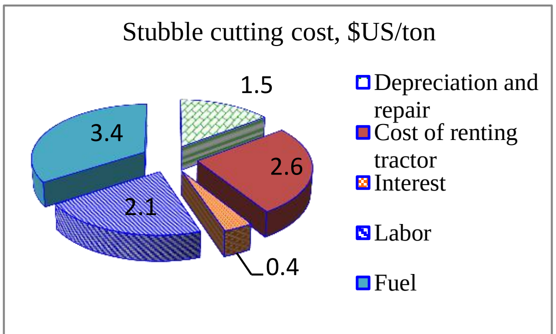

Fig. 10 Stubble cutting cost

At the study site (Long An Province), farmers sell their straw on-field with the price of 20 $US/ha. Assuming the same price with straw, the price of stubble at a moisture content of 12% is 38.5 $US/ton, corresponding to $US0.7 per round bale). With the yield of 2.0 ton/ha, the extra income corresponds to 77 $US/ha.

3.6 Environmental Impact

With the percentage of C in the straw of 41% [9], and based on the combustion equation, burning 1 ton of straw will emit 1.2 tons of CO_2. When stubble is used instead of burnt in the field, the equivalent amount of CO_2 emission reduction is about 2.4 ton/ha. Together with CO_2, stubble burning also emits 10,04 kg/ha of CH_4 and 0,154 kg/ha of N_2O [10].

In addition, the amount of carbon emitted as CO has been subtracted from the total stoichiometric CO_2-emission calculated based on the carbon content of stubble. Thus a global warning potential factor is calculated for CO with a ratio of 1.57 kg CO_2-eq per kg CO [11].

4. CONCLUSION

In general, in-field performance of the rice stubble cutting machine coupled with a windrow gathering system is satisfactory in its working capacity and other parameters. In addition, removing stubble from the field after harvesting creates good conditions for land preparation for subsequent crops. Using the machine for stubble cutting and gathering not only contributes to increases in rice farmers' income but also creates more benefits such as avoiding in-field burning of stubble that causes greenhouse gas emissions.

5. ACKNOWLEDGMENTS

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