Design and Performance Evaluation of Dwarf Napier Grass Harvester

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Abstract. Green forage is very important ingredient for animal feed either for meat cows or dairy cows. One of forage variety that now days becoming popularly used as animal feed is dwarf napier grass (*Pennisetum purpureum* cv Mott) because it has high productivity with short harvesting period. Cultivating dwarf napier grass is not difficult for the farmer, however harvesting this grass is quite difficult, hard work and generally still done manually by using a sickle. The purpose of this study is to design and evaluate performance of a harvesting machine for dwarf napier grass. Method of this research was common machine development method including functional and structural design analysis approaches. Performance test results showed that the machine was capable to harvest two rows of planting grass in one pass and average cutting height of 7.9 cm when using big tire and 8.6 cm when using small tire. The machine with large tire has Theoretical Field Capacity (TFC) 0.255 ha/hour, while its Effective Field Capacity (EFC) was 0.191 ha/hour and Field Efficiency (FE) was 75.01%. The result of performance test using small tire the TFC was 0.205 ha/hour, EFC was 0.145 ha/hour and FE was 71.04%. It was concluded that the newly modified napier grass harvester was satisfactorily designed and its performance increase harvesting efficiency.

1. Introduction
Livestock in Indonesia is the main sector to complete fiber and other animal elements need. The government continues to increase domestic livestock production, especially in ruminant animals such as cattle. Based on data of Indonesian Central Statistics Agency (BPS) Indonesia [1] cattle population in Indonesia continues to increase from 2009 with 12.76 million up to 2016 with 16.09 million cattle. Increasing ruminant animals population requires an increase in adequate animal feed stock. Especially forage foods such as grass, sorghum, corn and others. It is reported [2] that the highest grass and legume production was achieved at the beginning of the dry season, while the lowest production was achieved at the beginning of the rainy season.

The grass variety commonly used is napier grass (*Pennisetum purpureum* cv Mott) which is known as “odot” in local name. This grass is very popular because it is drought resistant, has a high nutrient content and has a high palatability for ruminants [3]. Odot grass has a high leaf ratio compared to the stem so that the distance between segments will be more compact [4]. Generally the odot grass harvesting process using a sickle or mower. Based on ergonomic side, both harvesting machines will cause fatigue in the operator's arm or shoulder. This study aims to analyze the design of a rice harvesting machine (reaper) to be modified into an napier grass harvesting machine. Modifications to the design were made to suit the needs of odot grass harvesting.
2. Methodology
The research was conducted at Siswadhi Soepardjo Field Laboratory, Mechanical and Biosystem Engineering and Farming Laboratory, Faculty of Animal Husbandry, IPB University. The materials used to make prototypes are a paddy reaper, odot grass, and construction steel. The method used in this study is a design method with a technical design approach that deals with various large unstructured problems. The method steps follow engineering design process, carried out by identifying problems, developing design concepts, analyzing designs, manufacturing/modification and performance testing.

The method of the performance test is carried out on several lines of napier grass field. The field area is 18.5 x 7.2 m with a total of 10 rows of odot grass. The scheme of the land for testing the performance of this machine can be seen in figure 1. This test is carried out by the central round method where harvesting is carried out from the outer line then moving to another line from the outside to the inside/center field. This method was chosen because it is an effective way for harvesting napier grass considering the mechanism of harvesting yields to the right side of the machine. Performance measurement was done by measuring Theoretical Field Capacity (TFC), Effective Field Capacity (EFC) and Field Efficiency (FE). TFC is cutting with multiple by forward speed, EFC is actual time per area of harvesting and FE is defined as percentage between EFC and TFC. In this field test two types of wheel were evaluated namely 1) small wheel with 52 cm diameter and 12 cm with and 2) large wheels with 65 cm diameter and 22 cm width.

![Figure 1. Field performance test scheme](image)

2.1 Design Criteria

1. The machine should cut the stems of napier grass with a clean cut without being torn.
2. The minimum cutting height is the former grass cutting stump or about 6-10 cm.
3. The reaper divider can comb grass in two rows with row spacing of 55-70 cm.
4. The results of cutting the napier grass stems can be carry out to right side of machine.
5. The machine can pass napier grass without running over the cutting rest (grass stump).

3. SIMULATIONS AND DISCUSSIONS

3.1 Design Concept
The design concept of reaper modification is focus on napier grass cutting mechanism and divider unit (figure 2). The cutting mechanism uses divider blades which consists of upper and lower blades. The upper blade will move dynamically right to left quickly while the lower knife will be static. The space between the blades is 5 cm so that it is enough to cut the grass stem which has an average diameter of 2.5 cm. Dividers which initially amounted to five units were reduced to three units. It aims to harvest double row odot grass in a single harvesting process. The distance between dividers is 70 cm.
3.2. Structural Analysis

3.2.1. Main Frame Analysis. The main frame is composed of C-channel steel and steel plate. The back side is welded to steel plate that holds the load of the driving motor and the gearbox. Frame design simulations used Solidworks Software with static loading 139.2 kg. This simulation aims to determine the strength of material used to be safe. The result of main frame stress simulation can be seen in figure 3. Based on this simulation, the stress value at frame material are safe. This can be seen from the blue indicator which shows the stress value of $6.134 \times 10^3$ N/mm$^2$. The maximum stress occurs at the front end frame which is valued at 30 N/mm$^2$. The value of the stress is very small compared to the value of the allowable stress limit of yield strength, which is 530 N/mm$^2$. Similar simulation were also to other machine structure.

3.2.2. Modification of Odot Grass Cutting Height. The optimum cutting height for napier grass is around 10 cm [5]. Whereas in the initial design of this reaper the cutting height was 15-30 cm from the ground surface. Cutting will be arranged by adding a supporting frame that adjusts the design. This supporting frame connects the cutting unit frame to the main frame by lowering the position of the cutting unit frame. This component is made of 40 x 40 mm L shape steel bar with a thickness of 5 mm made from galvanized steel.
3.3 Performance Test Analysis

3.3.1. Cutting Performance. The performance test results showed that the harvester cut the napier grass stem and bring out the harvested grass to the right side. The results of cutting grass also look good without any fiber coming out and without cracking as shown in figure 4. Based on the results of the cutting test, the height of cutting using a small wheel is higher than using a large wheel due to the position of the center of machine gravity using a smaller wheel closer to operator, so that the machine is more easily lifted up. However, this does not have a big effect because the knife is not raised too high and the knife can cut the grass directly. This can be seen from the cutting height data using large and small wheels which are not too much different. Another parameter measured from the harvesting capability of this machine is the diameter of the stems of the odot that has been successfully cut. Based on these data it is known that the average diameter of the trunk of the cut odot is 1.631 cm. The maximum truncated diameter of the trunk is 2.11 cm.

![Figure 4. Odot grass cutting result: (a) stems; (b) remaining stumps](image)

3.3.2. Blade Cutting Speed. Cutting speed is the main parameter that influences machine performance. The cutting knife used is a type of cutter bar knife. Based on the results, single PTO rotation is equal to 0.75 of the cutter bar's back and forth motion. The back and forth motion of the blade is along the pitch (the distance between the tips of the blades) which is 59 mm. So that the distance of one blade movement cycle is 118 mm. The blade speed is 5.16 m/s at an engine shaft rotational speed of 3079 rpm. At the engine shaft rotational speed the average forward speed of the machine using a large wheel is 0.472 m/s. These data represent a number of selected sample areas at random. The area taken was 5 x 3 m totaling 3 random plots. On average, the odot grass were completely cut off were as much as 56.4%, partially cut stem were 41.2% and 2.4% of stem were not cut at all. Some of these stems partially cut occur due to the presence of several grass stalks that have been cut but failed to be pulled by the chain runner/steering unit. The grass stems blocking out the available space for the blade.

3.3.3. Harvesting Side Remover Performance. The side remover mechanism uses a chain which is equipped with several hooks to pull, remove and lay down the crop to the right side of the machine. Based on the figure 5 it can be seen that the grass is cut into the cutting unit and pulled by the steering unit and immediately laid down to the right side. While machine moves forward, the odot grass is removed to the right side so that the grass can be neatly arranged along the harvesting path. The removing results are also seen in a safe position and the wheel could not run over the rest of the grass stump (figure 5). After that farmers only need to collect the harvest at some collect points. So this method can be more effective for harvesting odot grass than conventional methods.
3.3.4. Field Capacity and Efficiency. The capacity and efficiency result provide data on the forward speed, the operating time, the actual area used and the weight of the grass harvesting capacity. The data is the main data to find out TFC, EFC and FE. In the process of analyzing the performance of this machine used average forward speed data on transmission 1 with engine rotational speed of 3068 rpm and using large and small wheels as independent variable (comparison) the results of the performance of machine testing. Calculation of capacity and field efficiency of this machine presented in table 1.

| Wheel Type  | TFC (ha/hour) | EFC (ha/hour) | FE (%) | Slip (%) | Right Wheel | Left Wheel |
|-------------|---------------|---------------|--------|----------|-------------|------------|
| Big Wheel   | 0.255         | 0.191         | 75.01  | 16.21    | 19.81       |            |
| Small Wheel | 0.205         | 0.145         | 71.04  | 7.36     | 7.36        |            |

Based on measurements and analyze field capacity, it is known that the value of TFC is bigger than EFC. The TFC of large wheels is 0.255 ha/hour and EFC is 0.191 ha/hour, so that the FE of this machine using large wheels reaches 75.01%. Performance testing using small wheels showed the value of TFC of 0.205 ha/hour and EFC of 0.145 ha/hour, so the FE using small wheels is 71.04%. The field capacity results were mainly effected by the machine forward speed. The value of field capacity and field efficiency using large wheels is bigger than using small wheels due to the forward speed using large wheels is higher. This happen because a larger wheel diameter will travel a longer distance in the same rotational speed.

The field efficiency is also influenced by wheel slip. Slip is a condition in which a tractor experiences repetitive wheel rotation at one location with a certain slippage level. Slip value using large wheels is higher than using small wheels because the large wheels used have a smaller footprint width than the small wheels. The small wheel width is 22 cm while the big wheel width is 12 cm. The wider wheel will increase wheel traction because the contact surface area with the ground is bigger. A comparison of the design of large and small wheel lugs used can be seen in figure 6. In addition, the design of different traction wheel fins causes smaller wheels which have a horizontal and thinner fin design to give greater traction. The thickness of the big wheel fins is 15 mm while the thickness of the small wheel lugs is 3 mm. These thinner lugs will increase wheel traction. Therefore using a small wheel is more effective to reduce the amount of slip that occurs. The machine performance can also be analyzed by measuring the grass weight result. Wet basis yield weight data on performance testing in the field is 30.7 kg per two rows. The area of machine performance testing is 0.013 ha, so the yield weight that can be achieved with this machine is 11524 kg/ha. The weight of this crop is influenced by the quality of the grass.
harvested, the level of water content of the grass, the number of tillers in each clump, spacing of grass and the density of grass in the land.

Figure 6. Comparison of big and small wheel: (a) fin design; (b) size

4. Conclusion
Reaper modification have been successfully manufactured and tested. Modification scopes are shaft enlargement, the addition of supporting frames, divider modification and performance results comparison using two types of wheels, namely large wheels (diameter 65 cm) and small wheels (diameter 52 cm). Material strength analysis shows that shaft, main frame and supporting frame are safe and strong to use. This machine can harvest in two planting rows in single process, the results of cutting can be slide to right side of machine continuously and the remaining stumps are not crushed by wheel or operator. The average cutting height is 7.875 cm using a large wheel and 8.556 cm using a small wheel. The maximum speed of machine is 1.355 m/s. The machine is operated at transmission 1 and the engine shaft rotational speed is 3068 rpm. TFC obtained using large wheels is 0.255 ha/hour while the EFC of the machine is 0.191 ha/hour and FE is 75.01%. The results of the performance of the machine using a small wheel showed TLC value of 0.205 ha/hour, EFC of 0.145 ha/hour and FE value of 71.04%.

5. References
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