

## **To Develop a Tractor-Mounted Punching Machine That Efficiently Perforates Plastic and Biodegradable Mulching Sheets for Optimized Plant Growth**

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### **ABSTRACT**

Mulching is a method of covering the ground to retain moisture, increase soil fertility, and improve aesthetic appeal. Plastic mulches can be used to cultivate various vegetables, such as muskmelons, honeydews, cucumbers, tomatoes, peppers and watermelons etc. However, traditional methods like hand tools such a sharp circular pipe and a heated bowl filled with hot elements, and organic mulch sheets are not suitable for large-scale mulching. There is a risk that the user might be burned or injured if they use this. A tractor-drawn mulch sheet punching machine has been developed to reduce operating time and energy costs while improving consistency and safety in punching holes on mulching sheets. The machine's performance was assessed in field experiments with the 1.5 km/h, 2.5 km/h, and 3.5 km/h forward speed ranges, revealing that it saves 56.06% of fuel, 58.03% of time, and 44% of operating energy compared to current mulching techniques. The machine also completes mulching tasks 84.47% faster than traditional hand mulching, and designed equipment saves around 81.17% of operating time. From an economic perspective, the cost of operation 767.02 per hour and 5771.40 per hectare were found. The payback period of the developed machine is 5.87 years, minimizing overall operational time and energy costs for the mulching operation.

### **KEYWORDS**

Plastic Mulch, Biodegradable Mulching Sheets, Organic Mulch Sheet, Mulch Sheet Punching Machine, Tractor-Mounted Punching Machine.

### **INTRODUCTION**

The Ministry of Statistics & Program Implement (MOSPI) has released the second advance estimates of national income for 2022-23, showing agriculture's share in the total economy at 20.3%, 19%, and 18.3% respectively. The Ministry of Agriculture and Farmers Welfare has released preliminary estimates for major crop production for 2022-23, estimating food grain production at 3235.54 lakh tonnes (PIB Delhi 21 march 2023). Agriculture depends heavily on natural resources, with water being a significant limiting factor in enhancing production.

Farmers in recent years have adopted various techniques to overcome the problem of access use of water in crop production. Mulching is one such technique being practiced not only to conserve the water but also to improve the soil's physical characteristics, improve

plant growth and also increase productivity. ‘Molsch’ is a German word is the source for the term mulch which means an organic or inorganic material used to spread over the upper surface of the soil (Kaisrajan and Ngouajio 2012).

Mulching is one of the potential protected cultivation approaches to serve this purpose. It is a type of ground cover that can include manure, saw dust, seaweed, litter, stubbles, sands, pebbles, plastics, and other natural products. While the term mulching is a practice of covering the surface of soil with these materials to reduce moisture loss, and to balance wide variations in diurnal soil temperatures, especially in the root zone. It controls evaporation loss, and minimized energy supply to the evaporating site by cutting off solar radiation falling on the ground.

Mulching is crucial for limiting the first stage of drying, ensuring optimal moisture status, reducing soil temperature, preventing seedling mortality, and improving crop stand. The process reduces weed-flora competition with crop plants for water and nutrients, thereby increasing their availability for crop plants. In addition, mulching helps in improving downward movement of water. The efficiency of mulches in preserving moisture has usually been established to be greater under higher rainfall, drought conditions and during vegetative stages of crop growth when canopy cover remains scanty (Pedda Ghose Peera S. K. *et al.*, 2020).

This chapter deals with the design, development of mulch sheet punching machine and mulching farming factors. The review discusses the growing interest in plastic mulching for fruit and vegetable crops, with global mulching areas increasing by 50% since 1991. Black polyethylene paper mulch is recommended for vegetables, offering better fruit quality and yield. Mechanical techniques are preferred for efficiency and weed and insect control (S.V. Pathak *et al.* 2018). They work on mulches and various kind of mulching materials used in horticultural crops in different climate conditions according to different approaches. In mulching, plastic mulch, especially black plastic polyethylene are mostly used due to its good result, minimal prize and some biodegradable mulches are also used because it can be left in filed after harvesting of crop but they are more costly than plastic mulch and less durable than polyethylene (Monisha Rawat, *et al.*, 2020). This paper discusses research on organic and inorganic mulches, focusing on their use in agricultural environments. Organic mulch improves soil health, while black plastic mulch is highly effective. Biodegradable films are being introduced, and both types are beneficial for farmers to increase crop production (Kangujam Bokado, *et al.*, 2022). This review explores various types of mulches for dry land agriculture, including stubble, plastic, straw, and vertical mulching. Straw, despite being low in nutrient value, improves soil fertility after decomposition. Rice straw and black plastic mulch offer higher soil moisture conservation, protecting soil from sunlight and reducing evaporation. These practices can improve crop yield in dry land farming (N. Indianraj, *et al.*, 2022).

## **MATERIALS AND METHODS**

Here, the development, fabrication and testing of tractor operated punching machine for plastic and biodegradable mulching sheet have been described. Fabrication of the machine is done according to the mechanical and agronomical design considerations. The developed machine was designed in design software Auto-CAD. The present study was conducted during the year 2022-2023. The description of location of study area, experimental details, and observation recorded and methods adopted throughout the course of study entitled “Design and development of tractor operated punching machine for plastic and biodegradable mulching sheet, are presented under following heads-

- i. Measurement of Field Parameters
- ii. Design considerations.
- iii. Constructional details of the punching machine for plastic and bio-degradable mulching sheet.
- iv. Performance evaluation of punching machine for plastic and bio-degradable mulching sheet
- v. Cost estimation of the machine.

## **MEASUREMENT OF FIELD PARAMETERS**

### **Land preparation**

The land preparation for the testing of “Tractor operated mulch punching machine” was done with the help of tractor drawn rotavator, land leveller and mulching laying machine. The field was prepared by pulverizing the soil with the help of tractor drawn rotavator, and the land leveler was used to level the field before mulching operation.

### **Soil parameters**

The soil properties relevant to the design of punching machine for mulch sheet were identified as soil moisture, bulk density and cone index. The methods of measurement and characterization of these properties are discussed under the following headings.

### **Soil moisture**

Moisture content of soil affects draft of implement and slip. Soil having more moisture content gives more slip and hence increases the draft. The punching operation for mulch sheet was carried out at optimum soil moisture content in order to minimize field time losses, missing holes, energy input. Soil moisture content (%) on dry basis was determined by taking soil samples from three different locations at three different depths within a plot. The soil moisture was measured by oven dry method. The collected soil samples from each location were weighed initially and then kept in an oven for 24 hours at 105°C for obtaining dry weight of soil and again dry weights were taken (IS: 2720-2-1973).

The moisture content on dry basis was calculated using following equation.

$$\text{Soil moisture content (per cent dry weight basis)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

$W_1$  = Weight of wet soil sample, kg

$W_2$  = Weight of the oven dried soil, kg

### Bulk density

Bulk density of soil is the mass of oven dried soil per unit volume of soil. Soil samples were taken randomly from the field with the help of core cutter. The diameter and length of core cutter was 100 mm and 127.5 mm respectively. The collected samples from core cutter were placed in oven at 105 °C for 24 h for drying. The bulk density was determined by dividing the weight of oven dried soil sampled by volume of core cutter volume and calculated by using following formula.. The bulk density of soil was calculated by following equation.

Bulk density,  $\rho$  ( $\text{g cm}^3$ ) = (Mass of soil sample) / (Volume of core cutter)

$$\rho = \frac{M}{\pi D^2 L}$$

Where,

$\rho$  = bulk density,  $\text{g / cm}^3$

M = borne dry weight of soil sample, g

D = diameter of cylindrical core sampler, cm

L = length of cylindrical core sampler, cm

### DESIGN CONSIDERATIONS

The development of tractor operated punching machine for mulching sheets was designed as a functional and experimental unit. The design of machine components was based on the principles of operations and field tests. It was compared with the traditional as well as different method, to give a correct shape in form of prototype. The mechanical design details were also given with due attention so that it gave adequate functional rigidity for the design of machine.

#### Theoretical consideration for design

The development of tractor operated punching machine for different mulching sheets consists of several steps and would require basic information about the following-

- i. The development of machine will be tractor operated hence the total power requirement should not exceed the drawbar power of tractor.
- ii. Soil and climatic conditions during operation.
- iii. Field condition during operation.
- iv. Size of land holding.
- v. Socio-economic conditions of farmers.
- vi. Laborers requirements for operation.
- vii. Level of manufacturing skill at small finished components.
- viii. Ease of operation and maintenance.

- ix. Safety in operation and operator's comfort.
- x. Expected level of cost of machine and cost of operation.
- xi. Make design of the machine in computer aided software (*i.e.* solid works).
- xii. The economic justification could be based upon its long usage or related to the overcoming the timeliness constraints and effect on yield in conjunction with other essential inputs.

## **RESULT AND DISCUSSION**

This chapter presents results of the field performance of the developed punching machine for different mulch sheet. The results of speed, draft requirement, power requirement, field capacity, field efficiency, punching uniformity, cost of fabrication, etc. are discussed in detailed-

- i. Results of field related parameters
- ii. Results of operating parameters
- iii. Results of performance parameters
- iv. Cost analysis

## **RESULTS OF FIELD RELATED PARAMETERS**

### **Soil moisture content**

Soil samples were taken randomly from three different locations of the field at depth of 0 m, 0.10 m and 0.15 m from the surface of soil. The average moisture content at 0 m, 0.10 m and 0.15 m depth was found 5.83 %, 11.81% and 12.95% (db) respectively. Observed data of soil moisture content are presented in Appendix-A.

### **Bulk density of soil**

Soil sample was taken by core cutter method to determine bulk density of the test field soil. The inner diameter and length of the used core cutter were 100 mm and 127.5 mm respectively. The sample initially weighted before placing into an oven for 24 hours at 105 °C. After drying, the weight of sample was again measured. The calculated value of bulk density of field soil was found 1.23 g/cc.

## **RESULTS OF OPERATING PARAMETERS**

The tractor drawn mulch punching machine was tested in the experimental field of VIAET & SHUATS Prayagraj. The shape of field was rectangular and the area of total plot was 60m x 30m, where the field preparation was done by using MB plough, cultivator and mulch laying machine. The bed size of 60cm width, 10-15cm height was prepared. The field was well prepared which was adequate for lying of plastic mulch. After mulch laying operation the field performance test was conducted in order to obtain actual data for overall machine performance, operating accuracy, work capacity, field condition and field efficiency. During

field testing the parameter like draught, speed of operation, field capacities, field efficiency and power requirement were also measured.

### **Speed of Operation**

Speed of operation was calculated by observing the time required to cover the distance of 30 m. The calculations are done by using equation 3.3. Time was recorded using stop watch. The average value of the speed was found 2.5 km/h.

### **Draft of developed machine**

Draft of the developed mulching machine was determined by using 5 ton load cell which was placed between two tractors and implement was hitched by the rear tractor. The average draft of the developed machine was found to 213 kgf (2.2kN). The value of draft was calculated by using equation 3.4.

### **Power requirement**

The power requirement for the operation of developed mulching machine which was operated by tractor and power used from tractor was drawbar power. The average power requirement was found to be 15.66 kW (21.4hp). The values of power requirement are calculated by using equation 3.5.

### **Operating time**

During the operation the average time observed to operate the machine in total area of plot 180m<sup>2</sup> at treatment T1, T2 and T3 with speed 1.5 km/hr, 2.5km/hr and 3.5km/hr respectively. The observations of the average operating time for punching plastic mulch and bio-degradable mulch are shown in table 4.1 and 4.2.

**Table 4.1 Operating time for plastic mulch sheet**

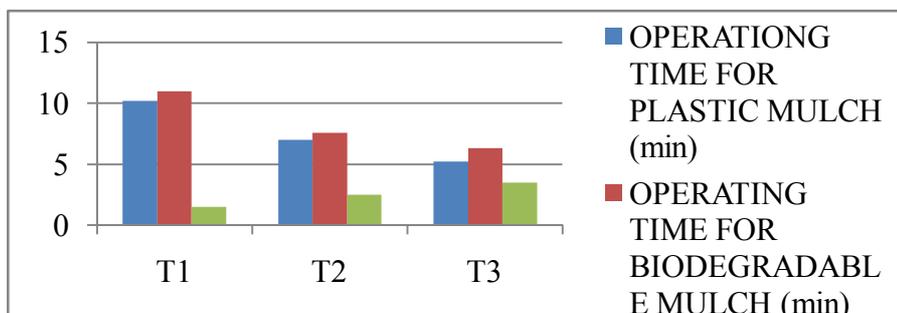
| <b>Treatment</b> | <b>Speed of Operation (km/h)</b> | <b>Operating Time (min)</b> |
|------------------|----------------------------------|-----------------------------|
| T1               | 1.5                              | 10.20                       |
| T2               | 2.5                              | 7.00                        |
| T3               | 3.5                              | 5.20                        |

**Table 4.2 Operating time for bio-degradable mulch sheet**

| <b>Treatment</b> | <b>Speed of Operation (km/h)</b> | <b>Operating Time (min)</b> |
|------------------|----------------------------------|-----------------------------|
| T1               | 1.5                              | 11.00                       |
| T2               | 2.5                              | 7.58                        |
| T3               | 3.5                              | 6.32                        |

**Comparison between operating time for plastic mulch and bio-degradable mulch sheet**

From figure 4.1 observation we get that for bio-degradable mulch sheet required time of operation is high (11 min) at lowest average speed 1.5km/hr. At speed 3.5km/hr for plastic mulch the operating time is 5.20 min which is lowest time of operation.



**Figure 4.1 Effect of speed on operating time**

**Fuel Consumption**

During the operation, the average fuel consumption observed for T1, T2 and T3 are calculated at different speeds. The Table 4.3 shows the fuel consumption (l/h) of tractor during operation at given speed.

**Table 4.3 Fuel consumption of machine with speed**

| Treatment | Speed of operation (km/h) | Fuel consumption (l/h) |
|-----------|---------------------------|------------------------|
| T1        | 1.5                       | 2.4                    |
| T2        | 2.5                       | 3.02                   |
| T3        | 3.5                       | 4.38                   |

**Wheel Slip**

The observations for determining the wheel slip at speed level 1.5 km/h, 2.5 km/h and 3.5 km/h were shown in Table. 4.4. The calculations for wheel slip are done by equation 3.6.

**Table 4.4 wheel slip of machine with speed**

| Treatment | Speed of operation (km/h) | Wheel slip (%) |
|-----------|---------------------------|----------------|
| T1        | 1.5                       | 2              |
| T2        | 2.5                       | 2.5            |
| T3        | 3.5                       | 3.2            |

**RESULTS OF PERFORMANCE PARAMETERS**

**Effect of different mulching sheet on theoretical field capacity, effective field capacity and field efficiency of developed machine.**

The theoretical field capacity, effective field capacity and field efficiency of developed machine are for doing operation on plastic mulch and bio-degradable mulch with treatment T1, T2 and T3 with different speed variations are shown in table 4.5 and 4.6. The average

field efficiency plastic mulching sheet was found 84.33 %. The average field efficiency for Bio-degradable mulching sheet was found 77.33 %.

**Table 4.5 Field Efficiency for plastic mulch sheet**

| Treatment | Operating speed (km/hr) | TFC (ha/hr) | EFC (ha/hr) | FE (%) |
|-----------|-------------------------|-------------|-------------|--------|
| T1        | 1.5                     | 0.11        | 0.10        | 90     |
| T2        | 2.5                     | 0.18        | 0.15        | 83     |
| T3        | 3.5                     | 0.25        | 0.20        | 80     |

**Table 4.6 Field Efficiency for Bio-degradable mulch sheet**

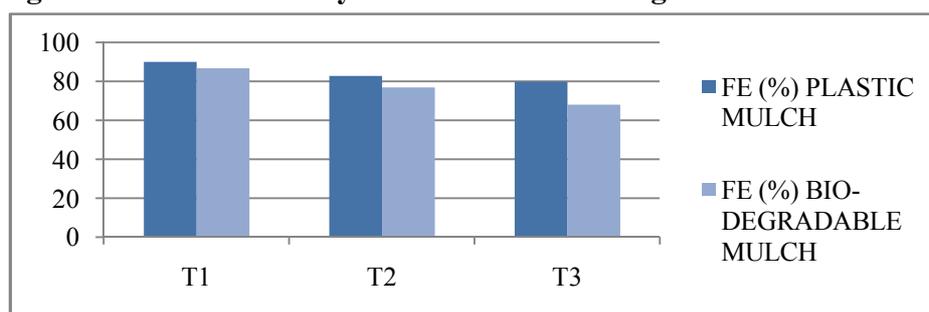
| Treatment | Operating speed (km/hr) | TFC (ha/hr) | EFC (ha/hr) | FE (%) |
|-----------|-------------------------|-------------|-------------|--------|
| T1        | 1.5                     | 0.11        | 0.09        | 87     |
| T2        | 2.5                     | 0.18        | 0.14        | 77     |
| T3        | 3.5                     | 0.25        | 0.17        | 68     |

#### Comparison between field efficiency of plastic and bio-degradable mulch sheet

Comparison between field efficiency of plastic and bio-degradable mulch sheet for T1, T2 and T3 at speed 1.5, 2.5 and 3.5 km/hr respectively shown in figure 4.4.

From figure 4.4 we observed that the field efficiency for plastic mulch sheet at speed 1.5km/hr for T1 is 90% which is highest. Field efficiency for bio-degradable mulch sheet at speed 3.5 km/hr for T3 is lowest 68%. Also we observed that as increasing operating speed field efficiency for both mulching sheet is decreases.

**Figure 4.4 Field efficiency of Plastic and Bio-Degradable mulch sheet**



#### Effect of mulching sheet on punching efficiency of developed machine

The punching efficiency of developed machine for doing operation on plastic mulch with treatment T1, T2 and T3 with different speed variations are shown in table 4.7. The value of punching efficiency was calculated by equation 3.10. The average punching efficiency for plastic mulch was found 80.85%.

**Table 4.7 Punching efficiency for plastic mulching sheet**

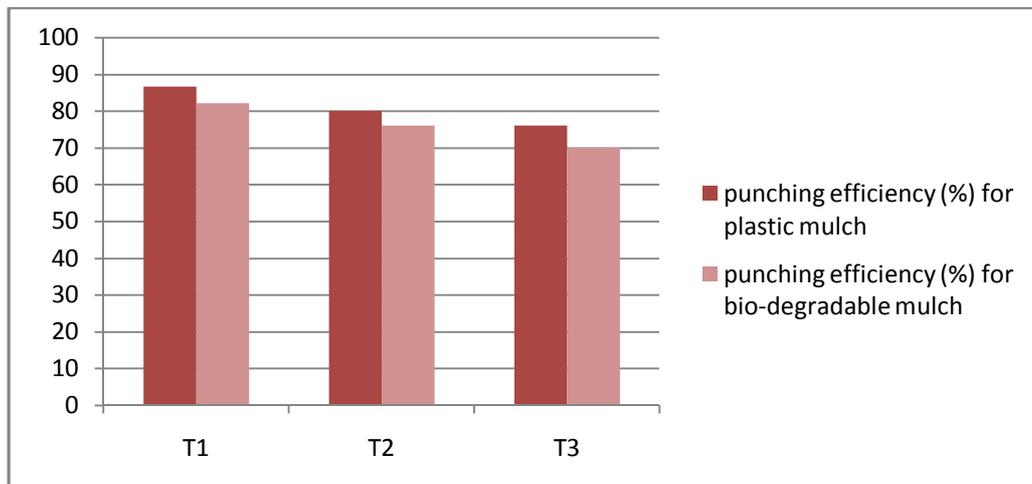
| Treatment | Speed of Operation (km/h) | Punching efficiency (%) |
|-----------|---------------------------|-------------------------|
| T1        | 1.5                       | 86.56                   |
| T2        | 2.5                       | 80                      |
| T3        | 3.5                       | 76                      |

The punching efficiency of developed machine for doing operation on Bio-degradable mulching sheet with treatment T1, T2 and T3 with different speed variations are shown in table 4.8. The values of punching efficiency were calculated by equation 3.10. The average punching efficiency for Bio-degradable mulching was found 76.02%.

**Table 4.8 Punching efficiency for Bio-degradable mulching sheet**

| Treatment | Speed of Operation (km/h) | Punching efficiency (%) |
|-----------|---------------------------|-------------------------|
| T1        | 1.5                       | 82.08                   |
| T2        | 2.5                       | 76                      |
| T3        | 3.5                       | 70                      |

**Comparison between punching efficiency of plastic and bio-degradable mulching sheet**



**Figure 4.5 Punching efficiency of plastic and Bio-degradable mulching sheet**

From figure 4.5 we observed that the punching efficiency for plastic mulching sheet in T1 at speed 1.5km/hr is 86.56 % which is highest. The lowest punching efficiency 70% was found in T3 at speed 3.5 km/hr for Bio-degradable mulching sheet. Also we observed that as increases speed of operation the punching efficiency is decreases for both plastic and Bio-degradable mulching sheet.

**Missing punches**

Due to wheel slip and any differences in height of bed there is possibility of improperly or missing the punching of holes on mulch sheet. Thus holes considered as missing punches and it was counted by observing the punched holes after field test. The values of missing punches for 180 m<sup>2</sup> are shown in table 4.9 and 4.10

**Table 4.9 Missing punches on plastic mulch sheet**

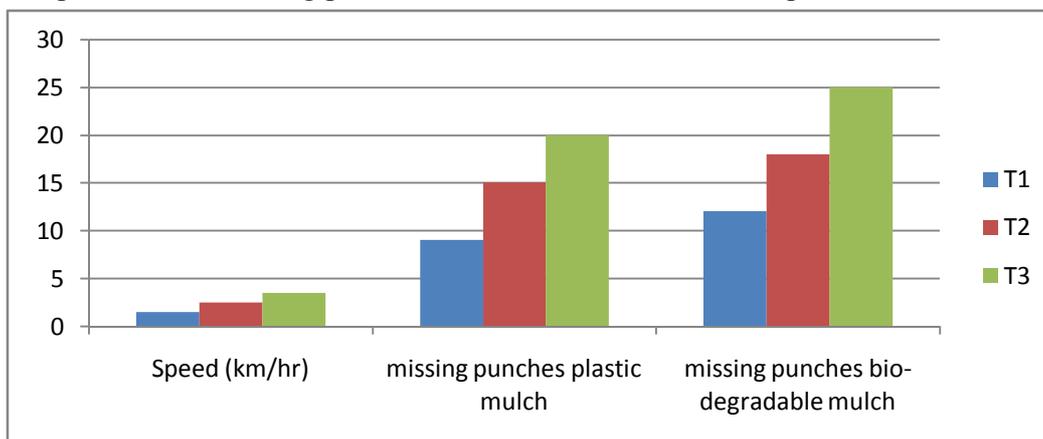
| Treatment | Speed (km/hr) | Theoretical punches | Actual punches | Missing punches |
|-----------|---------------|---------------------|----------------|-----------------|
| T1        | 1.5           | 67                  | 58             | 9               |
| T2        | 2.5           | 75                  | 60             | 15              |
| T3        | 3.5           | 85                  | 65             | 20              |

**Table 4.10 Missing punches on Bio-degradable mulch sheet**

| Treatment | Speed (km/hr) | Theoretical punches | Actual punches | Missing punches |
|-----------|---------------|---------------------|----------------|-----------------|
| T1        | 1.5           | 67                  | 55             | 12              |
| T2        | 2.5           | 75                  | 57             | 18              |
| T3        | 3.5           | 85                  | 60             | 25              |

**Missing punches of plastic and bio-degradable mulch sheet**

From figure 4.6 we observed that at a operation of plastic mulch sheet missing punches are low. At a operation of bio-degradable mulch sheet missing punches is high. As compared to speed of operation the missing punches increases as increases the speed.



**Figure 4.6 Missing punches**

**Punch spacing**

The distance between the holes punch by the developed machine was represent the crop to crop distance for cultivation. This punch spacing was measured with measuring scale by taking measurement from center to center distance between two holes punched by the machine at different operating speed. The observed value of punch spacing is shown in table 4.11

**Table 4.11 Punch spacing at different speed**

| <b>Treatment</b> | <b>Operating speed (km/hr)</b> | <b>Punch spacing (mm)</b> |
|------------------|--------------------------------|---------------------------|
| T1               | 1.5                            | 450                       |
| T2               | 2.5                            | 400                       |
| T3               | 3.5                            | 350                       |

## **CONCLUSION**

The developed tractor-drawn mulch sheet punching machine significantly enhances efficiency, safety, and cost-effectiveness in mulching operations. Compared to conventional methods, it reduces fuel consumption by 56.06%, time by 58.03% and operational energy by 44%. The machine achieves a maximum field efficiency of 90% at 1.5 km/h and an effective field capacity of 0.20 ha/h at 3.5 km/h. With an operational cost of 767.02 per hour and 5771.40 per hectare, the machine proves to be economically viable, with a payback period of 5.87 years. Overall, it minimizes operational time and energy costs, making mulching more efficient and sustainable for large-scale agricultural applications.

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