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Development and Performance Evaluation of Locally Manufactured Tractor-Drawn Plastic Mulch-Laying Implement Using Disc Plow at Different Forward Speeds

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RESEARCH ARTICLE INFORMATION	ABSTRACT

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The plastic mulch-laying implement was locally developed for the mechanical application of plastic mulch. The implement was developed using locally available materials, resulting in a lower cost of production. It was evaluated to test the soil covering performance using a disc plow at different forward speeds. The implement was evaluated at five forward speeds. The effect of the forward speeds on actual field capacity, field efficiency, and unsecured mulch was studied. The results of the experiment showed that the average actual field capacity is 0.14 ha/hr (1.12 ha/day). At low speed, the actual field capacity decreased, and unsecured mulch increased by an average of 13% and 6%, respectively, compared to the forward speed. The highest field efficiency of 46.14% was achieved at a forward speed. By means of benefit-cost ratio analysis, the plastic mulch-laying implement showed that it is economically viable. The results of this study showed that the plastic mulch-laying implement is reliable and efficient for plastic mulch application. Hence, it recommends using the plastic mulch-laying implement to make raised beds and lay plastic mulch at a forward speed.

Keywords: *Plastic mulch, forward speed, field efficiency, unsecured mulch, benefit-cost ratio*

Introduction

The Philippines is a tropical country; it is characterized by relatively high temperatures, high humidity, and abundant rainfall. More extreme temperatures and precipitation can prevent crops from growing, and extreme events, especially floods and droughts, can harm crops and reduce yields. Sumant et al. (2020) stated in their study that mulching is the process of covering the soil around the plant's root area to insulate the plant and its roots from the effects of extreme temperature fluctuations. The use of plasticulture in the production of crops helps to mitigate the extreme fluctuations in weather, especially temperature, rainfall, and wind (Manickam & Thilagam, 2010). Additionally, mulches could provide economical, aesthetic, and environmental advantages to agriculture and landscape (Iqbal, 2020).

Mulch technical term means 'covering of soil'. Plastic mulches are completely impermeable to water. Therefore, it prevents direct evaporation of moisture from the soil and thus limits the water losses and soil erosion over the surface. In this manner, it plays a positive role in water conservation. The suppression of evaporation also has a supplementary effect; it prevents the rise of water containing salt, which is important in countries with high salt content water resources (Anon, 2020). The use of plastic mulch has become a standard practice for many farmers to control weeds. The plastic also moderates soil temperature in ways that increase yields and season length for farmers. Kothiya et al. (2021) also stated that plastic mulch sheets have shown a significant effect on farming techniques. It has several advantages, like moisture conservation and yield enhancement. Gao et al. (2019) examined the effects of plastic mulching on the production of cotton, wheat, potatoes, and maize and found that it greatly increased yields (24.3% on average) and improved water consumption efficiency (27.6% on average).

Moreover, according to Sarian (2018), workers would manually roll out the plastic mulch, putting bamboo pegs along the sides to keep the sheet in place. This system can take 10 people, as long as two days, to mulch one hectare. The cost of manually mulching one hectare could reach P35,000, according to Delima of Agri-Tech Integrated Services Company. These manual operations are characterized by their time-consuming, labor-intensive, costly, and tedious nature. A tractor-drawn plastic mulch-laying machine was found to be superior to the traditional method of mulching (Parmar et al., 2023). Satasiya et al. (2025) concluded that the use of a plastic mulch-laying machine saves about 92.9% time and 80.37% of the cost of laying plastic mulch as compared to the conventional manual laying method. Results in a study by Meselhy in 2020 also showed that there was a decrease in mulching cost of about 68% compared to manual mulching. Furthermore, manual methods often result in uneven mulch paper placement, compromised work quality, paper tearing during handling, and difficulties in securing the mulch paper adequately (Malathi et al., 2024).

The mechanization of this operation reduces human effort to a certain limit in the field, making this highly valuable to the farmers; decrease in costs compared to the manual method; and higher mulching efficiency. This study also addresses Sustainable Development Goal (SDG) 9, particulalry in strengthening the industry, innovation, and infrastructure.

This study aimed to develop a plastic mulch-laying implement and evaluate the performance of the disc plow in securing the mulch at different forward speeds. The plastic mulch-laying implement was made to give optimal solutions to plastic mulch application.

Methods

Description of the Implement

The plastic mulch-laying implement is an agricultural implement for mulching using plastic films. All parts of the plastic mulch-laying implement, such as the three-point linkage, supporting wheels, ridge maker, mulch holder, press wheels, and soil covering disc, were attached to the frame. The construction details of the plastic mulch-laying implement are discussed in the succeeding paragraphs.

The frame had two horizontal members on the sides along the y-axis and four horizontal members along the x-axis, welded together forming a rectangular shape. A two-inch rectangular hollow tube was selected for the development of the frame, where all parts of the implement, like the three-point linkage, supporting wheels, ridge maker, press wheels, soil covering discs, and plastic mulch holder, were attached by welding or by using bolts and nuts. The three-point linkage was welded to the front part of the frame to easily attach and detach the implement to a four-wheel tractor. The mulch holder was developed using a 1" plain round bar. It was placed on top of the frame, connected through pillow blocks, which were secured to the frame by bolts and nuts.

Furthermore, two supporting wheels, 16" in diameter, were located at the front of the implement at the same horizontal member where the three-point linkage was welded. They were attached to the frame using bolts and nuts. The ridge maker was two metal discs, 14" in diameter, attached on both sides of the second horizontal member along the x-axis of the frame using bolts and nuts.

Additionally, two nine-inch press wheels were attached to both sides of the third horizontal member along the x-axis, pressing the plastic mulch firmly against the ground. These press wheels were connected to the frame by bolts and nuts. Two soil covering discs, 14" in diameter, were provided on both sides at an angle of 45° to the direction of travel just behind the press wheel. The soil covering discs were attached at the end of the frame using bolts and nuts. Below are the parts of the implement:

1. Frame
2. Plastic mulch holder
3. Plastic mulch lock
4. Three-point linkage
5. Supporting wheel
6. Ridge maker
7. Press wheels
8. Soil covering disc

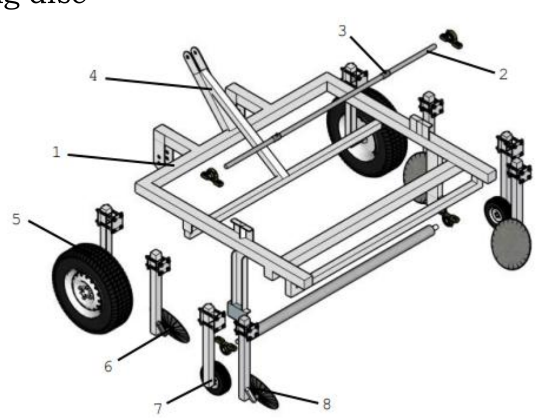

Figure 1. *Exploded View of the Plastic Mulch-Laying Implement*

Principles of Operation

The plastic mulch-laying implement had a three-point mechanism that could be attached to a four-wheel tractor. Before lowering the implement on the field, the plastic mulch was unrolled and placed at the starting point by the operator, allowing the press wheels to hold down the plastic mulch before operation. As the tractor moved forward, the ridge maker shaped the soil into raised beds. A mulch holder was mounted on top of the frame to hold the roll of plastic mulch. The plastic mulch began to unroll then laid over the prepared bed. Press wheels followed the plastic mulch as it was being laid on the soil, pressing it firmly against the ground, and enabling the soil covering discs to secure the plastic mulch. At the end of the field, the operator cut the plastic mulch and restarted the operation until the area was covered with plastic mulch.

Bed Spacing

The field was disc harrowed and rotavated to incorporate crop residues thoroughly. The implement was used to apply mulch in the field with a spacing of 60 cm between beds.

Treatments

The set of experiments was performed at Sitio Matartarang, Busilelao, Echague, Isabela. The treatments included operating the tractor at speeds of 1.5 kph, 2.5 kph, 3.5 kph, 4.5 kph, and 5.5 kph for T_1, T_2, T_3, T_4, and T_5, respectively. Each treatment was replicated three times. The randomization of the treatments in the layout was made by utilizing the fishbowl method.

Soil Characterization

Soil samples were collected for soil physical analysis to compute their bulk density, particle density, porosity, and moisture content.

Performance Efficiency Indicators and Formula

a. *Actual Field Capacity*

$$afc = \frac{A_e}{t} \quad \text{---------------------(1)}$$

where:
afc = actual field capacity, ha/h
A_e = effective area accomplished, ha
t = total operating time, hr

b. *Theoretical Field Capacity*

$$tfc = \frac{Wc\,S}{10{,}000} \quad \text{-----------------(2)}$$

where:
tfc = theoretical field capacity, ha/h
W_C = theoretical width of mulch spacing, m
S = speed of operation, m/h

c. *Field Efficiency*

$$\varepsilon_f = \frac{afc}{tfc} * 100 \quad \text{-----------(3)}$$

where:
ε_f = field efficiency, %
afc = actual field capacity, ha/h
tfc = theoretical field capacity, ha/h

Statistical Analysis

The data collected were tabulated and analyzed using single-factorial analysis of variance (ANOVA) for a Completely Randomized Design using the Statistical Tool for Agricultural Researchers (STAR) application. ANOVA was used to analyze the variance between five treatments to determine the statistically significant difference between them.

Results and Discussion

Observations

1. *Dimension of the Implement.* The dimension of the implement was determined using a measuring tape. The plastic mulch-laying implement has an overall height of 1143 mm, an overall width of 1981 mm, and an overall length of 2616 mm.
2. *Plastic Mulch.* Black plastic mulch was used for the performance testing of the implement with a 30-micron thickness and one meter width. The width of secured mulch on each side of each test has an average of 223.5 mm.
3. *Mulching.* The mulching carried out in plots covers 60.53% of the field area. Each plot is 30 meters in length and 1.12 meters wide. The height of mulched soil has an average of 109 mm.
4. *Field Operating Condition.* The site has a total area of 831 m2. The soil texture is clay soil. The bulk density of the soil was determined to be 1.55 g/cm3, which is within the normal range of the bulk densities for clay, ranging from 1.0 to 1.6 g/cm3. Soil porosity was observed to be 13.9 %. The field was rotavated four times to completely pulverize the soil.
5. *Labor Requirement.* The plastic mulch-laying implement requires two people, one to drive the four-wheeled tractor and the second person to cut, unroll, and place the mulch in place.
6. *Percentage of Unsecured Mulch.* The soil covering disc fails to cover the plastic mulch only at the starting point of each test. The remaining length of the plastic mulch is then secured with soil until the end of each test. A one-meter allowance can be used at the starting point of operation to avoid having unsecured mulch.
7. *Manual Application of Plastic Mulch.* The manual application of plastic mulch for a one-meter-wide and 30-meter-long plot took 38 minutes in total with two laborers. Creating a raised bed for the plot took 20 minutes, and securing the plastic mulch took 18 minutes. The longest time for mechanical plastic mulch application covering the same area using the implement was 62 seconds, operating at a 1.5 kph forward speed, which is 37 times faster than manual application.
8. *Torn Mulch Caused by Soil Covering Disc.* The mulch was torn by the disc during operation when Treatment 4 and Treatment 5 were used. The mean percentage of torn mulch caused by the soil covering disc is 0.25% for T4 and 0.51% for T5, respectively.
9. *Condition of Tractor.* The tractor used was a New Holland TS6.120, which has been in operation for three years. The condition of the tractor used still functions properly and is still usable for farm work.

Actual Field Capacity of the Plastic Mulch-Laying Implement

The actual field capacity is shown in Table 1a. Treatment 1 and 2 each have an average capacity of 0.13 ha/hr, Treatment 3 has an average capacity of 0.14 ha/hr, and Treatment 4 and 5 each have an average capacity of 0.15 ha/hr.

The Analysis of Variance (ANOVA) in Table 1b indicates that the actual field capacity is not affected by the increase in the operating speed of the tractor. It shows the relationship between the actual field capacity and forward speed. It shows that there is no significance between the forward speed and the actual field capacity.

Moreover, the relationship between the actual field capacity to the different forward speeds was subjected to regression analysis. The scatter diagram is shown in Figure 2. The regression equation developed was $y = 0.0194\ln(x) + 0.1163$. The equation developed for the actual field capacity in relation to the different forward speeds has a coefficient of determination (R^2) of 0.79.

Table 1a. Actual Field Capacity of the Plastic Mulch-Laying Implement at Different Forward Speeds

Treatment	Replication			Treatment Total	Treatmen t Mean
	I	II	III		
T_1	0.07	0.15	0.16	0.38	0.13
T_2	0.11	0.14	0.14	0.39	0.13
T_3	0.12	0.17	0.12	0.41	0.14
T_4	0.14	0.16	0.16	0.46	0.15
T_5	0.13	0.15	0.16	0.44	0.15
Grand Total	0.57	0.77	0.74	2.08	0.69
Grand Mean					0.14

Table 1b. Analysis of Variance for the Actual Field Capacity of the Plastic Mulch-Laying Implement at Different Forward Speeds

Sources of Variations	Degrees of Freedom	Sum of Squares	Mean Square	F-Computed	F-Tabular	
					5%	1%
Treatment	4	0.0015	0.0004	0.5^{ns}	3.48 7	5.99
Error	10	0.0079	0.0008			
Total	14	0.0094				

C.V. = 20.23 ^{ns} not significant

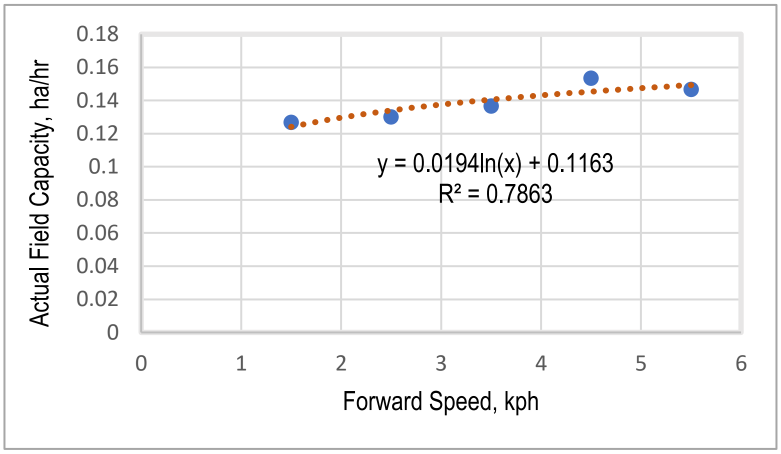

Figure 2. *Relationship of the Different Forward Speeds of the Tractor to the Actual Field Capacity of the Implement*

Field Efficiency of the Plastic Mulch-Laying Implement

The field efficiency was obtained by dividing the actual field capacity by the theoretical field capacity. The field efficiency is shown in Table 2a. Treatment 1 averaged 46.14% efficiency, followed by Treatment 2 at 28.41%, Treatment 3 at 21.34%, Treatment 4 at 18.62%, and Treatment 5 at 14.57%. The grand mean value is 25.82%.

The ANOVA presented in Table 2b revealed that various forward speeds are highly significant to the field efficiency. The table presented indicates that field efficiency is highly affected by the increase in forward speed of the tractor. As shown in the table, comparison of means using the LSD Test revealed that Treatments 2, 3, 4, and 5 are statistically the same but significantly different from Treatment 1.

Moreover, Figure 2a reveals the relationship between field efficiency and forward speed. It shows that there is a decrease in efficiency when the forward speed was increased.

The relationship between the field efficiency to the different forward speeds was subjected to regression analysis. The scatter diagram is shown in Figure 2b. The regression equation developed was $y = -23.74\ln(x) + 53.282$. The equation developed for the field efficiency in relation to the different forward speeds has a coefficient of determination (R^2) of 0.96.

Table 2a. Field Efficiency of the Plastic Mulch-Laying Implement at Different Forward Speeds

	Replication			Treatment Total	Treatment Mean
	I	II	III		
T_1	25.5	54.64	58.29	138.43	46.14^a
T_2	24.04	30.6	30.6	85.24	28.41^b
T_3	18.74	26.54	18.74	64.02	21.34^b
T_4	17	19.43	19.43	55.86	18.62^b
T_5	12.92	14.9	15.9	43.72	14.57^b
Grand Total	98.2	146.11	142.96	387.27	129.09
Grand Mean					25.82

Table 2b. Analysis of Variance for the Field Efficiency of the Plastic Mulch-Laying Implement at Different Forward Speeds

Sources of Variations	Degrees of Freedom	Sum of Squares	Mean Square	F-Computed	F-Tabular	
					5%	1%
Treatment	4	1854.83	463.71	6.41**	3.487	5.99
Error	10	723.70	72.37			
Total	14	2578.53				

C.V.= 32.95
LSD = 15.48

** highly significant

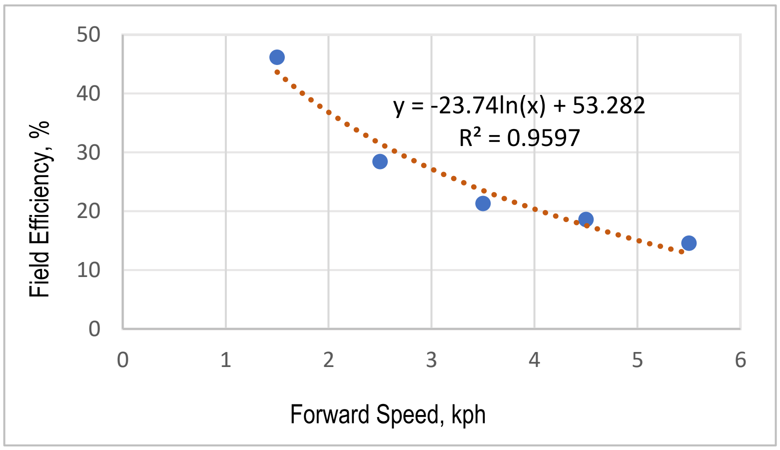

Figure 3. *Relationship of the Different Forward Speeds of the Tractor to the Field Efficiency of the Implement*

Fuel Consumption of the Plastic Mulch-Laying Implement

The fuel consumption is presented in Table 3a. It averages 1.33 L/h in Treatment 1, 1.72 L/h in Treatment 2, 1.76 L/h in Treatment 3, 2.05 L/h in Treatment 4, and 1.98 L/h in Treatment 5, yielding a grand mean of 1.77 L/h. The ANOVA in Table 3b reveals that various forward speeds are highly significant to fuel consumption. Comparison of means using the LSD test, as displayed in Table 6a, reveals that Treatments 4 and 5 are statistically the same, and Treatments 2 and 3 are also statistically the same, but both treatments are significantly different from each other.

Treatment 1 is statistically different from the other treatments. Furthermore, the relationship between fuel consumption to the different forward speeds was subjected to regression analysis. The scatter diagram is shown in Figure 4. The regression equation developed was $y = 1.2397e^{0.098x}$.The equation developed for the fuel consumption in relation to the different forward speeds has a coefficient of determination (R^2) of 0.81.

Table 3a. Fuel Consumption of the Plastic Mulch-Laying Implement at Different Forward Speeds

Treatment	Replication			Treatment Total	Treatment Mean
	I	II	III		
T_1	1.27	1.38	1.33	3.98	1.33[d]
T_2	1.83	1.78	1.54	5.15	1.72[c]
T_3	1.65	1.89	1.73	5.27	1.76[bc]
T_4	1.88	2.05	2.23	6.16	2.05[a]
T_5	2.13	1.92	1.89	5.94	1.98[ab]
Grand Total	8.76	9.02	8.72	26.50	8.84
Grand Mean					1.77

Table 3b. Analysis of Variance for Fuel Consumption of the Plastic Mulch-Laying Implement at Different Forward Speeds

Sources of Variations	Degrees of Freedom	Sum of Squares	Mean Square	F-Computed	F-Tabular	
					5%	1%
Treatment	4	0.9717	0.2429	13.57**	3.487	5.99
Error	10	0.1795	0.0179			
Total	14	1.1511				

C.V.= 7.58 ** highly significant
LSD = 0.24

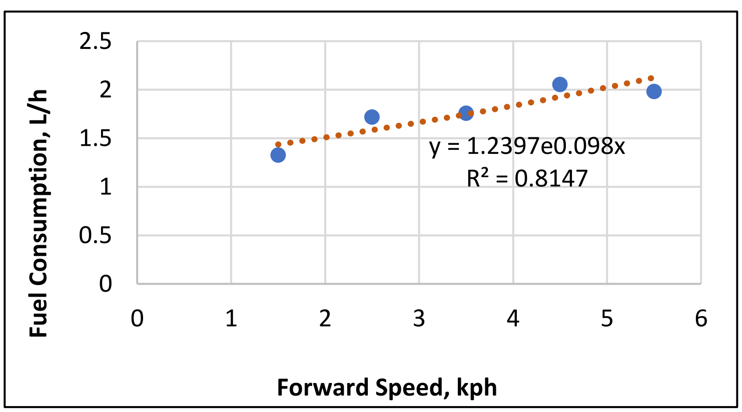

Figure 4. *Relationship of the Different Forward Speeds of the Tractor to the Fuel Consumption of the Implement*

Conclusion and Future Works

The soil covering performance of the disc showed no difference at increasing forward speeds, while the amount of torn mulch increased at higher speeds. The width of exposed mulch was greater at lower speeds. Despite these variations, the actual field capacity showed no significant difference while using different forward speeds. However, field efficiency decreased as speed increased, indicating that speed is inversely proportional to field efficiency. The fuel consumption was found to be higher at increasing forward speeds, highlighting the need for efficient fuel management. Additionally, the implement was found to be effective on slightly sloping fields, demonstrating the implement's adaptability across different terrains.

Furthermore, the use of a rotavator is recommended during operation. This decreases the turning time of the tractor, reducing time loss on the application of plastic mulch and increasing the actual field capacity. It also decreases the space between each plot, allowing a wider area that can be covered with plastic mulch. Using plastic mulch with a 30-micron thickness and above is also recommended.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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