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Economic Analysis of Low-Cost Tractor Drawn Plastic Mulching Machine

Bhupendra Singh Parmar [a++*], Atul Kumar Shrivastava [b#], Satish Kumar Singh [a++], Anurag Patel [a++] and Sachin Gajendra [a++]

[a] *ICAR- Central Institute of Agricultural Engineering, Bhopal-462 038, India.*
[b] *CAE, Jawaharlal Nehru Krishi Vishva Vidyalaya, Jabalpur-482 004, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The global yearly use of plastic mulching in agriculture is 2.1 million tonnes in 2020. Agriculture is the second most significant source of GHG emissions, accounting for around 13.5% of total global anthropogenic emissions. Plastic mulching is of paramount importance in horticulture for its numerous benefits. It reduces weed development, conserves soil moisture, regulates soil temperature, and prevents soil erosion by forming a protective barrier. Traditional method of mulching is laborious, time consuming having lower efficient and accurate mulching as compared to developed low cost tractor operated mulch laying machine. It comprises soil bed preparation, drip laying, mulch laying, mulch covering, and making holes for transplanting simultaneously. This paper contains the cost analysis of developed machine and its comparison with traditional mulching

++ *SRF;*
# *Dean & Head;*
**Corresponding author: E-mail: iambhupendra34@gmail.com;*

method. The draft, operational speed, power requirement effective field capacity, field efficiency, and energy consumption of developed machine were found as 175 kgf, 3.5 km.h^{-1}, 21.93 kW, 0.36 ha.h^{-1}, 85.6 %, and 21.43 MJ.ha^{-1} respectively. In cost estimation it is found that the cost of operation and overall cost of developed machine were 1048.3 ₹.ha^{-1} and ₹13000 respectively. It turned out that the machine was economical, saving time, energy, and operating costs. By introducing the concept of affordability and simplicity, the machine has the potential to change cultivation practices, increase yields and improve farmers' livelihoods in agricultural regions.

Keywords: Low cost mulching; mulching machine; tractor operated mulching machine; horticulture; plastic mulching.

1. INTRODUCTION

The use of modern agricultural techniques and technologies is essential to improve yields, reduce labour costs and ensure food security in agriculture. One such technology adopted in recent years and tractor-pulled plastic, an inexpensive alternative designed to spread plastic film on the soil surface in crop fields. Plastic mulch is used in agriculture to effectively suppress weeds, reduce soil water evaporation, keep soil temperature and humidity stable, promote crop growth, and increase yields [1,2]. Over 2.1 million tons of plastic mulch were used in agriculture worldwide in 2020 [3]. Plastic mulching is of paramount importance in horticulture for its multifaceted benefits. The main purpose of plastic mulches is to shield seedlings and shoots by preventing evaporation and providing insulation, which keeps soil temperature and humidity at or slightly above normal [4]. Fruits and vegetables play a vital role in horticulture production in India having 107.10 MT and 204.61 MT respectively during 2021-22 [5]. The practice of applying mulches for the production of vegetables is thousands of years old [6,7]. The use of plastic mulch in horticulture has been increased dramatically in the last 10 years throughout the world. The global yearly use of plastic mulching is 4 million tonnes, with a 5.6% annual increase [8].

The temperature of the soil beneath plastic mulch is determined by the thermal characteristics (reflectivity, absorptivity, or transmittancy) of the material to incoming solar radiation [9]. Dr. Emery Emmert (known as the Father of Plasticulture) spent most of his early pioneering research on the use of plastic mulches for vegetable production defining the impact different coloured mulches had on soil and air temperatures, moisture retention, and vegetable yields [10].

Global temperatures have been rising as greenhouse gas (GHG) emissions have increased. Although soil mulching is an excellent approach for increasing crop yield by conserving soil moisture and temperature, it is also a significant factor influencing GHG generation and emissions. Agriculture is the second greatest source of GHG emissions, accounting for approximately 13.5% of total world anthropogenic emissions [11]. Farming and field management have an indirect impact on GHG emissions and productivity by modifying the soil environment. Although SM can successfully minimize surface soil evaporation and enhance soil water content in the root zone, it has been discovered that it promotes CH_4 generation and emissions [12]. Crop production improved by 24.23% with plastic mulching, but Global Warming Potential increased by 14.17% due to CO_2 increase. According to the foregoing data, Soil mulching not only increased crop output but also dramatically increased GHG emissions. To reduce the negative impact of Soil mulching on GHG, full flat mulching with grave or straw plus drip irrigation under neutral or slightly alkaline soil with bulk density is recommended [13].

Black plastic mulch is an opaque black body absorber and radiator, absorbing the majority of incoming solar radiation's UV, visible, and infrared wavelengths and reradiating absorbed energy as heat radiation. When compared to bare soil, soil temperatures under black plastic mulch are normally 5F (2.8C) higher at 2 in. (5 cm) depth and 3F (1.7C) higher at 4 in. (10 cm) depth during the day. Black mulch is commonly utilised in vegetable production systems [14]. Plastic mulching's application range has expanded from dry and semi-arid regions in the north to high mountains and cold regions in the south. Covered crops have also moved beyond cash crops to include staple foods [15]. Mulch paper lowers the need of chemical fertiliser and herbicides, controls weeds, and keeps the field temperature stable [16].

Due to the difficulty in obtaining advanced mulching equipment, India continues to use the conventional method of mulching. In most region of India, plastic mulches were placed in the field by hand. Traditional method of mulching is laborious and time consuming. Its efficiency and accuracy of placing plastic mulch sheet is very poor which affects the primary motive of mulching and imbalance the soil temperature, eventually results in lower yield, however to increase efficiency, accuracy and time specialized equipment was developed.

The developed Mulch laying machine comprises soil bed preparation, drip laying, mulch laying, mulch covering, and making holes for transplanting simultaneously. The concept of low cost tractor drawn mulch represents a major innovation in plasticulture-agriculture. This includes a cost-effective, easy-to-use device that can be attached to a tractor, allowing small-scale farmers with limited resources to move toward plastic coating. This innovation aims to reduce the labour involved in manual processing while optimizing the use of materials and time. By introducing the concept of affordability and simplicity, the machine has the potential to change cultivation practices, increase yields and improve farmers' livelihoods in agricultural regions. Although this practice has shown benefits in crop yields and on its quality but the program aims to address these challenges, increasing the accessibility of technology to resource-poor smallholder farmers.

2. MATERIALS AND METHODS

Low cost tractor operated mulching machine with its components is shown in Fig. 1.

①Hitch, ②Bund former, ③Press wheel, ④Soil covering discs, ⑤Hole punching wheel, ⑥Drip roll holder, ⑦Mulch roll holder, ⑧Main frame

Fig. 1. Low cost tractor operated plastic mulch laying machine

The performance evaluation of developed machine was measured in terms of draft, power requirement, energy requirement, field capacity, fuel consumption are given below:

Draft: Total draft exerted on the equipment was computed using the formula.

$$D=D_1-D_2 \ldots\ldots \quad (1)$$

Where,
D = Draft of equipment, kg or N;
D_1 = Draft of equipment when equipment in operating condition, kg or N;
D_2 = Draft of equipment when equipment in non-operating condition, kg or N.

Power requirement: The power requirement for the operation was determined from the draft and speed using the relation

$$\text{Power (hp)} = \frac{\text{Draft} \times \text{Speed}}{75} \ldots\ldots \quad (2)$$

Where,
Draft = Draft of mulching machine (kg);
Speed = Speed of operation ($m.s^{-1}$).

Energy Consumption: Energy consumption during operation was calculated by using the following formula .

$$\text{Energy of machine, } \left(\frac{\text{MJ}}{\text{ha}}\right)= \frac{\text{W}}{\text{LH}} \times \text{HOU} \times \text{EE} \ldots\ldots \quad (3)$$

Where,
W = Total weight of implement, kg;
LH = Total useful working life of implement;
HOU = Hours of useful life of implement $h.ha^{-1}$;
EE = Equivalent Energy.

Fuel consumption: For the measurement of fuel consumption ($ml.hp^{-1}.h^{-1}$) tractor was operated under light load condition (LCF= 0.5) and following formula was used

$$\text{Fuel consumption } \left(\frac{\text{ml}}{\text{H}}\right) = \text{LCF} \times \text{SFC} \times \text{HOU} \times \text{HP} \ldots\ldots \quad (4)$$

Where,
LCF = Load coefficient factor, (unit less);
SFC = specific fuel consumption, ($ml.hp^{-1}.h^{-1}$);
HOU = hours of use of tractor, (h);
HP = horse power of tractor used, (hp)

Cost of operation: When any new technology is introduced to the farmer, they are interested to know whether the machine will be profitable to them or not. Cost analysis is very important for a new technology. The cost of using farm machinery consists of expenses for ownership, operation, and overhead charges. It may also include a margin for profit. Ownership costs are independent of use and are often called as fixed costs. Costs for operation vary directly with use and were referred to as a variable cost The cost of operation under each treatment was estimated as per IS: 9164-1979. The total cost of the machine was determined by knowing the cost of the .materials used for fabrication. The operational cost (₹.ha^{-1}) was calculated by assuming some data.

Fixed costs: It is the total cost of depreciation, interest on investment, tax, insurance and shelter. For calculating the depreciation of the machine, straight-line method was used.

Depreciation

$$D = \frac{C-S}{L \times H}\text{............} \qquad (5)$$

Where,
D = Depreciation per hour
C = Unit cost
S = Salvage value, 10% of unit cost;
H = Number of working hours per year and
L = Life of machine in year.

Annual interest: Annual interest was taken as 10% of initial investment

$$I = \frac{C+S}{2} \times \frac{i}{H}\text{.........} \qquad (6)$$

Where,
I = Interest per hour;
(C+S)/2 = Average investment; and
i = Interest rate per year, %.

Insurance and taxes: Insurance and taxes were estimated taking 1% of average purchase price of the machine into consideration.

Housing: It was calculated on the basis of 1% of the average purchase price of the machine.

Variable costs:

Fuel: The actual fuel consumption in each treatment was observed and estimation was done accordingly.

Oil (Lubrication): The cost of engine oils and lubricants was estimated as 30% of fuel consumption cost.

Repair and maintenance: Repair and maintenance cost was taken as 10% of initial investment.

$$\text{Repair and Maintenance cost} = \frac{m}{100} \times \frac{C}{H} \text{ ....} \qquad (7)$$

Where,
m = Repair and maintenance rate, 10%;
H = Annual use, h; and
C = Unit cost.

Labour Charges: The cost of labour was estimated taking the prevailing rate of 31.25 ₹.h^{-1} at the rate of ₹250 per day.

3. RESULTS AND DISCUSSION

Experimental trails were taken under field of department of farm machinery and power engineering, college of agricultural engineering, JNKVV, Jabalpur. Operational view of low cost tractor operated plastic mulch laying machine and traditional method of mulching under actual field condition are shown in Fig. 2. Also, the views of plastic sheet lay by developed mulching machine and traditional method of mulching are shown in Fig. 3.

Developed Mulching Machine
(All operation in a single pass)

Traditional mulching
(Laying, Covering & Punching separately)

Fig. 2 Comparative operation of mulch laying by developed machine and traditional mulching

Developed Mulching Machine

Traditional mulching

Fig. 3. Comparative views of mulch by developed machine and traditional mulching

Comparative performance of developed mulching machine and traditional mulching: Average speed of operation of tractor drawn plastic mulch laying machine was found to be 3.5 km.h^{-1} while speed of traditional method by manually laying was much less i.e. 0.25 km.h^{-1}. Actual field capacity of tractor drawn plastic mulch laying machine was found to be 0.36 ha.h^{-1} while actual field capacity by traditional method was 0.06 ha.h^{-1}. The field efficiency (η) of developed mulching machine was calculated i.e. 85.60 %. Time requirement for operation by tractor drawn plastic mulch laying machine was found to be 2.8 h.ha^{-1} while time requirement for operation by traditional method 16.7 h.ha^{-1}. Energy consumption by tractor drawn plastic mulch laying machine was found to be 21.43 MJ.ha^{-1} while energy consumption by traditional method 196.4 MJ.ha^{-1}. The average power requirement and fuel consumptions calculated by using specific fuel consumption method was found to be 21.93 kW (29.4 hp) and 4.5 l.h^{-1} (12.5 l.ha^{-1}) respectively. Overall graphical representation of comparative performance analysis of developed mulching machine with traditional mulching method is shown in Fig. 4 and Table 1.

Cost estimation and cost of operation: The plastic tractor operated mulching machine was developed considering the economy in cost of fabrication. The cost estimation of the developed mulching machine was based on the direct cost of material, process operation, labour and overhead. Cost of material was available on the basis of local market price. Cost of labour was estimated from standard rate of wages and the time required for job operations. Process operation cost for step turning, drilling, shaping and welding were determined by measuring the time of operation of respective processes. The unit cost of the developed plastic tractor operated mulching machine was calculated by considering the cost of different components. The estimated cost of the unit of a developed plastic mulching machine came out to be ₹13000.00 only.

The cost of operation included the cost of operation of the machine per hour, per ha is given in Table 2. The annual use of the mulch laying machine was taken only 200 hours per year, in assumption the fixed cost of mulching machine 11.38 ₹.h^{-1} and repair and maintenance cost was 6.5 ₹.h^{-1}. The total variable cost was 69 ₹.h^{-1}, It observed that cost of operation of traditional method is higher i.e. 3125 ₹.ha^{-1} then followed by of mulching machine which is 1048 ₹.ha^{-1} mentioned in Table 2.

Table 1. Comparative performance of developed machine and traditional mulching

Parameters	Developed machine	Traditional mulching
Speed, (km.h^{-1})	3.5	0.25
Draft, (kgf)	175	-
TFC, (ha.h^{-1})	0.42	-
AFC, (ha.h^{-1})	0.36	0.06
Field efficiency, (%)	85.60	-
Power requirement (KW)	21.93	-
Time req., (h.ha^{-1})	2.8	16.7
Energy consumption, (MJ.ha^{-1})	21.430	196.40
Minimum labour requirement	2	6

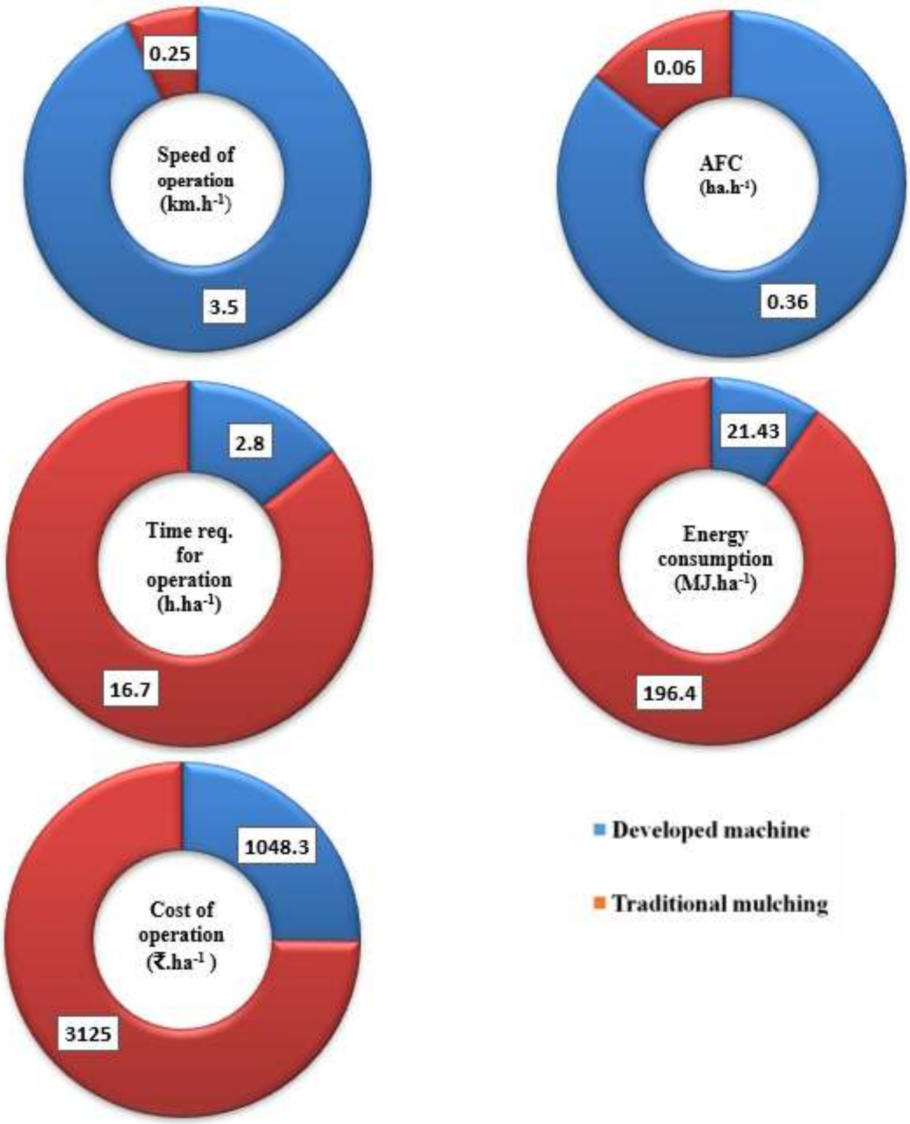

Fig. 4. Comparison of developed mulching machine and traditional mulching

Table 2. Calculation of cost of developed mulching machine per hour

Particulars	Developed mulching machine
Cost of machine, ₹	13000
Life machine year, years	10
Annual use, hours per year	200
Annual deprecation, ₹.h^{-1}	5.85
Annual interest @ 10% per annum, ₹.h^{-1}	3.56
Insurance 1%of the initial cost of machine, ₹.h^{-1}	0.65
Taxes 1% of the initial cost of machine, ₹.h^{-1}	0.65
Housing 1% of the initial cost of machine, ₹.h^{-1}	0.65
Total Fixed cost, (₹/h)	11.37
Repair and maintenance cost @ 10% of initial cost, ₹.h^{-1}	6.5
Wages of 2 operator (₹ 250/day), ₹.h^{-1}	62.50
Fuel consumption @66 ₹/l , ₹.h^{-1}	297
Total variable cost, (₹.h^{-1})	366
Total overhead cost, (₹.h^{-1}) = Fixed cost + Variable cost	377.37

Cost of operation in mulching by tractor drawn plastic mulch laying machine was found to be 1048.3 ₹.ha^{-1} while cost of operation in mulching by traditional method was found to be 3125 ₹.ha^{-1}. Comparison of cost of operation in mulching by both methods is also shown in Fig. 4. It has been revealed from the data that tractor operated plastic mulch laying machine performance is better for mulching cultivation of horticultural crops under black cotton soil. It saves time, energy and cost of mulching operations. This machine may also reduce the drudgery of operators/farmers.

4. CONCLUSION

Tractor drawn plastic mulch laying machine was found superior over traditional method of mulching. It saved sufficient time in actual field condition while traditional method took much time in operation. It can done all operations i.e. bund formation, plastic sheet and drip laying and hole punching simultaneously in one pass only. A tractor-operated plastic mulch laying machine was found to be superior to traditional methods in terms of time saved, energy consumption, and efficiency. The machine performed all operations simultaneously in one pass, saving 17% compared to the traditional method. It also consumed 6.1 times less energy and was more economical in both initial and operational costs. The machine also reduced manpower and labour requirements, making it recommended for large-scale horticultural crop cultivation. Developed machine was economical in initial and operational cost as compared to the available machines in market and costs only Rs. 13000 only. It reduces man power or labour requirement involved in operation. With the emerging value of plastic and its flexible nature, the type of farming is to be modified in India with this machine and may also reduce the drudgery of farmers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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