INTEGRATED PLASTIC MULCH LAYING MACHINE -A VIABLE TECHNOLOGY FOR SUSTAINABLE AGRICULTURAL PRODUCTION

Shoaib Amin1, Jagvir Dixit1, M. Muzamil1

1Division of Farm Machinery and Power Engineering, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, India

Abstract: A tractor drawn mulch laying machine was developed in order to integrate the operations and fix the anomalies in terms of labour associated with conventional mulch laying operations. The prototype integrates the operations of bed making, drip line laying, mulch laying, mulch covering and punching hole on mulch in one pass. The developed prototype was evaluated at three-levels of forward speed (3.0, 5.0, 7.0 kmh⁻¹), two-levels of bed width (76.2, 91.4 cm) and two-levels of dibbling hole spacing (15.2, 20.3 cm). The results of evaluation experiment for the developed machine showed that the draft requirement decreased with the increase in forward speed (3.0 to 7.0 kmh⁻¹), bed width (76.2 to 91.4 cm) and dibbling hole spacing (15.2 to 20.3 cm). Field efficiency increased with increase in forward speed, bed width and spacing of dibbling holes. Although at low speed (3.0 kmh⁻¹), the actual field capacity and field efficiency decreased about 57% and 5.0%, respectively while draft increased about 36 %, compared to the speed of 7.0 kmh⁻¹. However, at a speed of 3.0 kmh⁻¹, the mulch damage, uncovered mulch percentage and missing of dibbling hole decreased about 65%, 64% and 7.0 %, respectively. The standardized value of draft requirement, effective filed capacity and field efficiency were observed as 63.27 kp, 0.40 ha.h⁻¹ and 72.7% while as percentage uncovered mulch, percentage mulch damage and percentage missing number of holes were as 3.1 %, 3.4%, 6.25%, respectively.

*Corresponding Author. E-mail address: jagvirdixit@gmail.com
The man-hour requirement and cost of mulching operation with developed machine reduced about 97 % and 75 % as compared to conventional method of mulch laying. Therefore, the study recommends using the developed machine to install a raised-bed, laying of plastic mulch and drip irrigation pipes on the bed and making dibbling hole for vegetable seedling transplanting at a speed of 3 kmh\(^{-1}\) achieved the better efficiency.

**Key words:** Mulch laying machine, draft requirement, field efficiency, mulch damage, bed width, hole spacing, uncovered mulch

### INTRODUCTION

Agriculture plays a vital role in India’s economy, 54.6% of the population is engaged in agriculture and allied activities and it contributes 17% to country’s GDP [1], for the year 2018-19. Steps have been taken to improve soil fertility, farm mechanization, irrigation, protected cultivation including plasticulture [2]. The green revolution with its emphasis on high yielding variety seeds, fertilizers, pesticides and better methods of farming, swept like a wave into the Indian countryside. It turned us from being deficient in food grains to being self-sufficient [3]. But the increase in agricultural yield has to keep pace with the growing population that can be attained by mechanization in agriculture.

The present agricultural production is insufficient to mitigate the requirement of growing population due to the limited scope of increase in cultivable area and low level of mechanization [4]. Mechanization in agriculture has enhanced production and productivity of agricultural commodities through timeliness of operation, better management of inputs and reduction of post harvest losses [5] in the country. Mechanization enhances productivity of crop by 15% and reduces cost of crop production by 20% [4,5]. Indian farms are irrigated primarily by monsoons as three-fifth of the land is irrigated directly by rainfall. To irrigate these lands, India receives three fourth of its rains, in just four months of the year [6]. As per estimates by the year 2025 about one-third of India would be under absolute water scarce condition [2].

Therefore, the technique of creating micro-environment for plants in agriculture is at significant demand so as to increase the produce at the cost of consuming lesser amount of resources which can be achieved by plastic mulching in agricultural fields [7].

Mulch cover can play a neutral role or reduce the risk of insect pest attack to crop plants by preventing direct movement of insects from soil to plants. Plastic mulches are primarily used to protect seedlings and shoots through insulation and prevent evaporation, thus maintaining or slightly increasing soil temperature and humidity [8]. Furthermore, the application of plastic covers is known to reduce weed and pest pressure [9]. Often reported benefits are minimization of the development time for seed and fruit, yield increase, the prevention of soil erosion and weed growth and consequently reduction of herbicide and fertilizer use [10,11].

These prospects have made plastic films an upcoming technology, now a days making up by far the largest proportion of covered agricultural surface in Europe (4270 km\(^2\)), an area four times larger than that covered by greenhouses and six times that of low tunnels [12]. Plastic films are laid before crop planting or transplanting.
This includes preparation of seed bed, spread mulch film and anchoring of edges of film. Raised seed bed has to be prepared for plastic mulching [13].

Two persons are required for laying the plastic over the soil bed, while one more person behind them to shovel the soil onto the edges of the mulch. These operations when done by manually become very time consuming, labour intensive, tedious and costly.

Plastic mulching by conventional method requires more human labour, more time and more cost of operation [13]. A number of automatic mulch laying machines have been developed but they are either not available in India or their use is limited to only large-scale farmers due to high capital investment. The existing machines for plastic mulching operations have the snag of using separate bed-maker. They can lay down the plastic mulches for fixed bed width only and they don’t have the dibbling tool to make holes on the mulch moreover, their cost is very high. Hence, a new tractor drawn plastic mulch laying machine along with integral part as drip laying and mulch laying tool with soil covering on the edges and dibbling device was developed.

MATERIAL AND METHODS

The tractor operated plastic mulch laying machine was developed with aims to form wide raised bed, laying plastic mulch on bed surface, as well as laying lateral drip irrigation tapes/pipes on the surface of the raised-beds and punches hole in the plastic mulch for transplanting of vegetable seedlings.

Design Considerations

The development of integrated tractor drawn mulch laying machine was carried out by considering the agronomic and machine parameters. The design of machine components was based on the principles of operations and following functional requirements:

- To make two ridges on both sides so as to raise the soil in bed shape
- Laying of the mulch film on the well-prepared bed
- Unrolling the drip tape or drip roll on the bed surface formed by the machine
- To stretch the laid mulch film on the bed with the help of a press wheel
- Provision of earthing up unit to cover edges of mulch film with soil from both sides
- Provision for dibbling unit to make holes on mulch at required spacing
- The hitching of machine should be compatible with tractors of different makes and models
- The adjustment of bed size, mulch size, hole spacing and covering device should be easy

The conceptual model of proposed machine was developed using Auto-CAD 20.2.1 software package of Autodesk 2018. The conceptual model was prepared in 3D version of the software (Fig. 1) with rendering of 720p and CAD-walk of 360° for walk around view.
The tractor operated plastic mulch laying machine was designed, developed and fabricated at the Division of Farm Machinery and Power Engineering, S.K. University of Agricultural Sciences and Technology, Srinagar (India). The integrated tractor drawn mulch laying machine consisted of a frame, hitching unit, bed finisher, ridge maker/bed shaper, mulch laying unit (mulch holder + mulch guider), drip laying unit (drip holder + drip Guider), press wheels, earthing up unit and dibbling unit.

**Main frame**

The main frame was made up of galvanized iron square hollow pipe of 14-gauge. The frame (Fig. 2) was made rigid so as to support all the other components of the machine and to withstand different types of load. The length of the frame was 915 mm. and the height of main frame was kept at 813 mm above the ground level. All parts of machine-like hitching unit, press wheels, mulch laying unit and earthing up unit were attached to the main frame. The hitching unit and the bed finisher used to remove the extra material to scrap from the bed are an integral part of the main frame. There was a small hollow round pipe of size 152 mm with outer diameter (OD) 25mm welded to the main frame which serves as a drip guider.
Mulch laying unit

Mulch laying unit was for laying the mulch film on the bed. The mulch laying unit was fabricated using two galvanized iron square hollow pipes (254 × 32 mm), each was fixed to the supporting frame at one end and other end to the bearing.

A shaft (mulch holder) was provided in between the two parallel bearings so that it could be used to unroll the plastic film. The plastic film was fitted on the shaft by removing it from bearing at one side or on both sides by removing bolt and nut of mulch holder cum locking device. This unit was supported by a frame.

The height of the shaft of mulch laying unit was kept at 240 mm above the bed finisher. The length of mulch laying unit shaft was 1410 mm. A provision has been kept to use different size of mulch film.

Support frame

The support frame (Fig. 3) contains the assembly for pressing wheels, mulch holder and covering device holder. The mulch guider is also attached to the supporting frame. The mulch guider is made up of 8 mm mild steel solid rod with three bends to avoid any mulch damage by sharp ends, the three bends are provided at an angle of 120°, 120° and 135° and the length of mulch guider between different angles is 104, 150, 623 and 72 mm, respectively. The support frame is attached to the main frame by two galvanized iron hollow square of size 457 × 25 mm which are further welded to the mild steel square of same size as used for main frame, having length of 279 mm.
Tyre holder are also attached to the support frame with mild steel axle. The mulch roll holder welded to the supporting frame and has the height of 254 mm from the supporting frame.

At the rear side of the frame, covering device holder was mounted to the aligned part of the supporting frame with the help of nut-bolt and the angle to which the covering device holder was mounted on support frame.

**Press wheel**

The two press wheels were provided for compacting laid mulch film edges on the bed to protect it from the wind and a mulch roller was provided on its front (Fig. 4). The adjustable pneumatic rubber wheels of size 3.50-8" 4PR have been used in the machine for pressing the plastic film edges to the ground and were mounted on the support frame. The press wheels were fitted on axle of 101 x 38 mm called the tyre adjusting arm. The center to center distance of wheels was kept same as that of bed outer edge.
Earthing up unit (soil covering unit)

The function of the soil covering unit was to cover the mulch edges so as to fix the laid mulch in its position. Two earthing up units (Fig. 5) were provided on both sides at an angle of 60º to the direction of travel so as to increase the sweep area to deposit more soil on mulch edges.

It was mounted just behind the press wheels. The cross section of earthing up unit was designed, in such a way that it cuts soil up to a desired depth and properly covers the plastic film. It digs the soil up to a depth of about 5-7 cm and gathers soil and cover about 20 cm length of plastic film.

Drip laying unit

The drip laying unit consisted of drip roll holder and drip guider both of which were made of round hollow pipe. The drip guider consisted of a small hollow round bended pipe of size 152 mm with ϕ25 mm welded to the female telescopic arm of the main frame. The drip roll rotates on a shaft of size 635 mm x 25 mm. The drip roll unrolls on the shaft and drip went through drip guider and lays the drip on the bed. The drip roll rotates on the shaft plugged in ball bearings on both sides on two vertical square pipes of size 635 mm x 32 mm welded to the main frame.

Ridge maker/bed shaper

The ridge making unit (Fig. 6) consisted of the male telescopic square iron of size 444 x 25 mm welded at right angle to the bed shaper tool guider of size 114mm x 32 mm, bended MS sheet welded to two MS square pipes and the guider provided with two holes so as to adjust the bed shaper with the help of two nut bolts. The main function of the bed maker was to form a bed on which plastic mulch was laid out.
Bed Finisher

The proper shape of the bed was maintained by bed finisher by removing the extra soil. It was made of mild steel sheet supported by angle iron of size (948 x 2) mm x 25 mm and the height of the bed shaper was 152 mm. The two pieces were welded at an angle of 130° so that soil would sway sideward. The bed finisher is welded to the main frame thus remaining an undetectable part of the main frame.

Dibbling Device

The dibbling device (Fig. 7) was made using a circular wheel of 457mm φ and dibbling cones were provided on the periphery of wheel. The spokes were welded to inner side of ring on one side and other side is welded on round hollow pipe with of length 50 mm and φ38 mm. The ring rotates on an axle within the hollow pipe. The axle was made of round hollow pipe of φ 25 mm welded to an arm of square iron having length of 445 mm, breath 25 mm and thickness of 2 mm. To fix the location of ring on axle a bush of length 19 mm and φ 32 mm was welded to free end of axle. An arm is further welded to a hollow pipe of φ 32 mm and length 102 mm so as to allow the easy adjusting of dibbling device location by easy access of the device on the round pipe of φ 25 mm.

The details of the specification of developed machine are given in Table 1 and actual fabricated view of developed tractor operated integrated plastic mulch laying machine is shown in Fig. 8.
Table 1. Specification of the developed integrated tractor drawn mulch laying machine

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Units</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Source of power</td>
<td>hp</td>
<td>Tractor (&gt;30 hp)</td>
</tr>
<tr>
<td>2.</td>
<td>Overall dimensions (l x b x h)</td>
<td>mm</td>
<td>4780 x 1700 x 812</td>
</tr>
<tr>
<td>3.</td>
<td>No and size of Press Wheel</td>
<td>in</td>
<td>two, 84 PR</td>
</tr>
<tr>
<td>4.</td>
<td>No and Soil Covering Device Size</td>
<td>mm²</td>
<td>two, 254</td>
</tr>
<tr>
<td>5.</td>
<td>Main Frame Size (length)</td>
<td>mm</td>
<td>915</td>
</tr>
<tr>
<td>6.</td>
<td>Soil scraper / Soil shaper Size Angle</td>
<td>mm°</td>
<td>1896.2 / 135°</td>
</tr>
<tr>
<td>7.</td>
<td>No. and Bed Maker (BM) Size (l x h)</td>
<td>mm</td>
<td>Two, 444 x 114</td>
</tr>
<tr>
<td>8.</td>
<td>No. and Mulch Holder (MH) Size</td>
<td>mm</td>
<td>One, 1410</td>
</tr>
<tr>
<td>9.</td>
<td>No. and Drip Holder (DH) Size</td>
<td>mm</td>
<td>one, 635</td>
</tr>
<tr>
<td>10.</td>
<td>No. and Mulch Guider (MG) Size Angle</td>
<td>mm°</td>
<td>Two, 871</td>
</tr>
<tr>
<td>11.</td>
<td>No. and Supporting frame (SF) Size</td>
<td>mm</td>
<td>Two, 279</td>
</tr>
<tr>
<td>12.</td>
<td>No. and Dibbling Device (DD) Size</td>
<td>mm</td>
<td>Two, φ 457</td>
</tr>
<tr>
<td>13.</td>
<td>Mass of machine</td>
<td>kg</td>
<td>82</td>
</tr>
</tbody>
</table>

Fig. 7. Detailed Diagram of Dibbling Unit

Fig. 8. An overview of final assembled prototype
Working Principle of Tractor Drawn Integrated Mulch Laying Machine

The main working principle of the tractor drawn integrated mulch laying machine is by the virtue of the forward motion of machine from the tractor’s (prime mover) pull via its drawbar. The machine is mounted type therefore it is subjected to the hydraulic system of the tractor. Initially the plastic mulch is fixed by placing an adequate amount of soil on the mulch passed under press wheels. As the tractor pulls machine at the depth set by the hydraulics, the scraper (bed finisher) fixed on the front of the machine removes the extra material. Bed shaper at the depth fixed by hydraulics in the soil operated by secondary tillage implement form ridges on both sides and gives the bed shape to the soil passing through it. The drip tape roll adjusted on the machine unrolls and passes through drip guider and lays itself on the bed shaped soil now the mulch roll unrolls and is laid on the soil shaped as bed. The mulch passes under mulch guider to avoid it from being shrinked due to wind and then mulch is passes under press wheels to keep it spreaded on the soil. The press wheels run over the mulch right at the sections of the soil where ridge has been formed and then soil covering devices come into action to cover the mulch by diverting the soil on the edges of the mulch. Finally, the dibbling wheels serve their purpose to make holes on the mulch laid at the spacing required. At the end of row mulch is cut manually and soil is placed on the free end of laid mulch to avoid its displacement.

Field evaluation

This study was carried out at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India (latitude: 34° 08' 56" N, longitude: 74° 52' 22" E) on sandy loam soil during 2019-20 (Fig. 9). A rectangular field of size 33 x 12 m was taken for the evaluation of the developed prototype.

Before the evaluation of prototype under actual field conditions, the soil texture, soil moisture content and soil hardness was measured at seven randomly selected locations in the experimental field.

The soil texture was sandy loam with clay 7-20%, sand 43-52% and silt 15%. The average moisture content of soil surface layer (0-30 cm) was determined and found to be 12.3% (wb). The hardness of soil was measured at 16 cm and 30 cm depths as the soil working tool of the machine was made to penetrate the soil in the range of 16-30 cm (Table 2). The average hardness of soil at the depth of 16 cm and 30 cm were 1486 kPa and 2659 kPa, respectively (Table 2).

Experimental Design

The experiment was established as factorial design (unbalanced) in three replications, with three levels of forward speed (3, 5 and 7 km/h), two levels of bed width (76.2 and 91.4 cm) and two levels of hole spacing (15 and 20 cm). The speed range for the developed prototype was selected on the basis of fact that farm machinery achieves higher efficiency at the speed range of 4-6 km/h⁻¹ [14], the three levels of the speed range were above, below and in the range at which maximum field efficiency is achieved. The most common bed width being used in the vegetables is 80-90 cm [15]. The two test levels of the bed width were selected accordingly.
The test spacing of the plants (dibbling hole) were kept at 15 cm and 20 cm which are being extensively used in the mulching fields [16]. The plant-plant spacing was adjustable in the developed prototype. Experimental details and treatment combinations presented in Table 3 and Table 4, respectively.

Table 2. Measurements of the field parameters

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Soil type</th>
<th>Soil Moisture, w.b. (%)</th>
<th>Soil Hardness (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>At 16 cm depth</td>
<td>At 30 cm depth</td>
</tr>
<tr>
<td>1</td>
<td>Sandy Loam</td>
<td>10.9</td>
<td>1518</td>
</tr>
<tr>
<td>2</td>
<td>Sandy Loam</td>
<td>11.9</td>
<td>1511</td>
</tr>
<tr>
<td>3</td>
<td>Sandy Loam</td>
<td>12.3</td>
<td>1507</td>
</tr>
<tr>
<td>4</td>
<td>Sandy Loam</td>
<td>12.4</td>
<td>1503</td>
</tr>
<tr>
<td>5</td>
<td>Sandy Loam</td>
<td>12.5</td>
<td>1470</td>
</tr>
<tr>
<td>6</td>
<td>Sandy Loam</td>
<td>13.1</td>
<td>1466</td>
</tr>
<tr>
<td>7</td>
<td>Sandy Loam</td>
<td>13.3</td>
<td>1459</td>
</tr>
<tr>
<td>Average</td>
<td>12.3</td>
<td>1486</td>
<td>2659</td>
</tr>
<tr>
<td>Max.</td>
<td>13.3</td>
<td>1518</td>
<td>2753</td>
</tr>
<tr>
<td>Min.</td>
<td>10.9</td>
<td>1459</td>
<td>2582</td>
</tr>
<tr>
<td>S. D</td>
<td>0.008</td>
<td>24.555</td>
<td>58.554</td>
</tr>
<tr>
<td>S. E</td>
<td>0.003</td>
<td>9.28</td>
<td>22.131</td>
</tr>
</tbody>
</table>

Table 3. Plan of the experiment

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Levels</th>
<th>Values</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward speed (S)</td>
<td>3</td>
<td>(S₁) = 3 kmh⁻¹</td>
<td>• Draft requirement (kp).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(S₂) = 5 kmh⁻¹</td>
<td>• Effective field capacity (hah⁻¹)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(S₃) = 7 kmh⁻¹</td>
<td>• Uncovered mulch edges (%)</td>
</tr>
<tr>
<td>Bed Width (B)</td>
<td>2</td>
<td>(B₁) = 76.2 cm</td>
<td>• Mulch damage (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(B₂) = 91.4 cm</td>
<td>• Field efficiency (%)</td>
</tr>
<tr>
<td>Spacing (D)</td>
<td>2</td>
<td>(D₁) = 20 cm</td>
<td>• Missing of holes by dibbler (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(D₂) = 15 cm</td>
<td>• Man-h requirement (man-h ha⁻¹)</td>
</tr>
</tbody>
</table>

Table 4. Treatment combinations

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Treatment Combinations</th>
<th>Description of Treatment-Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>S₁B₁D₁</td>
<td>Speed 3 kmh⁻¹ + Bed Width 76.2 cm + Spacing 20.32 cm</td>
</tr>
<tr>
<td>2.</td>
<td>S₁B₁D₂</td>
<td>Speed 3 kmh⁻¹ + Bed Width 76.2 cm + Spacing 15.24 cm</td>
</tr>
<tr>
<td>3.</td>
<td>S₂B₁D₁</td>
<td>Speed 5 kmh⁻¹ + Bed Width 76.2 cm + Spacing 20.32 cm</td>
</tr>
<tr>
<td>4.</td>
<td>S₂B₁D₂</td>
<td>Speed 5 kmh⁻¹ + Bed Width 76.2 cm + Spacing 15.24 cm</td>
</tr>
<tr>
<td>5.</td>
<td>S₁B₁D₁</td>
<td>Speed 7 kmh⁻¹ + Bed Width 76.2 cm + Spacing 20.32 cm</td>
</tr>
<tr>
<td>6.</td>
<td>S₁B₁D₂</td>
<td>Speed 7 kmh⁻¹ + Bed Width 76.2 cm + Spacing 15.24 cm</td>
</tr>
<tr>
<td>7.</td>
<td>S₂B₁D₁</td>
<td>Speed 3 kmh⁻¹ + Bed Width 90.4 cm + Spacing 20.32 cm</td>
</tr>
<tr>
<td>8.</td>
<td>S₂B₁D₂</td>
<td>Speed 3 kmh⁻¹ + Bed Width 90.4 cm + Spacing 15.24 cm</td>
</tr>
<tr>
<td>9.</td>
<td>S₁B₁D₁</td>
<td>Speed 5 kmh⁻¹ + Bed Width 90.4 cm + Spacing 20.32 cm</td>
</tr>
<tr>
<td>10.</td>
<td>S₁B₁D₂</td>
<td>Speed 5 kmh⁻¹ + Bed Width 90.4 cm + Spacing 15.24 cm</td>
</tr>
<tr>
<td>11.</td>
<td>S₂B₁D₁</td>
<td>Speed 7 kmh⁻¹ + Bed Width 90.4 cm + Spacing 20.32 cm</td>
</tr>
<tr>
<td>12.</td>
<td>S₂B₁D₂</td>
<td>Speed 7 kmh⁻¹ + Bed Width 90.4 cm + Spacing 15.24 cm</td>
</tr>
</tbody>
</table>
Measurement of response parameters

Draft Requirement

The pull was measured using a Monard Digitalizer load cell by placing it along the line of pull between the developed prototype and the tractor (Fig. 10). The angle between the line of pull and horizontal was measured (9°) and draft was calculated as

\[ D = P \cos \phi \]  

(1)

Where,

- \( D \): Draft required, (kp)
- \( P \): Pull measured by load cell, (kp)
- \( \phi \): Angle between the line of pull and horizontal

Fig. 9. An overview of operation of tractor operated mulch laying machine

Fig. 10. Measuring draft using Monard Digitalizer load cell
Theoretical field capacity

The theoretical field capacity is the rate of field coverage that was obtained considering if implement was performing its function 100 % of the time at the rated speed and always covering 100 % of its rated width.

\[
TFC = \frac{W \times S}{10}
\]

(2)

Where,

- TFC = Theoretical field capacity, ha.h^{-1}
- S = Speed of operation, kmh^{-1}
- W = Theoretical width of implement, m

Effective field capacity

The actual field capacity is the actual average rate of coverage by the implement. The total time required covering the mulch in an area was recorded by using stop watch and effective field capacity was calculated as follows:

\[
EFC = \frac{A}{T}
\]

(3)

Where,

- EFC = Effective field capacity, ha.h^{-1}
- A = Actual area covered, ha
- T = Effective time, hour

Uncovered mulch edges

The percentage uncovered mulch edge was measured by using a 30 m inch tape on both side of the mulch for 10 m length. The percentage uncovered mulch edges were calculated by using the following formula.

\[
\text{Uncovered mulch edges} = \frac{\text{Length of uncovered mulch (both sides), m}}{\text{Total length of mulch laid (both sides), m}} \times 100
\]

(4)

Mulch damage

The percentage of mulch damage was measured by using 30 m inch tape to calculate the damaged area by considering the least possible rectangle portion enclosing damaged area and then percentage of mulch damage was calculated by following formula.

\[
\text{Mulch damage (\%)} = \frac{\text{Area of damaged mulch after mulch pass}}{\text{Total area of mulch laid after machine pass}} \times 100
\]

(5)
Field efficiency

The field efficiency is the ratio of effective field capacity to the theoretical field capacity and expressed in per cent.

\[
\text{Field efficiency (FE)} = \frac{\text{AFC}}{\text{TFC}} \times 100
\]  

(6)

Where,

\( \text{AFC} \) = Actual field capacity, ha.h\(^{-1} \)

\( \text{TFC} \) = Theoretical field capacity, ha.h\(^{-1} \)

Missing number of holes by dibbler (%)

The percentage of missing number of holes were calculated by counting the theoretical number of holes made in 10-meter length of machine passed mulch and actual number of holes made in a 10-meter length of machine passed mulch by visual interpretation using following formulas.

\[
\text{Percentage of Missing holes} = \frac{\text{Missing number of holes (10m length)}}{\text{Theoretical holes to be made (10m length)}} \times 100
\]  

(7)

Man-hour requirement

The man-hour requirement was calculated as per the labour required to perform integrated mulching operation by the machine which involves the tractor operator and a helper required to accompany machine so as to engage and cut the mulch and drip tape at the start and end of bed length.

Statistical Analysis

The factorial design (unbalanced) was used to analyze the data as there were three levels of speed, two levels of bed width and two levels of hole spacing thus factorial design (unbalanced) was used for statistical analysis. SPSS version 21 software was used for analysis of the data.

Numerical Standardization of Responses

The standardization of response parameters was done using design expert software version 10.0.1. While standardization, goal for independent parameters was to keep them in range while among responses, the goal for effective field capacity and field efficiency was to maximize them and for draft requirement, percentage uncovered mulch, percentage mulch damage, percentage missing number of holes and man-hour requirement was to minimize.
RESULTS AND DISCUSSION

Effect of forward speed, bed width and spacing of holes:

Draft requirement

Draft required to pull the developed machine was affected by all the three independent parameters (Fig. 11). The mean draft required to pull the prototype was found maximum (among selected treatment combinations) as 86.28 kp at bed width of 76.2 cm (B₁), spacing of holes of 15 cm (D₂) and forward speed of 3 kmh⁻¹ (S₁).

At forward speed of S₁, S₂ and S₃, the mean draft required to pull the developed prototype was 74.73, 64.36 and 54.82 kp. The draft decreased with the increase in forward speed. It can be attributed to the fact that when developed machine is at rest, there is a static friction between the soil and the working tool of the machine, friction is higher and as soon as tractor gets into motion, the limiting friction comes into play between the working devices of the machine and the soil, at that time higher pull is required to overcome limiting friction while as at higher speed, the limiting friction is converted into dynamic friction which decreases the pull to overcome the resistance against it due to the inertia.

The draft decreased as the bed width increased from 76.2 cm (B₁) to 91.4 cm (B₂) because the laid mulch was held tightly on the wider bed size and the dibbling device operates effectively by punching on the plastic mulch at the required spacing. Draft required was seen increasing as the spacing of holes decreased from 20 cm (D₁) to 15 cm (D₂) due to the clogging of dibbling cones by tearing the mulch when spacing of holes was lesser. Similar trend was reported [17] that the average draft requirement was 447.8 N (45.6 kp) and reduced as the forward speed was increased during the evaluation of bullock drawn mulching machine at forward speed from 1.33 to 1.36 kmh⁻¹. The results obtained are also in agreement with the findings of other researchers [18].

Fig. 11. Influence of forward speed, bed width and dibbling hole spacing on draft requirement effective field capacity

S: Forward speed of tractor (S₁: 3 kmh⁻¹, S₂: 5 kmh⁻¹, S₃: 7 kmh⁻¹)
B: Bed Width (B₁: 76.2 cm, B₂: 91.4 cm)
D: Spacing of holes (D₁: 20 cm, D₂: 15 cm)
Effective field capacity was affected by forward speed and bed width. It increased as the forward speed and bed width increased. The mean effective field capacity was found minimum as 0.312 ha.h\(^{-1}\) at forward speed of 3 kmh\(^{-1}\) (S\(_1\)) and bed width of 76.2 cm (B\(_1\)) while as it was found 0.861 ha.h\(^{-1}\), maximum (among the selected treatment combinations) at spacing of holes of 20 cm (D\(_1\)), forward speed of 7 kmh\(^{-1}\) (S\(_3\)) and bed width of 91.4 cm (B\(_2\)). The results are in close agreement with the findings of [17,19], where it was reported that the EFC was 0.113 ha.h\(^{-1}\) at forward speed of 1.35 kmh\(^{-1}\). The mean effective field capacity also decreased from 0.577 ha.h\(^{-1}\) to 0.535 ha.h\(^{-1}\) as spacing of holes reduced from 20 cm (D\(_1\)) to 15 cm (D\(_2\)). This was due to the choking of dibbling cones by shredding the mulch when spacing of holes was lesser (15 cm) but at higher spacing of holes, the punching of mulch was executed without ripping due to the inertia of the dibbling wheel. Consequently, spacing of holes was found significant at the 5% level of significance.

Field efficiency

Field efficiency was affected by all the three independent parameters. It increased with increase in forward speed and bed width while it decreased with the decrease in spacing of holes (Table 5).

Field efficiency was found maximum as 73.97% at forward speed of 7 kmh\(^{-1}\) (S\(_3\)) and bed width of 91.4 cm (B\(_2\)). FE was found minimum as 57.69 % at forward speed of 3 kmh\(^{-1}\) (S\(_1\)) and bed width of 76.2 cm (B\(_1\)). In general, field efficiency increased as forward speed and bed width increased from 3 kmh\(^{-1}\) (S\(_1\)) to 7 kmh\(^{-1}\) (S\(_3\)) and 76.2 cm (B\(_1\)) to 91.4 cm (B\(_2\)), respectively. Other researchers also reported that field efficiency increased with forward speed and observed maximum field efficiency of 69.67 % at the forward speed of 1.35 kmh\(^{-1}\) [17]. The field efficiency was observed lower at forward speed of 7 kmh\(^{-1}\) because at this speed dibbling wheel wrap the mulch on dibbling cones.
Field efficiency increased from 66.32 to 69.43 % as the spacing of holes increased from 15 cm (D_2) to 20 cm (D_1). This is attributed to the rationale that as the distance between the dibbling cones is lesser, larger surface area of plastic mulch film is attained under the dibbling cones and hence punching effect of dibbling cones is reduced, instead plastic mulch film elongates over the dibbling cones and the mulch film is teared off, tractor has to be stopped and choked dibbling cones need to be cleaned to prevent further mulch damage.

While as when distance between dibbling cones is larger, very less surface area of plastic mulch comes under the dibbling cone. Moreover, due to the inertia of wheel, dibbling cones punch through the mulch film without choking the dibbling device.

### Mulch damage

The mulch damage was found increasing as forward speed of tractor increased from S_1 to S_3 (Table 6). Mean mulch damage was found minimum as 2.86 % at forward speed of 3 kmh^{-1} and spacing of holes of 20 cm (D_1) while it was found maximum as 14.76 % at forward speed of 7 kmh^{-1} and bed width of 91.4 cm (B_2). The increased mulch damage at higher speeds was due to the jumping of dibbling wheel which results in tearing of mulch due to the sharp dibbling cone. Mulch damage decreased as the bed width increased from B_1 (76.2 cm) to B_2 (91.4 cm) due to the choking of the dibbling cones as when bed width is lesser, the mulch is kept loose on the bed. The mulch damage was seen decreasing as the spacing of holes reduced from 20 (D_1) to 15 cm (D_2).

<table>
<thead>
<tr>
<th>B.W / S.H</th>
<th>Speed</th>
<th>D1 Mean ± S. D</th>
<th>D2 Mean ± S. D</th>
<th>Sub-Mean (SB) Mean ± S. D</th>
<th>Total Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_1</td>
<td>62.70 ± 3.53</td>
<td>57.69 ± 4.75</td>
<td>60.19 ± 4.64</td>
<td>72.74 ± 1.48</td>
<td>69.22 ± 2.27</td>
</tr>
<tr>
<td></td>
<td>3.53</td>
<td>4.75</td>
<td>4.64</td>
<td>1.48</td>
<td>2.27</td>
</tr>
<tr>
<td>S_1</td>
<td>66.86 ± 0.76</td>
<td>64.81 ± 1.38</td>
<td>65.84 ± 1.50</td>
<td>73.49 ± 0.97</td>
<td>70.51 ± 0.72</td>
</tr>
<tr>
<td></td>
<td>0.76</td>
<td>1.38</td>
<td>1.50</td>
<td>0.97</td>
<td>0.72</td>
</tr>
<tr>
<td>S_3</td>
<td>66.83 ± 0.51</td>
<td>64.20 ± 1.97</td>
<td>65.51 ± 1.93</td>
<td>73.97 ± 2.13</td>
<td>71.47 ± 0.93</td>
</tr>
<tr>
<td></td>
<td>0.51</td>
<td>1.97</td>
<td>1.93</td>
<td>2.13</td>
<td>0.93</td>
</tr>
<tr>
<td>Sub-Mean (BD)</td>
<td>65.46 ± 2.76</td>
<td>62.23 ± 4.33</td>
<td>63.85 ± 3.89</td>
<td>73.40 ± 1.48</td>
<td>70.40 ± 1.61</td>
</tr>
<tr>
<td>Total Mean</td>
<td>63.84 ± 3.54</td>
<td>71.9 ± 1.54</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C.D (P ≤ 0.05)  
D : 0.215  
S x B : 1.859

Note: Only the factor(s) or interaction(s) with C.D value mentioned (above) are significant otherwise non-significant.

S = Forward speed of tractor  
B = Bed Width  
D = Spacing of Holes
Table 6. Alteration in mulch damage (%) due to forward speed, bed width and spacing of holes

<table>
<thead>
<tr>
<th>B.W / S.H Speed</th>
<th>B1</th>
<th>Sub-Mean (SB)</th>
<th>B2</th>
<th>Sub-Mean (SB)</th>
<th>Total Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>2.86 ± 0.70</td>
<td>3.40 ± 1.47</td>
<td>3.16 ± 0.81</td>
<td>3.01 ± 0.90</td>
<td></td>
</tr>
<tr>
<td>D2</td>
<td>4.23 ± 1.07</td>
<td>4.13 ± 1.85</td>
<td>4.11 ± 1.04</td>
<td>4.12 ± 1.55</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>2.55 ± 1.43</td>
<td>1.97 ± 0.70</td>
<td>1.36 ± 1.36</td>
<td>1.38 ± 1.38</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>9.70 ± 2.95</td>
<td>4.16 ± 0.80</td>
<td>5.05 ± 1.82</td>
<td>8.64 ± 4.59</td>
<td></td>
</tr>
<tr>
<td>Sub-Mean (BD)</td>
<td>5.60 ± 3.48</td>
<td>3.80 ± 2.21</td>
<td>4.42 ± 1.70</td>
<td>4.11 ± 1.57</td>
<td></td>
</tr>
<tr>
<td>Total Mean</td>
<td>6.41 ± 4.70</td>
<td>4.11 ± 1.46</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C.D (P ≤ 0.05)

S x B : 1.381
S x D : 1.381

Note: Only the factor(s) or interaction(s) with C.D value mentioned (above) are significant otherwise non-significant.

S = Forward speed of tractor : \( S_1 = 3 \text{ kmh}^{-1}, S_2 = 5 \text{ kmh}^{-1}, S_3 = 7 \text{ kmh}^{-1} \)

B = Bed Width : \( B_1 = 76.2 \text{ cm} \) & \( B_2 = 91.44 \text{ cm} \)

D = Spacing of Holes : \( D_1 = 20 \text{ cm} \) & \( D_2 = 15 \text{ cm} \)

Man-hour requirement

Man-hour requirement was found affected by the forward speed and bed width. It decreased as the forward speed and bed width increased. Man-hour requirement was minimum (among selected treatment combinations) as 2.31 man-hours ha\(^{-1}\) at speed of 7 kmh\(^{-1}\) \( (S_3) \), spacing of holes of 20 cm \( (D_1) \) and bed width of 91.4 cm \( (B_2) \), while it was maximum (among selected treatment combinations) as 6.75 man-hours per hectare \( (\text{ha}^{-1}) \) at forward speed of 3 kmh\(^{-1}\) \( (S_1) \) and bed width of 76.2 cm \( (B_1) \). Man-hour requirement depends on time required to cover the field since the field coverage depends on forward speed of tractor and width of operation therefore, increase in forward speed and bed width from 3 kmh\(^{-1}\) \( (S_1) \) to 7 kmh\(^{-1}\) \( (S_3) \) and from 76.2 cm \( (B_1) \) to 91.4 cm \( (B_2) \) respectively decreased the man-hour required to cover one hectare by mulching. The results are in close agreement with the findings of other researcher \[19,20\].

Missing number of holes

The missing number of holes increased in general as forward speed of tractor and bed width increased (Fig. 14). It was found maximum as 10.96 % at speed of 7 kmh\(^{-1}\), bed width of 76.2 cm \( (B_1) \) and at spacing of holes of 15 cm \( (D_2) \) while it was minimum at speed of 3 kmh\(^{-1}\) \( (S_1) \), bed width of 91.4 cm \( (B_2) \) and spacing of holes of 20 cm \( (D_1) \).

The missing number of holes dependent on bed width and forward speed of tractor as the forward speed affects the inertia that causes the punching of mulch film and bed width determines the loosen or tighten mulch film on the prepared bed.
As soon as forward speed increases, missing holes increases due to jumping of dibbling wheels which causes damage as well as missing number of holes on the mulch film while as increasing bed width results in tightening of mulch film on the top bed width on which punching by dibbling cone is effective instead of wrapping of mulch film along the direction travel (in case of loosen mulch film on the top bed width).

\[
S = \text{Forward speed of tractor} (S_1: 3 \text{ kmh}^{-1}, S_2: 5 \text{ kmh}^{-1}, S_3: 7 \text{ kmh}^{-1})
\]
\[
B = \text{Bed Width} \quad (B_1: 76.2 \text{ cm}, \ B_2: 91.44 \text{ cm})
\]
\[
D = \text{Spacing of holes} \quad (D_1: 20 \text{ cm}, \ D_2: 15 \text{ cm})
\]

Fig. 13. Variation due to forward Speed, bed width and hole spacing on man-h requirement (MHR)

\[
S = \text{Forward speed of tractor} (S_1: 3 \text{ kmh}^{-1}, S_2: 5 \text{ kmh}^{-1}, S_3: 7 \text{ kmh}^{-1})
\]
\[
B = \text{Bed Width} \quad (B_1: 76.2 \text{ cm}, \ B_2: 91.44 \text{ cm})
\]
\[
D = \text{Spacing of holes} \quad (D_1: 20 \text{ cm}, \ D_2: 15 \text{ cm})
\]

Fig. 14. Variation due to forward Speed, bed width and hole spacing on dibbling hole missing (MNH)
Uncovered mulch

The uncovered mulch edge (%) was found affected by forward speed of tractor. It increased as forward speed increased from 3 kmh\(^{-1}\) (S\(_1\)) to 7 kmh\(^{-1}\) (S\(_3\)).

It was found minimum (among the selected treatment combinations) as 3.60 % at the forward speed of 3 kmh\(^{-1}\) while it was found maximum (among selected treatment combinations) as 10.23 % at forward speed of 7 kmh\(^{-1}\) (Table 7). With increase in speed left some patches of mulch edges uncovered since some of the soil clods disturb the soil movement along the direction projected by covering device. Hence, statistical analysis revealed that the percentage uncovered mulch damage was affected by the forward speed of tractor and was found significant at 5 % level of significance.

Table 7. Influence of forward speed, bed width and spacing of holes on uncovered mulch (%)

<table>
<thead>
<tr>
<th>B.W / S.H Speed</th>
<th>B(_1)</th>
<th>B(_2)</th>
<th>Sub-Mean (SB)</th>
<th>Total Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>2.50 ± 0.26</td>
<td>3.56 ± 1.70</td>
<td>3.03 ± 0.11</td>
<td>3.63 ± 1.40</td>
</tr>
<tr>
<td>D2</td>
<td>4.63 ± 1.93</td>
<td>4.13 ± 1.84</td>
<td>4.50 ± 2.25</td>
<td>3.60 ± 1.48</td>
</tr>
<tr>
<td>S(_1)</td>
<td>4.73 ± 2.35</td>
<td>6.13 ± 2.77</td>
<td>5.13 ± 2.43</td>
<td>4.72 ± 2.14</td>
</tr>
<tr>
<td>S(_2)</td>
<td>2.35 ± 1.36</td>
<td>2.25 ± 2.77</td>
<td>2.56 ± 2.00</td>
<td>2.59 ± 1.48</td>
</tr>
<tr>
<td>S(_3)</td>
<td>12.66 ± 6.58</td>
<td>11.50 ± 6.16</td>
<td>12.08 ± 10.60</td>
<td>12.38 ± 4.02</td>
</tr>
<tr>
<td>Sub-Means (BD)</td>
<td>6.63 ± 5.80</td>
<td>6.55 ± 4.65</td>
<td>4.56 ± 4.90</td>
<td>5.77 ± 3.02</td>
</tr>
<tr>
<td>Total Mean</td>
<td>5.80 ± 3.11</td>
<td>4.22 ± 1.90</td>
<td>2.00 ± 4.05</td>
<td>10.23 ± 4.57</td>
</tr>
</tbody>
</table>

C.D (P ≤ 0.05) | 1.757 |

Note: Only the factor(s) or interaction(s) with C.D value mentioned (above) are significant otherwise non-significant.

S = Forward speed of tractor : S\(_1\) = 3 kmh\(^{-1}\), S\(_2\) = 5 kmh\(^{-1}\), S\(_3\) = 7 kmh\(^{-1}\)
B = Bed Width : B\(_1\) = 76.2 cm & B\(_2\) = 91.44 cm
D = Spacing of Holes : D\(_1\) = 20 cm & D\(_2\) = 15 cm

Standardization of the Responses

The optimum response values were obtained from optimization software “Design Expert 10.0.1”. The machine operating parameters were standardized so that all the responses maximize the overall performance of developed prototype. Therefore, the standardized response parameters were obtained as 52.65 kp ; 0.80 ha.h\(^{-1}\); 71.50 %, and 2.59 man-hour ha\(^{-1}\) for draft requirement, effective field capacity, field efficiency, and man-hour requirement, respectively.
Similarly, other standardized response parameters were obtained as 6.942, 3.592 and 3.711 % for percentage uncovered mulch, percentage mulch damage and percentage missing number of holes respectively.

The operating parameters were standardized as forward speed of 3 kmh\(^{-1}\), bed width of 91.4 (B\(_2\)) and spacing of holes of 20 cm (D\(_1\)).

**CONCLUSIONS**

A tractor drawn plastic mulch laying machine was developed to mechanize the conventional plastic mulching, laying drip irrigation pipes (surface) and dibbling hole in the mulch for seedling transplanting which, worked to facilitate the implementation of this method, saves time, labour and increases timeliness of operation. The draft requirement decreased with the increase in forward speed (3.0 to 7.0 kmh\(^{-1}\)), bed width (76.2 to 91.4 cm) and dibbling hole spacing (15.2 to 20.3 cm). Although at low speed (3.0 kmh\(^{-1}\)), the actual field capacity and field efficiency decreased about 57% and 5.0%, respectively while draft required increased about 36 %, compared to the speed of 7.0 kmh\(^{-1}\).

However, at a speed of 3.0 kmh\(^{-1}\), the mulch damage, un-covered mulch percentage and missing of dibbling hole decreased about 65%, 64% and 7.0 %, respectively. The study recommends using the developed machine to install a raised-bed and laying both of plastic mulch and drip irrigation pipes on bed surface at a speed of 3 km.h\(^{-1}\).

In the future, this technology could be modified and implemented to mechanize plastic mulch laying operation, where human fatigue and drudgery are involved.

**REFERENCES**


INTEGRISANA MAŠINA ZA POLAGANJE PLASTIČNOG MALČA – ODRŽIVA TEHNOLOGIJA ZA ODRŽIVU POLJOPRIVREDNU PROIZVODNJU

Shoaib Amin¹, Jagvir Dixit¹* and M. Muzamil¹

¹Division of Farm Machinery and Power Engineering, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, India

**Abstract:** Razvijena konstrukcija vučene traktorske mašine za polaganje malča kako bi se integrisale operacije i popravili nedostatci u pogledu rada povezanim sa konvencionalnim operacijama polaganja malča.

Prototip mašine integriše operacije u jednom prolazu: formiranje posteljice, prostiranje malča, pokrivanje malča i bušenje odgovarajućih rupa-ovora za rasad na pokrivaču i malču.

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Razvijeni prototip nošene mašine testiran je sa tri različite brzine napred (3,0; 5,0; 7,0 kmh\(^{-1}\)), dva nivoa širine posteljice (76,2 i 91,4 cm) i dva nivoa razmaka rupa za rasad (15,2 i 20,3 cm).

Rezultati predviđenog eksperimenta i ispitivanja za ovu mašinu pokazuju da se sila vuče menja sa povećanjem brzine traktora napred (3,0 do 7,0 kmh\(^{-1}\)), promenom širine osnove ležišta (76,2 do 91,4 cm) i promenom razmaka rupa za rasad (15,2 do 20,3 cm). Učinak mašine (agregata) povećava sa povećanjem brzine i to napred, širine osnove i razmaka rupa za rasad. Iako se pri maloj brzini (3,0 kmh\(^{-1}\)), stvarni učinak i efikasnost u polju smanjuju za približno 57% odnosno 5,0%, dok se sila vuče povećava za približno 36%, sa povećanjem brzine do 7,0 kmh\(^{-1}\). Međutim, pri maloj brzini od 3,0 kmh\(^{-1}\), oštećenje pokrivača-malča je smanjeno za 65%, nepokrivenost malča smanjena za 64% i nedostatak rupa za rasad iznosi do 7%.

Standardna vrednost za silu vuče zahteva 63,27 kp, efektivni učinak na polju je 0,40 hah\(^{-1}\) i ukupni učinak je 72,7%. Nepokriveni malč 3,1 %, oštećenja malča 3,4 % i nedostajući broj rupa za rasad je 6,25%. Potreba za radnim satima i troškovi rada malčiranja sa ovom novom mašinom smanjeni su približno 97% i 75% u poredjenju sa konvencionalnom metodom polaganja malča. U ovoj studiji preporučuje se korišćenje nove integrisane mašine za formiranje uzdignute gredice (bankovi), polaganje plastičnih cevi za navodnjavanje i izradu rupa za rasad brzinom od 3 kmh\(^{-1}\) da bi se postigla bolja efikasnost.

**Ključne reči:** Mašina za polaganje malča, zahtev za vuču, učinak, oštećenje malča, širina osnove trake, razmak rupa, nepokriveni malč

Prihvaćen: 15.02.2022.